

Do spillovers justify subsidies to commercial R&D?

Four microeconomic essays

by

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The facts do not tell their own story; they must be cross-examined. They must be carefully analyzed, systematized, compared and interpreted.

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Abstracts

Chapter 1: In the introductory chapter, I place my thesis in an empirical research tradition going back to the mid-1950s, investigating the economics of technological change. Key issues have been the private and social returns to R&D, and the scope for technology policy in enhancing economic growth. It is widely accepted that the social returns to R&D is greater than the private returns, and that public support for R&D may be welfare improving. At the same time, a number of issues regarding the extent of the market failure and the governments' ability to improve on the market solution are unresolved. The main part of the introduction summarizes the following four chapters of the thesis. At the end I briefly reflect on my findings and their relevance for technology policy.

Chapter 2: Economists have recently drawn attention to the importance of generic or general purpose technologies (GPTs) and their significance for economic growth. An interesting part of this research identifies coordination problems in the introduction of GPTs, and the potentially large benefits in coordinating research and product development. Thinking about information technology as a GPT, with the associated coordination problems, seems to fit well with the motivation behind governmental support schemes to IT and related high-tech industries in Norway. The first part of this essay focuses on a series of such IT-programs that have been implemented in Norway from the early 1980s with the objective of coordinating the development of information technology and its application throughout the economy. The second part of the essay examines in some detail the largest of these programs through its planning and implementation stages, and emphasizes how closely it is connected to recent economic analysis of GPTs. The third part examines to what extent these governmental plans and subsidy schemes have been successful in creating economic results in terms of growth and profits in the IT and IT-related industries. The final part of the essay discusses some lessons about the problems with technology policy at a practical level.

Chapter 3: A number of market failures have been associated with R&D investments, and significant amounts of public money have been spent on programs to stimulate innovative activities. This essay reviews some recent microeconomic studies evaluating effects of government-sponsored commercial R&D, and pays particular attention to the conceptual problems involved. Neither the firms receiving support, nor those that do not receive support, constitute random samples. Furthermore, those not receiving support may be affected by the programs due to spillover effects which often are the main justification for R&D subsidies. Constructing a valid control group under these circumstances is difficult, and the essay draws attention to some recent advances in econometric methods for evaluation studies based on non-experimental data. The essay also discusses some analytical questions beyond these estimation problems that need to be addressed in order to assess whether R&D support schemes can be justified. For instance, what are the implications if firms' R&D investments are complementary to each other, and to what extent are potential R&D spillovers internalized in the market?

Chapter 4: Labor mobility is often considered to be an important source of knowledge spillovers, making it difficult for firms to appropriate returns to R&D investments. In this essay I argue that inter-firm transfers of knowledge embodied in people should be analyzed within a human capital framework. Testing such a framework using a matched employer-employee data set, I find that the technical staff in R&D-intensive firms pays for the knowledge they accumulate on the job through lower wages in the beginning of their career. Later they earn a return on these implicit investments through higher wages. This suggests that the potential externalities associated with labor mobility, at least to some extent, are internalized in the labor market.

Chapter 5: Most R&D projects fail from a commercial point of view, and technological shifts may quickly turn even successful innovations into failure. It is, however, possible that projects which fail commercially produce knowledge with some social value. Such knowledge is likely to be embodied in workers or teams of workers. In order to evaluate the social returns to research, it is therefore desirable to trace workers as they move across firms and industries. In this essay I utilize a large matched employer-employee data set and test for the existence of potential knowledge spillovers transmitted through the labor market. The specific case analysed is a series of Norwegian IT-programs so far considered unsuccessful, but which recently have been linked to the rise of a new generation of successful IT-firms. It has been argued that know-how and networks built up in leading companies during the programs still 'fertilize' the Norwegian IT-industry. I find little support for this claim. Workers with experience from companies that received R&D subsidies were largely re-employed in IT-industries, but they have not outperformed similar workers without such experience. An analysis of firms that are spin-offs from formerly subsidized IT-firms reveals that they perform below, rather than above, average.

Chapter 1

Introduction and summary *

1 R&D-investments and economic growth

From the very beginning, economists have been preoccupied with economic growth and appreciated that improvements in material well-being is closely linked to innovation and technological change. It was not until the mid-fifties, however, that economists seriously started to study technological change as the outcome of purposeful investments made in response to anticipated profits. Interestingly, it was empirically minded economists that most strongly emphasized the view that technological change was determined inside the economic system, and their analyses preceded the fully fledged endogenous growth theory by three decades.¹

The first attempt to calculate returns to R&D was done by Theodore W. Schultz (1953) investigating the relationship between output growth in agriculture and public investments in agricultural research. It was Zvi Griliches, however, who most vigorously followed up this line of research, applying the tools of modern econometrics to investigate the activities that cause productivity growth. I think of my thesis as part of a research program that was initiated by Griliches' (1957) landmark study of hybrid corn, and over the next four decades developed into a major field by him, his students and numerous other economists.

A central issue in this research is the private and social benefits that arise from new technologies, and the closely related question of whether entrepreneurs and private firms have sufficiently strong incentives to invest in R&D. Kenneth Arrow (1962) provided an illuminating theoretical analysis of this question, pointing out that a free market economy will underinvest in research for several reasons. First, the outcome of such investments are highly uncertain, and insurance against this risk cannot be provided without severely weakening the incentives to succeed. Second, innovators can only to a limited extent appropriate the return to their innovations because valuable information easily leak out to competitors and others. This is often referred to as knowledge spillovers. Third, there are increasing returns to scale in knowledge production because ideas are nonrivalous, i.e.

* I have reduced the number of references in this introduction to a minimum. Full references can be found in the chapters summarized. I am grateful to Hans Jarle Kind, Tor Jakob Klette and Erik Ø. Sørensen for useful comments.

¹The call for an endogenous growth theory is particularly clearly stated in Jacob Schmookler (1965).

their use by one person or firm does not diminish their availability. In recent years, the last two points have been re-emphasized and further developed in the new endogenous growth theory, cf. e.g. Paul M. Romer (1990).

If a free market economy does not allocate an optimal amount of resources to inventive activity, public support mechanisms may be welfare improving. Actually, some major mechanisms were in place long before the economic profession started to ponder this question. Governments and patrons have financed research at universities since the Middle Ages, and the first patent laws, securing inventors the exclusive right to exploit their ideas commercially, were in place in Venice as early as 1474. Governments also have a long history of stimulating technological development through military spendings and other public procurements. Finally, individuals that make significant discoveries have always been rewarded with fame, an important incentive mechanism in any society.

When entrepreneurs such as Thomas Edison and Henry Ford made their great inventions, however, they did so without receiving R&D subsidies or tax credits. Subsidies to *commercial* R&D became commonplace in the OECD countries after World War II, and the main argument has been that there are positive externalities, *spillovers*, associated with R&D investments. To what extent such spillovers justify subsidies, is the overall theme addressed by the four essays in this thesis. Opponents of subsidies claim that the degree of underinvestment in private R&D is exaggerated, and that governments lack the ability to stimulate R&D in an efficient manner. The expected private return to R&D is in many cases large enough to justify investments without public support, and the fact that social returns may be far larger is then irrelevant. It is only projects that are profitable from a social point of view, but not from a private point of view, that should receive subsidies. It is difficult for bureaucrats to identify such projects. Subsidies may crowd out private R&D investments and lead firms to engage in unproductive rent-seeking activities. There also exist market mechanisms that can induce too much, rather than too little, R&D investments. If a firm can gain large market shares by making a small quality improvement in a product, the private return may be larger than the social return because other firms' R&D investments become obsolete.

Most economists agree that technology policy is important, and that the government should stimulate research. Designing an optimal policy, however, is difficult. A number of questions can only be resolved through empirical analysis, and finding the necessary answers takes the joint effort of many economists. The essays collected in this thesis shed light on some issues that I consider particularly important in this respect. The rest of this introductory chapter is organized as follows: The next four sections summarize chapter two, three, four and five, respectively. In the last section I briefly reflect on my findings and their relevance for technology policy.

2 From growth theory to technology policy - coordination problems in theory and practise

As already mentioned, externalities associated with R&D, learning and innovation have been emphasized in the new growth theory, and it has been widely recognized that these externalities create coordination problems and scope for welfare improving government interventions. It has also been emphasized that the development of new industries in the presence of such externalities tend to create multiple equilibria where one equilibrium corresponds to the new industry never reaching a 'critical mass' or never 'taking off', while other equilibria correspond to the industry 'taking off' and starting on a cumulative growth process.

A particular coordination problem that my co-author Tor Jakob Klette and I focus on in chapter 2, arises when the technology in question is 'generic'. Information technology is one example of this, and it is a technology which has been actively promoted by most OECD governments, including Norway. Traditionally, economists have had difficulties making sense of such terms as 'generic technology'. Timothy Bresnahan and Manuel Trajtenberg (1995), however, introduced the notion of 'general purpose technologies', and have by their analysis drawn attention to the potential importance of generic or general purpose technologies for economic growth.

General purpose technologies (GPTs) are characterized by their wide applicability, their potential for development and what Bresnahan and Trajtenberg call innovative complementarities. By innovative complementarities they have in mind positive pecuniary externalities between the development of the basic general purpose technology and innovations in the sectors using this technology. Such externalities tend to create coordination problems and Bresnahan and Trajtenberg argue that due to the pervasive applicability of 'general purpose technologies', these coordination problems might be large even in a macroeconomic perspective.

Thinking about information technology as a GPT, with the associated coordination problems, seems to fit well with the motivation behind governmental support schemes to IT and related high-tech industries in Norway. Chapter 2 focuses on a series of such IT-programs that were implemented in Norway from the early 1980s. The motivation was to promote the production and utilization of information technology, and also to coordinate the various policy tools involved. The major part of these IT-programs became targeted directly at promoting the manufacturing of IT-products, and their considerable size is indicated by the total expenditures amounting to NOK 4.4 billion for the largest of the programs, the National Program for Information Technology, implemented over the four-year period 1987-1990.

In the first part of chapter 2 we examine in some detail this program through its planning and implementation stages and emphasize how closely the program is connected to the economic analysis of GPTs. The second part of chapter 2 examines to what extent this

and the other IT programs of the 1980s and 1990s were successful in creating economic results.

We start the quantitative analysis by comparing the performance of targeted firms to other firms in high-tech industries. The econometric analysis reveals few significant differences between the supported and the non-supported firms, despite the large amounts of R&D support provided. Next, we present a more aggregated analysis, based on industry-level data for Norway and other OECD countries. The motivation for this is that some of the benefits from the program may have spilled over to non-supported firms with the result that the comparison between the supported firms and the non-supported firms will underestimate the effect of the program. It is, however, difficult to identify a similar non-supported industry that can serve as a control group. We consider two alternatives. The first comparison is between the targeted high-tech industries and the rest of the manufacturing sector as a whole. This is clearly not a clean quasi-experiment, but it is nevertheless interesting to compare e.g. the profit rates and the returns to investments in the targeted industries to other industries. The second comparison contrasts the targeted high-tech industries in Norway with the same industries in other OECD countries. Once again, the comparison is not a clean quasi-experiment, because high-tech industries in other OECD countries also received considerable governmental support. The OECD data suggest, however, that the increase, and perhaps also the level (relative to private R&D spending) of governmental support to these industries was significantly larger in Norway than in most other countries.

We find that the targeted industries did not show any outstanding performance compared to the rest of the manufacturing sector in Norway, nor in comparison to the same industries in other OECD countries. Our general conclusion, therefore, is that the IT-programs, while well justified according to economic theory, seem to have failed in promoting the development of the IT manufacturing sector. In the last part of chapter 2, we proceed to discuss why the technology programs were unsuccessful despite their appeal *ex ante*.

In order to understand why the programs failed, it is important to notice that in the simplistic game theoretic models often used to illustrate coordination problems, information is given. In real world coordination problems, however, obtaining relevant information is a serious obstacle. Exactly which firms and what activities should be coordinated and in what way? These questions are very hard to answer in a rapidly developing field such as information technology and they might be particularly hard to solve in a small open economy where a large majority of the innovations take place abroad. Institutional resistance and inertia put further constraints on the governments' ability to implement and coordinate technology policy.

To conclude, we believe that industrial innovation is an activity where coordination problems and market failure can be pervasive, but we also think it is an activity where policy makers and bureaucrats often lack the information and adaptive capacity needed to improve on the market solution. On the positive side, however, we point out that coor-

dination problems created by complementary innovative activities across different firms seem in many cases to be partly resolved by private institutions such as industry associations, privately funded research joint ventures and other cooperative research agreements. These are mechanisms that deserve attention in future research.

3 Do subsidies to commercial R&D reduce market failure? Microeconomic evaluation studies

Inspired by the study in chapter 2, chapter 3 is devoted to a discussion of the conceptual difficulties involved in evaluating effects of R&D subsidies. Compared to the emphasis put on technology policy by politicians, and the size of the programs implemented, the effort put into evaluating in quantitative terms the economic benefits and costs of R&D subsidies has been rather modest. Most evaluations are based on case studies whose representativeness and objectiveness may be questioned. Together with my co-authors Tor Jakob Klette and Zvi Griliches, therefore, I draw in chapter 3 attention to some recent contributions to the evaluation literature that use econometric techniques based on micro-data, and to some policy questions we think need further clarification. We start the chapter by reviewing five microeconomic studies that try to evaluate the effects of government sponsored commercial R&D, and refer to these studies in the methodological discussion that follows.

When evaluating the effects of government sponsored research, one tries to unveil what would have taken place without the subsidies, and it is important to realize that evaluating large scale subsidy programs is an exercise in counterfactual analysis. This poses a number of challenges, and the first methodological problem we discuss is selection. Although the political economy process that determines the allocation of R&D subsidies may introduce a considerable element of randomness, it is clearly dubious to assume that the outcome of governments' deliberate selection process is largely random. The performance of the non-supported firms may differ systematically from what the supported firms would have experienced in the absence of the support schemes. Such systematic differences do not make traditional evaluation results uninteresting, but it limits the kind of questions the evaluations can answer. In our discussion, we try to clarify the potential biases involved in various studies, and we explain how evaluation studies may be improved if they utilize some recent advances in econometrics associated with the evaluation of labor market programs and so-called 'difference-in-difference' estimators.

There is much to learn from the literature on evaluation of labor market programs, but the labor market analogy is not adequate in all respects. Having discussed the basic selection problem, we point out some further methodological problems that are unique to R&D subsidy programs. First, spillovers to technologically related firms are often a major justification for the programs. This implies that the performance of the non-supported firms may be influenced by the support given to the program firms. An intriguing problem then

arises: If the program is successful in creating innovations that spill over to technologically related firms, it is very difficult to find similar non-supported firms that can identify the counterfactual outcome for the supported firms. This leads to the paradoxical situation that if an evaluation study finds little difference between the supported firms and the non-supported firms, it could either be because the R&D program was unsuccessful and generated little innovation, or because the R&D program was highly successful and generated new innovations that created large positive spillovers to the non-supported firms. Resolving this problem is difficult, and we suspect further progress will require theoretical modelling that imposes more structure on the analysis.

A second methodological problem that is unique to R&D subsidy programs, is the highly skewed distribution of returns to R&D. This skewness might be particularly pronounced for the outcome of government sponsored R&D projects because governments often intend to support high-risk R&D. One may argue, therefore, that the main parameter of interest is not the average impact of the R&D-support on the supported firms, but the average rate of return to the whole R&D subsidy program. In this perspective, the weighted average estimates provided by the ‘difference-in-differences’ estimator or similar estimators, may not apply the economically relevant weights to the individual observations. We suggest in response to this that it may be fruitful to combine econometric analyses with case studies of the most successful projects.

The rest of chapter 3 discusses R&D-spillovers. Not only do spillovers make it difficult to assess the benefits to private firms receiving support, but measuring the magnitude of the spillovers is by itself a crucial part of evaluating the programs. We argue that most studies do not go as far in this respect as one would like from a theoretical point of view. In particular, pecuniary externalities to customers and consumers are often excluded from the analyses. This being said, it is widely acknowledged that it is hard to distinguish knowledge spillovers from rent spillovers, and even the best methodologies used to estimate knowledge spillover cannot, in our opinion, satisfactorily distinguish between true externalities and knowledge transfers that are internalized in the market. We have, however, no doubt that spillovers exist, or that their magnitude is substantial. The last part of chapter 3, therefore, discusses what policy implications can be drawn, *given* that spillovers exist.

If spillovers can be received *without* costs, it is quite obvious that the main argument in favor of subsidies is valid: Firms performing R&D do not reap the whole benefit, and as they equate marginal cost to marginal private benefit, their investments will be below the social optimum. There is, however, a number of reasons why this argument is incomplete, and we discuss four issues that deserve further attention when evaluating the net welfare gains associated with R&D subsidies. First, the empirical evidence regarding the relationship between own and others’ R&D suggests that complementarities in R&D are important in many cases, and it is easy to envisage that firms must invest in research themselves in order to benefit from external knowledge pools. This may create a positive feedback mechanism between R&D investments in technologically related

firms. Spillovers, therefore, may be somewhat less of an impediment to R&D investments than many economists and policy makers believe. On the other hand, positive feedback mechanisms may create multiple equilibria, and support to targeted high-tech sectors is often rooted in the view that subsidies are needed to get emerging industrial activities to 'take off' and reach 'a critical mass', cf. chapter 2. This is a valid argument in favor of R&D subsidies, but as emphasized in chapter 2, it is important to analyze to what extent governments in practice have the necessary capabilities to improve on the market solution.

A second issue we draw attention to in chapter 3 regards technology policy in small open economies. Empirical results suggest that knowledge spillovers to some extent are geographically bounded, a first prerequisite for national policies to influence comparative advantages. A careful analysis of the likely distribution of spillovers is still necessary, however. As already mentioned, the total gain from national R&D investments includes not only knowledge spillovers, but also rent spillovers to end customers and buyers of intermediate goods. Rent spillovers may be considerable, and if profits are driven to zero by competition as many theoretical models assume, only rent spillovers are relevant for policy. In export sectors, often targeted by R&D subsidy programs, the share of the rent spillovers accruing to non-nationals may be substantial. One may then question why the government of the source country should bear the financial burden. On the other hand, the existence of international spillovers gives scope for increased global efficiency through R&D cooperation between countries.

A third issue in the last part of chapter 3, is R&D joint ventures. Inspired by the Coase theorem and observations on cooperative agreements, some of them reported in chapter 2, we argue that the ability of the market to internalize knowledge externalities should not be neglected. Our point is not that spillovers are fully taken care of by contracting, but that both in theoretical and empirical analysis more attention should be paid to the contractual arrangements utilized and invented by firms to overcome the potential spillover problems generated by innovative activities. The final issue we raise in chapter 3 relates this Coasian perspective to the labor market, and we discuss to what extent labor mobility should be considered a source of knowledge spillovers. Among the many topics for further research suggested in chapter 3, this is the one I have given most attention so far. The resulting analysis is reported in chapter 4.

4 Is Mobility of Technical Personnel a Source of R&D Spillovers?

Numerous workers have access to valuable research results and trade secrets. These workers may be tempted to exploit this knowledge by leaving their current employer and joining a competitor or starting their own business. This has led many economists to consider labor mobility an important source of knowledge externalities or *spillovers*. The problem is highly relevant for technology policy because spillovers inhibit firms in appropriating

the full returns to their R&D investments and will cause underinvestment in R&D.

In chapter 4, I argue that the view laid out above is too simple. Labor mobility is no doubt an important source of knowledge *diffusion*, but inter-firm transfers of knowledge embodied in people should be analyzed within a human capital framework. Such a framework suggests that there might be market mechanisms that, at least to some degree, internalize the potential externalities associated with labor mobility. The argument is simple: To the extent that workers in R&D-intensive firms get access to valuable knowledge on the job, they will expect higher wages in the future. When holding jobs that give access to such knowledge, they should therefore be willing to pay for what they learn by accepting wages below their alternative wage. Put differently and a bit more generally, one may think of jobs as tied packages of work and learning. Workers sell the services of their skills and simultaneously purchase an opportunity to augment those skills. The difference between the maximum market rental of a worker's existing skills and the wage that he or she receives in a given job is an implicit price paid for learning. Human capital theory also predicts that workers' incentive to pay for human capital accumulation is largest at young age. As workers grow older they will have fewer years to collect returns on a given investment, and obviously workers have no incentive to pay for increasing their human capital in the last year before retirement.

In the first part of chapter 4, I try to clarify how labor mobility can affect R&D investments by discussing in detail the arguments presented above. I draw in particular on theoretical models by Sherwin Rosen (1972) and Ariel Pakes and Shmuel Nitzan (1983). Next, I present a framework to test the hypothesis that workers implicitly pay for the knowledge they accumulate in research firms, and finally I present empirical findings based on a large matched employer-employee data set from the Norwegian machinery and equipment industry, suggesting that such wage mechanisms actually exist.

The price paid for 'on-the-job-learning' should vary according to how much a worker may potentially learn on the job. In my analysis I use the employer's R&D intensity as a proxy for this variable. When testing the market value of the accumulated knowledge it is necessary to decompose workers' human capital, and estimate the price or relative weight of the various components. I do this using a standard log-linear hedonic wage regression. Some problems are, however, immediately evident. Work experience needs to be decomposed according to the training or research content of the jobs that the workers have had at different stages of their career, but complete information about the workers' career histories is not available. Furthermore, it is far from obvious how one can summarize what is known about the workers' experience from different firms into a good measure of human capital. I suggest several solutions to these problems.

My first approach is to assume that workers career trajectories are such that their research exposure is constant over the career. Mobility patterns found in the data suggest that this assumption is not unreasonable, i.e. workers tend to move between firms with similar R&D-intensities. This implies that R&D intensity at each point of time in a career reveal information both about current learning and about the workers' accumulated

R&D experience. More specifically, the estimated joint effect will give the returns to R&D experience minus the cost of current learning. Working for a highly R&D intensive employer should cause a large negative wage premium early in the career, reflecting the implicit price paid for R&D experience. At that point in the career, this experience has not had much time to affect the stock of human capital, but as time goes by, workers' willingness to pay for human capital accumulation decreases and approaches zero, while differences in previous R&D experience will translate into differences in human capital. Workers who are in R&D intensive firms and have a long R&D intensive career behind them, should therefore have a large positive wage premium reflecting the human capital accumulated.

Utilizing this approach, I find that scientists and engineers who choose an 'R&D intensive' career accept a wage discount of about six percent in their first year after graduation. This may be a conservative estimate, because there may be a tendency for R&D intensive firms to hire the best workers. Towards the end of their career, scientists and engineers receive a wage premium of about seven percent. Similar results apply for workers with secondary technical education. The fact that I find as strong results for workers with secondary technical education as for scientists and engineers, indicates that firms' R&D-intensity is not only a measure of learning associated with doing research, but also a proxy for the value of general work experience from high-tech firms. This is not surprising. There may be more to learn in firms conducting research because such firms are likely to use the most up-to date technology and frequently change their products and production processes.

The analysis summarized above utilizes cross sectional information only, and estimates, as explained, the return to previous R&D experience *minus* the price paid for current learning. Utilizing the longitudinal dimension of the data set, it is possible to specify these two components separately. The learning opportunity that a worker faces depends only on *current* R&D intensity, while average R&D intensity in *previous years* reveal information about workers' R&D experience. A more sophisticated approach is thus to estimate the price paid for learning separately from the return to research experience, by including both a measure of previous R&D experience and the R&D intensity of the current employer. This is more demanding with respect to data, but an explorative analysis suggest that having work experience from R&D intensive firms is associated with higher wages, while the employers' *current* R&D intensity reduce wages for workers with less than 20 years experience. Furthermore, as predicted by human capital theory, the youngest workers appear to invest most heavily in on-the-job learning.

Chapter 4 is, as far as I know, the first paper to look at the effect of R&D on wages. There exists, however, a large literature on the effect of formal on-the-job training. In this literature, a number of authors have found training to be correlated with wage growth, but finding support for a negative effect on starting wages such as human capital theory predicts is unusual. Common interpretations are that workers do not pay for general training, or that the implicit price is masked by a positive ability bias. In this perspective,

the strong negative effect of R&D on starting wages present in my sample, is remarkable. It suggests that firms' technology levels are more important to wages than formal training. One explanation for this could be that while most formal training is short term, working in a technologically challenging environment affects human capital accumulation for the entire duration of a job.

An important question that my analysis does not clarify is whether workers pay for the *full* value of the knowledge they accumulate in R&D intensive firms. From a theoretical point of view it is conceivable that labor mobility creates some externalities. If firms have limited ability to commit themselves to share future profits with their employees, or if several workers have access to exactly the same research results, this may undermine the wage contracts necessary to assure optimal R&D investments. Furthermore, information asymmetries and other barriers to mobility may enhance firms' ability to appropriate rents, while at the same time reduce workers' incentives to pay for knowledge accumulation. Mechanisms which induce employers to pay for general human capital accumulation create a positive externality to the worker's future employer if the worker decides to quit or if the firm goes out of business. A complete welfare analysis must also incorporate that even if workers pay for all the knowledge they accumulate, this 'solution' to the spillover problem does not guarantee optimal R&D investments. If workers co-finance R&D through lower wages, and the value of the knowledge they accumulate depend on the outcome of the R&D project, they become exposed to the risk associated with the project. Risk aversion among workers may then become a new source of distortion since human capital investments cannot be diversified. Liquidity constraints making workers unwilling to trade off current wage for future wage on a large scale, may also create problems. I believe the best way to investigate these issues is to model explicit mechanisms that might cause externalities, and derive testable implication from such specific models.

5 Spin-offs and spillovers: Tracing knowledge by following employees across firms

Most R&D projects fail from a commercial point of view, and technological shifts may quickly turn even successful innovations into failure. This reflects the high risk associated with research, but also that it is difficult to appropriate the returns to knowledge. For this reason it is possible that projects and firms that fail commercially still produce knowledge with some social value. This possibility seems particularly relevant for subsidized R&D, since subsidies are deliberately aimed at projects with high risk and large externalities. The substantial amount of money spent by OECD governments on R&D subsidies makes this an important hypothesis to test. A possible 'scrap value' associated with unsuccessful projects and firms can significantly influence the social returns to R&D subsidies and reduce the overall risk associated with technology programs.

This issue has so far not been investigated in the technology program evaluation lit-

erature, but case studies from the semi-conductor industry point to employee mobility and the creation of spin-off firms as important vehicles for R&D spillovers. The recent availability of large matched employer-employee data sets makes it possible to analyze statistically the importance of human capital and employee mobility suggested by such case studies. In chapter 5 I illustrate how this can be done by taking a second look at the technology programs evaluated in chapter 2.

As emphasized in chapter 4, research is a learning process. Knowledge built up in failed projects and firms is therefore likely to be embodied in workers or teams of workers. In order to assess the value of such knowledge, it is necessary to trace workers as they move across firms and industries seeking to maximize the returns to their human capital. Furthermore, tracing knowledge flows by following employees is not only relevant when firms fail. It can also be useful when analyzing particularly successful firms and technologies, since entrepreneurs often 'cash out' on their investments by selling their company to larger, established firms. Analyses of the opposite process, i.e. the formation of spin-off firms, is also possible within a framework where employees are followed over time and across firms. I hope, therefore, that the ideas presented in chapter 5 may be useful in a more general context than program evaluation.

Chapter 2 concluded that the Norwegian IT-programs in the 1980s and early 1990s were largely unsuccessful. An important motivation for making a further analysis of these programs is recent claims that the growth of the Norwegian IT-industry in the late 1990s was stimulated by knowledge built up in formerly subsidized firms. In particular, employees of the fallen industry leader, Norsk Data, have been pointed to as key contributors in a new generation of successful firms. One expression of the idea that this company had a lasting impact on the industry, can be found in Norway's leading engineering magazine, *Teknisk Ukeblad*. In the fall of 1999, in an article titled "The lighthouse of the Norwegian IT-industry" it was argued that

[a]ll over Norway we see spin-off effects from the Norsk Data era; thousands of people that worked in or with Norsk Data built up know-how whose existence it is hard to imagine without this company. Many of these people started new firms together with old colleagues or business contacts, others have contributed with their experience in other sectors of the economy.

The article leaves the impression that the statement is based on knowledge about a handful of cases. In order to evaluate whether these cases are representative for 'thousands of people', a quantitative framework is called for.

The first step in my analysis is to see where the technical expertise in the subsidized firms became employed later on. I find that many of the workers separating from subsidized IT manufacturing firms transferred to the growing IT service industry. This suggests that there is a link between the R&D subsidies awarded in the 1980s and the strong growth in the IT-service sector in the 1990s, but obviously it does not prove that subsidies caused

this growth. Looking next at unemployment, re-education, relocations and similar variables, the positive 'first impression' is strengthened as workers from subsidized firms do not seem to have faced any particular difficulties in finding new jobs. Their knowledge, therefore, is likely to have been at least partly transferable. Having established this, I move on to analyze earnings, which is the main indicator of labor market success.

If know-how accumulated in subsidized firms provided a basis for growth elsewhere, we would expect experience from subsidized firms to have higher value in the labor market than experience from other firms. This assertion can be tested using extended wage regressions. Lacking a 'pre treatment' period I start out exploring scientists and engineers' wage level during the program. Next, I investigate wage growth following the program, and finally I look at the wage level after the program.

The wage regressions from the program years suggest that working in IT firms at the time was an investment in general human capital, much more so than working in other R&D firms. There is, however, nothing in the data suggesting that investments in general human capital were particularly large for workers in subsidized firms. It is still possible that human capital built up in subsidized firms during the program years proved itself to be particularly productive later on, but the analyses that follow show that scientists and engineers with experience from subsidized firms perform exactly as good, or bad, as workers from non-subsidized firms. Workers in all IT-firms seem to have invested in general human capital by accepting wages below their alternative wage in the 1980s, but they have not experienced higher wage growth than otherwise similar workers later on. With respect to workers in subsidized firms, they do not seem to have gained anything in particular from participating in the subsidized projects. This suggests that the return to the knowledge investments made by the government and the workers themselves was zero.

A complementary approach to looking at the performance of individual workers is to focus on the performance of spin-off firms defined by groups of workers that have stayed together. This approach is explored in the last part of chapter 5. When several workers from the same firm continue to work together, it is reasonable to assume that they are exploiting know-how accumulated in their previous work environment, and that there are positive complementarities between them that make them stay together. It is also possible that firm profits is a better performance measure than wages, particularly if the spin-off firms to some extent are worker-owned.

The first performance measure I consider is sales growth. It seems that spin-off firms perform slightly better than other firms along this dimension, but the difference is not significant. Next I look at profitability. Whether looking at return on sales, return on assets or return on equity, I find that spin-off firms are significantly *less* profitable than other firms. It is difficult to explain this result, but one possibility is that the spin-off firms mostly consists of troubled remnants of previously subsidized units, and that they are kept running because their core know-how has low alternative value. In any case, the analysis does not support the idea that important returns from the IT-program ended up outside the

originally subsidized units.

6 Concluding remarks

On May 8th 2001, in a statement to the Norwegian Parliament about the government's IT-policy, the Norwegian minister of trade and industry, Grete Knudsen, explained that when her government took office a year earlier they "realized that an even stronger co-ordination of the IT-policy was necessary", and she proclaimed: "The IT revolution is not dead. It is now it really starts".² For someone who have studied the history of Norwegian IT-policy, these statements have a familiar ring to them. Norwegian governments have since the late 1940s consistently tried to promote electronics and information technology, but there is little evidence to suggest that these efforts have been successful. This, of course, does not prove the minister wrong. An even stronger focus on, and co-ordination of, the IT-policy *may* clearly be desirable, and we *may* currently experience a period where the 'IT revolution' is gaining momentum rather than leveling off. It is, however, important that new initiatives are made in light of past experiences.

I have in this thesis questioned the government's ability to improve on the market solution, I have questioned some of the arguments in favor of subsidies to commercial R&D and I have emphasized that there are market mechanisms capable of internalizing some of the many externalities associated with innovative activities. My main point is not that there is *no* scope for public intervention, nor that such interventions *have* to fail. Evaluation studies from other countries, some of them summarized in chapter 3, suggests that technology programs can stimulate private R&D and generate positive externalities. My point is that we should be humble about what we know and what can be achieved.

Uncertainty with respect to the effect of technology programs and their optimal design implies that there is much to gain from systematic accumulation of knowledge. We need to learn more about what works and what does not work, and we need to feed this information back into public agencies so that their programs are continuously redesigned according to best practice. I have in this thesis discussed some of the difficulties involved in policy evaluation, and suggested some non-experimental methodologies that may be applied in future studies. A more radical approach to enhance our understanding, would be to experiment deliberately. Adam Jaffe (2000) has said that he is "personally puzzled as to why it is okay to randomize when people's lives are at stake (drug trials), but not when research money is at stake". I strongly agree with him at this point. I also agree with his final conclusion, that much can be achieved without introducing explicit randomization if program evaluation is built "into the design of public research support programs". This approach requires that data on project characteristics for all applicants is accumulated and made available to researchers together with data on awarded subsidies.

² "Redegjørelse av nærings og handelsministeren om IT-politikk", *Forhandlinger i Stortinget nr. 192*, page 2853-2858. My translation.

In future work, I hope to utilize such data from the Research Council of Norway in order to investigate whether current technology programs produce more positive outcomes than those evaluated in this thesis.

Finally, I would like to stress that R&D subsidies is not the only policy instrument relevant to high-tech industries. Higher education, academic research and economic policy in general are areas of vital importance. Educated workers is a key input, and academic research is important both to technological progress and to technology transfer. Furthermore, what is good for the economy at large is good for high-tech industries. A stable and efficient tax system, a high quality legal system and good infrastructure may in the long run be more important than specific technology programs. This last statement, however, does not imply that I consider such programs unimportant or uninteresting. Having spent several years working on the topic, I am eager to continue in the field.

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Chapter 2

Tor Jakob Klette* and Jarle Møen**

From Growth Theory to Technology Policy – Coordination Problems in Theory and Practice

Information technology has been recognized as a 'generic technology' with 'strategic importance' for economic development by many commentators and governments. In this spirit a number of countries, including Norway, have implemented governmental programs to promote the production and application of information technology. Economists have had a hard time making sense of terms such as a 'generic technology' and a technology being of 'strategic importance', at least until Bresnahan and Trajtenberg (1995) introduced the notion of 'general purpose technologies', and examined their potential importance for economic growth. General purpose technologies are characterized by their wide applicability, their potential for development and what Bresnahan and Trajtenberg called innovative complementarities. By innovative complementarities they had in mind positive pecuniary externalities between the develop-

ment of the basic general purpose technology and innovations in the sectors using this technology. Such externalities tend to create coordination problems and Bresnahan and Trajtenberg argued that due to the pervasive applicability of 'general purpose technologies', these coordination problems might be large even in a macroeconomic perspective.

As we explain in detail below, the analysis of coordination problems associated with 'general purpose technologies' seems to capture quite well the motivation behind the substantial effort and money spent by governmental agencies in Norway to promote the production and utilization of information technology, and also the many attempts to coordinate the various policy tools involved in this effort. The dominating part of these IT-programs became targeted directly at promoting the manufacturing of IT-products. The IT-programs were implemented throughout the 1980s and 1990s, and their considerable size is indicated

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by the total expenditures amounting to NOK 4.4 billion (\$ 620 Mill.) for the largest of the programs implemented over the four year period 1987–1990.

Having discussed the theory and the programs in the first two sections, we present a quantitative analysis of the impact of the IT-related technology programs on the manufacturing part of the IT-industry including closely related high tech manufacturing sectors. In the first part of this analysis we compare the performance of targeted firms to other firms in the same industries. Next, we consider the development of the IT-industry and the related high tech manufacturing sectors relative to the performance of the manufacturing sector at large, and finally we compare the performance of these sectors in Norway to their performance in other OECD economies.

The general conclusion is that the IT-programs, while well justified according to economic principles, seem to have failed in promoting the development of the IT manufacturing sector in Norway. In the last part of the paper we discuss various explanations for the failure of these programs such as informational problems and institutional inertia in the governmental agencies heading their implementation.

From new growth theory and coordination problems to technology policy

Innovation, economic growth and technology policy

Externalities associated with R&D, learning and innovation have been emphasized in

recent developments in growth theory, and it has been widely recognized that these externalities create coordination problems and possibly scope for welfare improving government interventions. Theoretical work on economic development and growth has emphasized that the development of new industries in the presence of such externalities tend to create multiple equilibria where one equilibrium corresponds to the new industry never reaching a 'critical mass' or never 'taking off'¹, while other equilibria correspond to the industry 'taking off' and starting on a cumulative growth process². It is the complementarity in activities across independent firms, e.g. in innovation activities, that give rise to multiple equilibria with high and low levels of growth.

There are several policy tools available to deal with externalities and coordination problems in innovative activities as discussed by Romer (1993) and many others. In theory, external effects can be corrected for by tax credits, grants, public production and extending property rights through patents or copyrights. All these means have been used by the OECD countries to promote R&D and innovation. However, the issue of optimal design of R&D and innovation policies is far from settled, and the practice of technology policy vary substantially across countries, technological fields and various stages of the innovation process³.

A particular coordination problem that we want to focus on arises when the technology in question is 'generic'. Information technology is one example of this, and it is a technology which has been actively promoted by most OECD governments.

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1. See the appendix in Da Rin and Hellman (1997) for a formal discussion of the notion of critical mass and take off problems in the presence of positive externalities and complementarities.
 2. See e.g. Murphy et al. (1989), Milgrom et al. (1991), and for a survey, Matsuyama (1995).
 3. See Mowery (1995).

An economic analysis of 'generic' or 'general purpose' technologies

According to Bresnahan and Trajtenberg (1995), economic models, including most growth theoretical models, tend to "treat all forms of technical change in the same, diffuse manner", and there has been little economic analysis suggesting that research and innovation associated with 'generic' technologies such as information technology require particular attention. This motivated Bresnahan and Trajtenberg (1995) to introduce the notion of 'General purpose technologies'⁴ (hereafter GPTs), which they characterized by: (i) *pervasiveness*, (ii) *potential for technical improvements*, and (iii) *innovational complementarities*. Drawing on studies by economic historians on the role of the steam engine, the factory system and electricity, they argue that GPTs may be essential to understand the importance of innovation for economic growth. With respect to recent history, Bresnahan and Trajtenberg focus on the development of semiconductors and IT.

There are two features of general purpose technologies that we should emphasize. First, generality of purpose which means that a GPT potentially can be applied in several *application sectors*. Second, that such applications require *complementary innovations*. That is, there is complementarity between innovations in the GPT and innovations in the related application sectors. An innovation in an application sector will make the GPT more useful and thereby extend its market. A larger market means that further innovations in the GPT will be profitable. A better GPT will in turn widen its usefulness in the application sectors and thereby make further complementary innovations in the applica-

tion sectors profitable. This complementarity between innovations in the GPT and an associated application sector involves pecuniary externalities which tend to create a coordination problem.

There is a second type of complementarity associated with GPTs. An innovation in one application sector will, as we just have explained, create incentives to develop further improvements in the GPT. Improvement of the GPT will benefit *other* application sectors associated with the GPT, and hence, there is complementarity not only between the GPT and each application sector, but also between innovations in different application sectors. This creates further pecuniary externalities, and a need for coordinating innovations both between the GPT and each application sector and between different application sectors associated with the same GPT.

Bresnahan and Trajtenberg (1995) argue that the development of a GPT and its applications have a sequential order. Specific innovations in the application sectors can only be implemented profitably when the GPT has reached a certain stage of development. This sequential aspect of innovations in the GPT and innovations in the application sectors reinforce the desirability of coordinating R&D and innovative activities. Bresnahan and Trajtenberg point to the current complaints of software developers against Microsoft as an illustration of the coordination problems that might arise. Software developers argue that Microsoft 'excessively' exploits its coordination advantage as the developer of both Windows and other software, by not disclosing as soon as possible features in new versions of Windows. The general point is that there might be a

4. See also the subsequent work in Helpman (1998)

significant advantage for the developers of various applications to have detailed insights into the research and development of the basic technology, i.e. the GPT itself.

Bresnahan and Trajtenberg conclude that arm-length market transactions between the GPT and its users will give 'too little, too late' innovation. Difficulties in forecasting and coordinating the technological developments in the GPT or in the various application sectors can lower the rate of technical advance, diffusion and development of new as well as old sectors of the economy. Economists, when recognizing these coordination problems and their undesirable consequences for economic growth, tend to point out the scope for welfare improving government intervention.

Technology policy and IT as a general purpose technology

Information technology at several levels can be characterized as a GPT. First, at a basic technological level, the development of semiconductors and integrated circuits have served as a GPT for a vast number of application sectors, and there have been strong innovational complementarities between the development of the integrated circuits and innovations in various kinds of computers, telecommunication equipment and a whole range of other electronic devices. Second, if we focus on the development of the computer, in particular the PC, this represents a GPT in itself, having e.g. different pieces of software serving as application sectors. Thinking further about various kinds of software associated with the PCs, we can recognize e.g. the worksheet or word processors as GPTs at a new level.

Our point is that the introduction of various parts of information technology often involve innovative complementarities and might therefore create some of the coordination problems that we discussed above. This perceived need for coordination seems to capture quite well the motivation behind the policy initiatives related to production and application of information technology made by the Norwegian government in the 1980s and 1990s. Similar initiatives were launched by the governments in other OECD economies.

Introducing the National Program for Information Technology for the period 1987-90, the government wrote in its budget report⁵:

The motivation for the program is information technology's role as a strategically important field for manufacturing growth, and furthermore its general significance for increasing productivity and growth in other industries and services.

This argument was elaborated on in the report from the official commission evaluating the program, where the following aspects of information technology were emphasized⁶:

Information technology has broad industrial and economy wide applications, but this is not entirely exceptional. More basic for this type of technology is the need not only to develop the technology itself, but to adopt the technology to the needs in quite different applications; in manufacturing, the public

5. 'Statsbudsjettet 1986/87', St.prp. nr. 1, p. 40. Our translation.

6. Harlem et al. (1990), p. 235. Our translation.

sector and in the economy at large. In this situation there are two essential factors relevant for the development of a coordinated technology policy: The applications represent the market for the manufacturers while the manufacturers are problem solvers for the users. This creates a demand for an IT-policy reflecting the integration between researchers, users and producers.

The report from the official commission then goes on to discuss to what extent the targeted program for information technology was an appropriate policy tool, and we will return to their conclusions below.

The Norwegian policy initiatives on information technology in the 1980s and 1990s were motivated by an understanding of the broad set of potential applications for IT and the interaction between the basic innovations and the adoption and development of these innovations in the applications sectors. This motivation for a coordinated plan and a government initiative targeted at information technology, is in our interpretation congruent to the analysis of GPTs and the coordination problems emphasized by Bresnahan and Trajtenberg (1995).

Coordination problems and the Norwegian IT-programs

The technology programs related to information technology in the 1980s and 1990s

In Norway in the 1980s, there were some widely held worries about the state of the domestic information technology industries, and the emphasis was on the following three sets of problems: (i) Fragmentation of public funds for R&D, innovation and utilization of IT-technology, (ii) too many small and independent firms, and (iii) little long term planning and originality in product development⁷. The promotion of the IT-industry in the period we consider from 1982 to 1995 was organized and coordinated through a number of plans and programs of various size⁸. The largest plan in this period was the aforementioned National Program for Information Technology⁹, lasting from 1987 to 1990. This program had total expenditures of NOK 4.4 billion¹⁰ and included a number of 'subprograms' (see below).

Before 1987, the Royal Norwegian Council for Scientific and Industrial Research (NTNF) had implemented several funding schemes which were predecessors to the National Program for Information Technology¹¹, and

7. See Hervik and Guvåg (1989), p. 7 and Harlem et al. (1990), ch.3 .

8. The R&D subsidy programs have been administered by various research councils and governmental funds. With respect to the high tech industries the Royal Norwegian Council for Scientific and Industrial Research and the Fund for Industry were the most prominent agencies. In the early 1990s the various research councils were merged into the Norwegian Research Council, and most governmental industry funds were merged into the Norwegian Industry and Regional Development Fund. Besides these agencies, R&D grants have also been awarded directly through ministries.

9. 'Den nasjonale handlingsplan for informasjonsteknologi'. See Harlem et al. (1990) and Buland (1996) for detailed documentation.

10. Approximately \$ 620 Mill. NOK 2.1 billion of the expenditures were 'fresh money', see Harlem et al. (1990), ch. 7.2.4.

11. These included: (i) 'Nyskappingsplanen 1977-82', see Grønhaug and Fredriksen (1984). (ii) 'NTNFs Handlingsprogram for Mikroelektronikk og Databehandling 1982-85', see Klette and Søgne (1986). (iii) 'Nyskaping i næringslivet' which started in 1984. (iv) 'NTNF's spesialprogram for mikroelektronikk' which started in 1985. All these activities were related and the last two programs were continued within the National Program for Information Technology from 1987. The research councils also sponsored a number of individual research projects related to IT. See 'Stortings prp. nr. 133, 1977/78' for details.

the industrial part of the National Program for Information Technology was succeeded by the 'National Plan for Improved Utilization of Information Technology in the Norwegian Industry 1992-95'¹². This last program was small in terms of its independent budget, and its main objective was to coordinate ongoing public support schemes related to information technology.

In the rest of this paper we will refer to the various support schemes for industrial applications of information technology as the 'IT-programs'. Before we turn to an overall evaluation of the economic impact of the IT-programs, we will discuss more closely the National Program for Information Technology. As stated, this was the most important and ambitious of the programs, and its implementation and organization are extensively documented in Harlem et al. (1990), Buland (1996) and other publications.

A closer look at the National Program for Information Technology, 1987-90

The National Program for Information Technology was a broad plan to coordinate activities aimed at promoting the production and applications of information technology. The plan covered basic research, education, production of integrated circuits and computers, and applications of information technology throughout the economy including the public sector¹³. Even though

the original plan had a very broad scope, the actual implementation of the program focused heavily on manufacturing of electronics and other IT-products. According to Harlem et al. (1990)¹⁴:

The program's focus on manufacturing can be observed in the distribution of project grants by institution; 48 percent of the budget went to firms [which were mainly firms in electronics and related high tech industries], while another 33 percent went to government labs which in practice also were focused on applied research for the manufacturing sector.

The project funds were very unevenly distributed across firms, with the ten largest recipients receiving 35 percent of the funds. These firms were producing electronic products, telecommunication equipment, instruments and computers¹⁵. The largest recipient, Norsk Data, received by itself more than 12 percent of the budget allocated to firms¹⁶.

Table 1 presents the expenditures for the National Program for Information Technology 1987-90. To illustrate the considerable magnitude of the numbers in Table 1, one should notice that e.g. publicly funded technological and scientific R&D in universities and governmental labs in 1989 in total amounted to NOK 2542 Mill¹⁷.

As can be seen from Table 1, a significant

12. "IT-plan for næringslivet 1992-95", see Olsen et al. (1997) for details.

13. See Harlem et al. (1990), chs. 4 and 7.2.

14. P. 64, our translation.

15. The ten largest recipients were Norsk Data, Autodisplay, EB Nera, Nordic VLSI, EB, LCD Vision, Seatex, Micron, Simrad Subsea and Alcatel/STK. The order reflects the size of the funding.

16. This percentage does not include the so-called FUNN-project. See Harlem et al. (1990), especially ch. 4.1.1 for further details on Norsk Data's projects within the National Program for Information Technology.

17. See NIFU (1991), Table T6 and N2. Publicly funded technological R&D in universities and governmental labs in total amounted to NOK 1245 Mill, while the public funding for scientific research in universities was NOK 1297 Mill. Publicly funded R&D in private firms was NOK 465 Mill. in 1989.

Table 1. Expenditure within the «National Program for Information Technology 1987–90» broken down by field and year. Million NOK

	1987	1988	1989	1990	Total
Education	306	373	426	427	1 532
Research	138	132	135	130	534
Product development	134	151	239	220	745
Applications	329	369	398	474	1 570
Total	907	1 025	1 197	1 252	4 381

Source: Own computations based on Harlem et al. (1990), chapter 7.2.4.

part of the National Program for Information Technology's budget went to education and to a lesser degree also to basic research related to IT. At least the educational part of the program has been considered successful by Harlem et al. (1990) and others, but our focus is on the substantially larger parts of the IT-programs that were targeted more directly at industrial production and applications of information technology.

A quantitative assessment of the economic results of high tech support in the 1980s and 1990s

Expectations about the effects of the IT-policy

Based on the theoretical arguments related to GPTs, one would expect the IT programs and the coordination effort to stimulate economic performance in the targeted firms and industries. Such expectations were most clearly stated by the committee heading the implementation of the National Program for Information Technology from 1988–90, which anticipated an annual growth of 15 percent in sales and 20 percent in exports from IT manufacturing as a result of the Program; see Harlem et al. (1990), pp. 173–4.

It is not obvious how one could test such predictions, since we do not know what

would have happened if the program had not been initiated. We have confronted the predictions with observed outcomes in a number of ways. Our first approach is based on comparing the performance of the firms receiving R&D support to other firms operating in the same industries, and the prediction we consider is that the supported firms performed better than other firms. The hypothesis is that the supported firms belong to targeted technology groups which will benefit more from the IT programs and are more able to exploit the innovative opportunities related to IT than other firms in the IT industry.

One can argue that the comparison between supported and other firms in the same industry is too narrow a view and that the IT-programs have created benefits for *all* firms in IT-related industries. As a second approach we therefore consider the performance of the supported industries relative to the rest of the manufacturing sector, and finally, we also compare the performance of the high tech industries in Norway to their performance in other OECD economies. The last comparison must be interpreted with caution since the IT industry have been strongly supported also in other OECD economies, as we will discuss below.

The magnitude of the R&D support to the high tech industries

We define the IT or information technology industry as consisting of the manufacture of office machinery and communication equipment, i.e. ISIC 3825 and 3832. This is the kind of production most intensely promoted by the governmental programs described above, and consequently the sectors where we should expect to see the main effects. However, related sectors also received significant support, and many companies have both production and research activities covering a broader class of products. Due to this and due to the associated classification problems and possible spillovers between closely related production activities within companies, we have in our econometric work decided to use R&D data aggregated to the three digit line of business level. Our sample, therefore, covers more general high tech industries than IT, namely the manufacture of machinery, electrical equipment and technical instruments, i.e. ISIC 382, 383 and 385¹⁸. The R&D support most relevant for our discussion is the subsidies administered by the research councils and industry funds, and this R&D support has on average been about 80 million NOK a year, having a maximum of 123 million NOK in 1987. Since then the support has decreased by 46 percent in nominal terms or by 58 percent if the figures are deflated by the consumer price index. In 1995 the support was about 67 million kroner which was about 1250 kroner per employee in the high tech industries¹⁹. The research councils and industry funds financed about 6 percent of the total R&D investments in these industries in 1987 and about 3 percent in

1995. Including the grants awarded directly through ministries, the shares increases to about 24 percent and 11 percent respectively.

Microeconomic evidence on subsidized versus non-subsidized firms

Short and medium run effects of public R&D support

It is difficult to find one variable that defines the success of a firm. We therefore study the effect of receiving public R&D support on a variety of different performance measures. Furthermore, as there is no theoretical model predicting how a particular level of subsidy will affect these different measures, we use a simple dummy variable approach, following Irwin and Klenow (1996). Our basic idea is to compare subsidized and non-subsidized firms to clarify whether subsidized firms on average have performed better than the others. The advantage of doing this within a regression framework, is that it enables us to control for other variables that might be correlated both with performance and with the probability of receiving a subsidy. Based on the time series files of the Norwegian manufacturing statistics collected by Statistics Norway, we have constructed eight performance measures containing information on four different aspects of firm success. Information on R&D and R&D subsidies is merged in from the R&D surveys conducted by the Royal Norwegian Council for Scientific and Industrial Research (NTNF) in the years 1982–1989 and by Statistics Norway in the years 1991–1995.

18. In a previous version of this paper Klette and Møen (1998), we also presented an analysis based on a sample for the more narrowly defined IT industry consisting of ISIC 3825 and 3832.

19. Looking at the IT-industry in isolation, the support per employee from the Research Council and the Industry Fund was three times larger.

The R&D subsidy dummies are based on the share of subsidies to total R&D over the three years prior to the year of observation. We do not expect a small subsidy to have much effect on performance, and therefore we do not distinguish between zero and less than a five percent subsidy share. On the other hand, a large subsidy might affect a firm differently than a medium subsidy, and to test this hypothesis we have one dummy indicating more than a 5 percent subsidy share and an additional dummy indicating more than a 25 percent subsidy share²⁰. Using these definitions, there are 841 observations with more than a 5 percent subsidy share, and 357 of these have more than a 25 percent subsidy share. There are 1958 observations with positive R&D in at least one of the three years prior to the year of observation, and altogether our sample consists of about 6000 plant-year observations spanning ISIC 382, 383 and 385 in the years 1983 to 1995. A previous version of this paper (Klette and Møen, 1998a) gives further details on sample and variable construction.

We have started out regressing each performance measure on the two subsidy dummies, time and industry dummies. It is possible that significant coefficients on the subsidy dummies are due to reversed causality, i.e. that successful, or possibly unsuccessful, firms have a better chance of receiving subsidies. This can, at least partly, be controlled for by introducing plant specific fixed effects, which is equivalent to measuring all variables as deviations from the firm specific means. Unfortunately, this

comes at a cost, as the downward bias on the estimated coefficients due to measurement errors, is likely to increase²¹.

It should be emphasized that the units of observation in the regressions are manufacturing plants, while the R&D statistics for these plants are based on the R&D activity at the level of the business unit within the firm which they belong to. With plants as units of observation we are able to keep track of the history of production activities that belong to restructured firms. This is essential since several of the largest IT-firms, e.g. Norsk Data and Kongsberg Våpenfabrikk, were restructured within the period covered by our sample. To keep the terminology simple we will, however, refer to R&D firms and other firms in the discussion of our results, rather than more precise terms such as plants belonging to R&D performing firms.

We start out by analyzing the effect of subsidies on firm growth, and the results are given in the first two columns in Table 2. Table 2.A reports results from ordinary OLS regressions, while Table 2.B reports results from regressions that incorporate plant fixed effects. In column 1, the growth measure is based on man-hours, and in column 2 the growth measure is based on sales. No matter which measure is used, there do not appear to be important differences between subsidized and non-subsidized firms. The point estimates are negative but statistically insignificant for firms receiving between 5 and 25 percent subsidies, and positive or close to zero (but statistically insignificant) for firms receiving more than 25 percent subsidies²². In

20. Firms with a subsidy share exceeding 25 percent are quite similar to other firms with respect to size, capital intensity and profit margins. However, they receive 70 percent of total R&D support, but only 39 percent of the R&D support from the research councils. These firms account for 33 percent of total R&D in the high tech industries we consider.

21. Cf. Griliches and Hausman (1986)

22. This effect is given by the sum of the two coefficients. Testing robustness, we have found that the results

Table 2. The effect of R&D subsidies on firm performance

	Growth in manhours	Growth in sales	Return on assets	Profit margin	Labour productivity	Total factor productivity	Investment Intensity	Inten. in priv. finan. R&D
A: OLS estimates								
Dum. for R&D sub. share >0.05	-0.007 (0.018)	-0.021 (0.030)	0.049 (0.051)	0.033 (0.035)	-0.027 (0.022)	0.001 (0.010)	0.0027 (0.0036)	0.029 (0.030)
Dum. for R&D sub. share >0.25	0.044 (0.030)	0.083 (0.060)	0.049 (0.094)	-0.045 (0.041)	0.017 (0.031)	-0.0003 (0.013)	0.0025 (0.0061)	-0.026 (0.036)
Dum. for reporting R&D	-0.041*** (0.011)	-0.019 (0.020)	-0.11 (0.12)	0.024*** (0.007)	0.083*** (0.012)	0.061*** (0.006)	-0.0032 (0.0027)	
No. of observations	5622	5622	6020	6041	6041	5874	6041	1958
R-squared	0.03	0.02	0.004	0.03	0.12	0.13	0.01	0.11
Root mean square error	0.40	0.61	7.11	0.28	42.5	0.17	0.09	0.37
B: Fixed effects estimates								
Dum. for R&D sub. share >0.05	-0.019 (0.020)	-0.063* (0.034)	-0.075 (0.012)	0.011 (0.031)	-0.063*** (0.022)	-0.023** (0.009)	0.0013 (0.049)	0.021 (0.030)
Dum. for R&D sub. share >0.25	0.018 (0.037)	0.094 (0.070)	0.017 (0.013)	-0.063 (0.067)	0.005 (0.030)	0.013 (0.012)	-0.0037 (0.0071)	-0.049 (0.069)
Dum. for reporting R&D	-0.023 (0.020)	0.011 (0.034)	0.035 (0.17)	0.023*** (0.009)	0.029* (0.016)	0.030*** (0.008)	-0.0051 (0.0043)	
No. of observations	5622	5622	6020	6041	6041	5874	6041	1958
Root mean square error	0.40	0.61	7.11	0.28	42.5	0.17	0.09	0.37

OLS estimates based on yearly data from ISIC 382, 383 and 385 in 1982-1995. The sample is moderately trimmed. Robust standard errors in parenthesis. Time dummies are included in all regressions. Industry dummies at the five digit SIC level are included in the OLS regression. The R&D subsidy share is the sum of deflated R&D subsidies over the three years prior to the year of observation divided by the corresponding sum of total R&D investments. If only one or two years prior to the year of observation is available, the subsidy share is based on this information alone. The R&D dummy is one if the firm has reported R&D in one of the three years prior to the year of observation. Labor productivity is measured as the log of value added per man-hour deflated by the consumer price index. The total factor productivity index is a translog multilateral measure comparing output and the use of capital, labour and materials to a hypothetical reference firm producing the yearly median output using the yearly median of each input. Constant returns to scale is assumed and the elasticities of labor and materials are calculated using cost shares. The index is based on the work of Caves, Christensen and Diewert (1982). The intensity of investments is investments in physical capital divided by sales. The intensity of privately financed R&D is privately financed R&D divided by sales.

*** Significant at the 1% level

** Significant at the 5% level

* Significant at the 10% level

passing, we notice that the results in Table 2 also show that R&D firms have on average grown more slowly than non-R&D firms, both in terms of man-hours and sales²³.

The effect of subsidies on profitability are examined in column 3 and 4 in Table 2. We measure profitability both as return to assets and by the profit margin. One might argue that return to assets is the more relevant measure of the two, but the reliability of this measure is reduced by the large measurement errors associated with the capital variable. This is evident from the small R-square and the large root mean square error in column 3, and there are no significant coefficients emerging from these regressions, whether estimated with or without fixed effects. Neither does column 4 show any significant difference in the profit margins between firms with and without R&D subsidies. However, there seems to be a general characteristic of *all* R&D performing firms that they have higher profit margins than firms without R&D, as shown by the positive and significant coefficient for the dummy for firms reporting R&D.

Turning to the effect of subsidies on productivity, the regression results are reported in columns 5 and 6. We have used both labor productivity, column 5, and total factor productivity, column 6, as the dependent variable. Our results show that the subsidized firms have a lower level of productivity, and the differences are statistically highly significant when fixed effects are included.

The effect of subsidies on the investment intensity is reported in column 7 in Table 2. The investment intensity is defined as

investments in machinery and buildings relative to sales, and we consider this measure as a proxy for expected growth in sales. Furthermore, we believe that expected growth in sales is positively correlated with the success of the firm's R&D projects, particularly after industry differences have been controlled for. Looking at column 7, we find that there are no systematic differences between subsidized and non-subsidized firms in this respect.

Private R&D expenditure could also be considered a proxy for past R&D success, and besides this, stimulating R&D expenditure has been an explicit aim of the technology programs. From column 8 we see that there are no significant difference between the intensity of privately financed R&D in subsidized and non-subsidized firms. In an ongoing companion study, Klette and Møen (1998b), we examine the effect of R&D subsidies on private R&D expenditure in more detail, applying various econometric approaches. Preliminary results from that study confirm that subsidies do have some effect on private R&D expenditure.

Longer run effects

Studying the effect of R&D within the high tech industries, it is customary to assume a one year lag between the R&D investments and the *first* effect on production. This is justified by the short-term nature of much commercial R&D, but it seems likely that the peak of the impact has more than a one year lag. For this reason we defined our subsidy dummy in the last section using a three year 'window'. However, it could be that R&D projects supported by public agencies have a particularly long-term nature, and it has been

presented in Table 2 are largely unchanged if we neglect the firms receiving large, defense related R&D contracts.

23. This is consistent with the findings reported in Klette and Førre (1998).

Table 3. The aggregate development for R&D firms established in ISIC 382, 383 or 385 not later than 1985

	R&D firms with R&D subsidy share less than 5%			R&D firms with R&D subsidy share greater than or equal to 5%		
	1985	1995	Growth	1985	1995	Growth
Private R&D investments	990	850	-14%	810	660	-18%
– average	8.8	10.5	19%	8.4	9.9	17%
R&D intensity	4.1%	4.8%	15%	8.1%	6.7%	-17%
Employment	22280	14940	-33%	16480	9400	-43%
– average	199	184	-8%	172	140	-19%
Sales	14530	18080	24%	10380	12370	19%
– average	130	223	72%	108	185	71%
Labor productivity	151	253	68%	146	253	74%
Capital intensity	0.46	0.66	44%	0.61	0.97	60%
Return on assets	19.1%	24.7%	30%	12.4%	18.0%	45%
Return on sales	13.4%	13.5%	0.5%	11.9%	13.2%	11%
No. of plants	112	81	-28%	96	67	-30%

The subsidy share is the part of the firm's deflated R&D investments in 1985-1993 which was financed by public grants. R&D investments are deflated by a wage index and given in millions of 1995 NOK. Sales are given in nominal millions NOK. Labor productivity is value added per manhour in nominal NOK. Capital intensity is assets per employee, given in nominal millions NOK. The calculations are based on plant level data.

argued that the effect of the subsidies given in the late 1980s has not been visible until lately²⁴. Against this, one might argue that the growth experienced during the last years, is more likely to be an ordinary business cycle effect than an effect of previous technology programs, as there has been strong growth in all sectors of the Norwegian economy. In order to investigate this issue closer, we have compared the growth of subsidized and non-subsidized firms that existed in 1985, over the entire decade 1985 to 1995. We have defined subsidized firms as firms who had more than

five percent of their R&D expenses over the years 1985 to 1993 financed by the government and we have aggregated across all firms in each group²⁵. The results are reported in Table 3. Once again we have used several different performance measures, and we have deliberately chosen measures that are easy to interpret.

Looking at Table 3, we may first note that subsidized firms have a higher R&D intensity than non-subsidized firms. This indicates that the chance of getting R&D subsidies has been greater for the R&D

24 See e.g. the front page of Computer World no. 38, 1997.

25. In an earlier version of this paper, Klette and Møen (1998a), we also considered the performance of the median firm in each group, and we examined differences in performance within the more narrowly defined IT-industry. Considering the IT industry narrowly defined, there is some evidence that the subsidized firms have performed better than the non-subsidized ones, but the evidence is not very strong.

intensive firms. However, we see that the growth in private R&D investments as well as in R&D intensity have been greater for the non-subsidized firms, and consequently the subsidies do not seem to have stimulated R&D investments. With respect to growth, whether in employees or sales, we see a similar pattern as the non-subsidized firms have performed better than the subsidized ones. Looking at labor productivity, we find that both the level and the growth rate were of about the same magnitude for the two groups. However, as the subsidized firms started out with a higher capital intensity and had a stronger growth in the capital intensity, they seem to have performed worse than the non-subsidized firms with respect to total factor productivity. Turning to profitability which might be considered the most important measure, the non-subsidized firms were the most profitable both in the beginning and in the end of the period, and the subsidized firms had by 1995 not even caught up with the 1985 level of the non-subsidized firms. On the other hand, the subsidized firms did have a stronger growth in profitability than the non-subsidized ones. Finally, looking at the exit rate given in the last row, we see that there is no significant difference between the two groups.

Industrial growth

The aim of the technology programs have been to promote the entire Norwegian IT industry, and in addition to R&D subsidies, relevant education and academic research have also been supported. One way to evaluate the totality of these efforts is to compare the experience of the Norwegian high tech industries to total Norwegian

manufacturing and to the IT industries in other OECD countries. We have performed international comparisons using data from the OECD STAN, ANBERD and BERD databases.

Starting out looking at Table 4, we can see that in Norway the share of IT and general high tech in total manufacturing is smaller than the OECD average. Furthermore, from 1983 to 1995, these shares do not change significantly²⁶. Despite these industries being less important in Norway than overall in the OECD, Norway is conducting more of its total manufacturing R&D within these industries. The reason for this is most likely the composition of Norwegian manufacturing, its major sectors having low R&D intensities.

The distribution of subsidies is given in the last two rows. In Norway, the ratio between the share of R&D subsidies received by high tech industries and these industries' share of total R&D, is higher than the OECD average. The Norwegian high tech industries also have a higher share of their R&D financed by subsidies than the corresponding OECD average. The difference is most significant in 1987 when Norway launched the National Program for Information Technology as described above. The Norwegian industry received about the same amount of R&D support as the OECD average (in relative terms) at the beginning of the time period studied, but by 1987 this had changed as the Norwegian IT industry at that time received significantly more support than the OECD average. One should, however, notice that international comparisons of public R&D support are problematic, as it is hard to identify with much precision how much of e.g. defence related research that

26. Defining the manufacturing IT-industry as most of NACE sectors 30–33, gives the same conclusion.

Table 4. The importance of high technology and IT relative to total manufacturing

	1983		1987		1991		1995	
	Norway	OECD	Norway	OECD	Norway	OECD	Norway	OECD
Employment	19%	24%	21%	25%	20%	25%	19%	-
Value added	19%	22%	20%	21%	19%	22%	19%	-
Total R&D including R&D institutes	54%	41%	54%	43%	47%	43%	-	-
Total intramural R&D	60%	37%	54%	40%	51%	40%	-	-
Total subsidy to intramural R&D	80%	48%	85%	34%	76%	39%	-	-
Subs. as share of tot. intramural R&D	12%	11%	20%	10%	15%	8%	-	-

ISIC 382, 383 and 385. The OECD columns give the aggregate of 13 major industrialized countries for which we have complete data. These are Norway, Sweden, Finland, Denmark, Germany, UK, France, Italy, Spain, USA, Canada, Australia and Japan. All variables, except subsidy as share of total intramural R&D, are measured in percent of all manufacturing industries.

Source: OECD, DSTI(STAN, ANBERD and BERD).

benefits the IT industry. Furthermore, in several OECD countries significant amounts of public R&D support are given in terms of tax reliefs, and such tax allowances are not reflected in the numbers reported in Table 4²⁷. In this perspective, one should not take the OECD numbers presented in Table 4 at face value and conclude that Norway had a subsidy share in R&D which in 1987 was twice as large as in other OECD countries.

Despite this reservation about the OECD numbers, we believe it is interesting to compare the performance of the Norwegian IT industry to the IT industry in other OECD countries as we do in Figure 1 which displays the relationship between R&D intensity and production²⁸. Not surprisingly, it is evident that Norway has a very small

share of the world market. At the same time, the R&D intensity in the Norwegian IT industry is very high, and only Sweden had a comparable increase in the R&D intensity. Despite the increased R&D intensity, in the years 1988 to 1992 Norway was the only country with a fall in production. This fall in production is obviously related to the severe recession experienced in Norway during these years, but if the Norwegian IT industry had been internationally competitive, the condition on the domestic market should not have been too severe an obstacle in a period of growth in the international market²⁹.

Summary of economic results

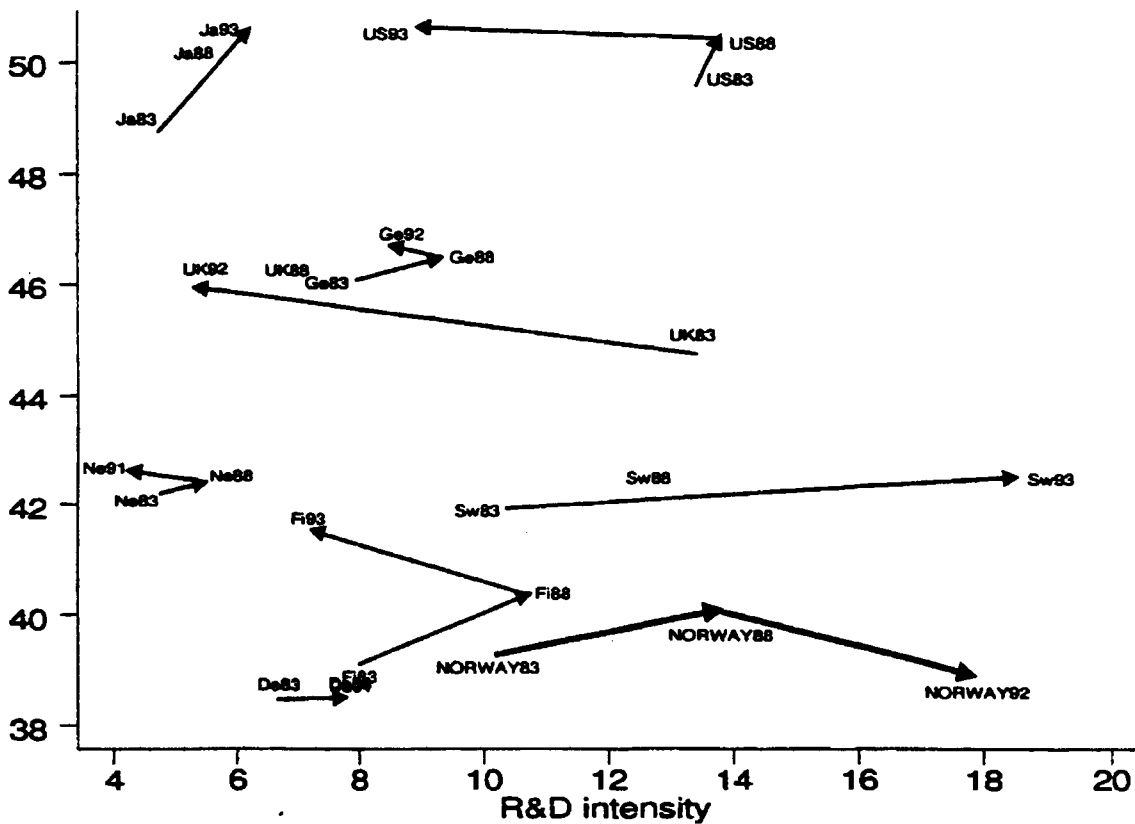
Most countries support IT and related high tech industries. In Norway, the R&D

27. See Bloom et al. (1997) for an analysis of R&D tax subsidies in a number of OECD countries.

28. In Klette and Møen (1998a), we also examine the differences across OECD countries in terms of R&D, employment growth, labor productivity and export performance for the IT-industry. Notice that Figure 1 is based on the IT-industry narrowly defined.

29. Further discussion of the magnitude of the IT program in Norway compared to other OECD countries can be found in Buland (1996, ch. 2) and Harlem et al. (1990, ch. 2).

Figure 1. R&D intensity and production in the IT industry (ISIC 3825 and 3832). Norway compared to other OECD countries.



Production is measured as the log of gross output in 1985 dollars. R&D intensity is R&D investments in percent of gross output.

Source: OECD, DSTI(STAN and ANBERD).

subsidies were particularly large in the second half of the 1980s, both in a national and probably also in an international perspective. In this section we have investigated the effect of these subsidies, using several different approaches and data sources. First, comparing subsidized and non-subsidized firms within the high tech industries, there is little evidence in favor of the subsidized firms being more successful. Second, looking at these industries relative to aggregate

Norwegian manufacturing, their importance have not increased. Third, comparing the development of the Norwegian IT industry to the IT industry of other OECD countries, the Norwegian industry does not perform particularly well. Obviously, if someone claims that the subsidized firms and the entire Norwegian IT industry would have performed a lot worse without the support, we cannot prove him or her wrong³⁰. Nonetheless, we believe a reasonable inter-

30. In that case, however, it would still be difficult to argue in favour of the subsidies, as the rate of return on invested capital in technology industries has been lower than the rate of return in other manufacturing industries, according to the Federation of Norwegian Engineering Industries (1998).

pretation of our results is that the public financial support to R&D and innovation in the IT industry did not create a substantial stimulus to its performance, in contrast to what one would expect from the arguments made by the promoters of the IT-programs and from the theoretical arguments presented above.

Coordination problems and technology policy in practice

The IT-programs – coordination failures at the policy level

We have pointed out that GPTs - general purpose technologies - often create coordination problems that will tend to slow down the development of the GPTs and thereby the emergence of new industries and economic growth more generally. We have also argued that it is reasonable to interpret the Norwegian IT-programs as governmental efforts to overcome these coordination problems and thereby encourage R&D, innovation and utilization of IT-related products.

Our empirical analysis of the economic performance in the firms and sectors targeted by the IT-programs revealed few results suggesting that they have benefitted significantly from the financial stimulation and the coordination effort of the programs. These findings lead to the conclusion stated above that the Norwegian governmental effort to stimulate and coordinate the development of IT-products and applications have not been very successful. We are,

however, not the first evaluation study to recognize the failure of the coordination activities in the IT-programs; this aspect has been emphasized in all previous evaluation reports. A report evaluating the part of the National Program for Information Technology organized by the Industry Fund, concluded that they found few concrete results with respect to the creation of 'strategic alliances' or 'coordinated groups' which was an explicit and major objective of this part of the program³¹. In the overall evaluation a year later, Harlem et al. (1990) concluded that "the plan has undoubtedly failed in improving coordination and integration of policy towards information technology"³². The difficulties involved in implementing coordinating activities could clearly be recognized during the operation of the program as the committee heading the implementation was entirely reorganized twice during the program's four years of existence. The reorganization of the heading committees was to a large extent due to dissatisfaction in the Ministry of Industry with the way the various activities were organized and the lack of broader coordination, as described in Harlem et al. (1990), ch. 5³³.

Two years later, in the government's report to the Parliament on the research activity in the Norwegian economy, it was referred to this negative conclusion by Harlem et al. (1990) and the report elaborated on it³⁴: "The main conclusion is that [the research programs including the research activities

31. See Hervik and Guvåg (1989).

32. P. 233, our translation. We recognize that the focus on coordination failures in this and other evaluation reports often refers to problems in coordinating *institutional arrangements* rather than the projects directly. However, it seems likely that poor coordination at an institutional level will show up as poor coordination also at a project level and our empirical findings confirm this expectation by showing that the coordination at the project level was not very successful.

33. See also Buland (1996), especially chs. 9 and 10.

34. Cf. Ministry of Church, Education and Research (1992), p. 92-94.

within the National Program for Information Technology] did not lead to the intended coordination for the programs as a whole, not in the relationship between the government agencies and the private agents, nor between the various government agencies.” Furthermore, “the research programs have not been successful as policy tools, neither with respect to organization, planning or information. Research activities have to a large extent remained as fragmented as before the programs were implemented.” These conclusions were based on an assessment of 9 research programs, including research programs on biotechnology, offshore and other activities, in addition to information technology which was by far the largest among them.

Given these clearly recognized problems with the coordination efforts up to 1992, it is a bit depressing to read the main conclusions of the report on the evaluation of the ‘National Plan for Improved Utilization of Information Technology in the Norwegian Industry 1992–95’ presented in Olsen et al. (1997)³⁵:

[The plan] never became an instrument for coordination of governmental institutions and means The plan never managed to mobilize any strategic use of other resource and means present in governmental institutions ... To explain this poor coordinating performance, several factors ought to be mentioned. First, it appears as very unclear exactly what the plan was going to coordinate, and why coordination was important. Second, institutional resistance ... never produced a climate

conducive for cooperation and coordination among the relevant institutions.

The explanatory factors emphasized in this quote from Olsen et al. (1997) deserve further attention and we will return to them below. First, we want to point out that the two important questions of what the plans were supposed to coordinate, and why coordination was important, were only considered in general and superficial terms in the evaluation reports. The evaluation reports unanimously complain about poor coordination, but there is a striking omission of analysis at a practical level of what the plans were supposed to coordinate, and why. For instance, none of the reports identified or examined concrete examples of opportunities for beneficial coordination that were missed. One interpretation of this omission is that a careful discussion of such specific opportunities would require a lot of detailed information and therefore would be too difficult or time consuming – even with the benefits of hindsight. The amount of information required to identify coordination opportunities is the issue that we want to consider next.

Two pessimistic and one optimistic view of coordination problems

Coordination beyond stylized models

Above we have tried to link the IT-programs to recent theoretical work on innovative complementarities, GPTs and coordination problems in order to identify more clearly the basic principles. However, understanding the basic principles of coordination problems does not take one very far in the direction of

35. Cf. Olsen et al. (1997), p.vii. One should keep in mind that when the Norwegian research councils were completely reorganized in 1992 by the establishment of the Norwegian Research Council, it was largely based on the hope that this should promote coordination of related but poorly coordinated activities that previously had been organized by different research councils.

useful, practical conclusions about how to construct technology policy. Understanding the basic problems, one is led to a new but not simpler set of questions: What activities in what firms are complementary and need to be coordinated, and in what way? An appropriate choice of policy tools requires a detailed understanding of the externalities and the innovative complementarities involved, as well as the nature of the firms' behavior and constraints.

Matsuyama (1997) and others have emphasized that the informational requirements at a practical level raises serious questions about the possibilities for government policy to correct coordinating problems in the real world. Matsuyama argues that coordination problems are pervasive phenomena and he emphasizes that economists' illustration of coordination problems by means of simplistic game theoretic models are useful to illustrate coordination problems as a possibility. But such game theoretic models tend to trivialize the coordination difficulties that face policy makers; in real coordination problems, the nature of 'the game', the pay-off structure, the identity of the players and even their number are often unknown to the policy makers. Furthermore, the nature of the game can change rapidly and dramatically due to outside influences. These problems might be particularly relevant in a rapidly developing technological field such as information technology and in a small open economy such as the Norwegian.

Consider as an example the case of Norsk Data which was one of the largest, and no doubt the leading manufacturing firm in the Norwegian IT-industry in the 1980s. Norsk Data's production of minicomputers with its

integrated software was highly successful until the mid 1980s and it was recognized as the fastest growing and third most profitable computer firm in the world in 1986³⁶. However, the situation was entirely different two years later when it became clear that so-called open standards – in particular the UNIX operating system – eliminated the need for tight integration between production of the computer hardware and the software. Norsk Data was running large deficits at the end of the decade and heading fast towards bankruptcy. It was finally dissolved and partly sold to the German firm Siemens/Nixdorf in 1991. As mentioned above, Norsk Data was the largest recipient of project support within the National Program for Information Technology, something which perhaps illustrates the information problem emphasized by Matsuyama (1997).

Institutional inertia as a barrier to coordination
Bresnahan and Trajtenberg (1995) have made a related point in their analysis of coordination problems associated with general purpose technologies. They argue that the institutions designed to correct the coordination problems display much more inertia than the leading technologies. When a GPT era approaches its end and a new GPT emerges, the old institutions will resist change and the economy might 'get stuck' with the wrong institutions, namely those that have been designed to solve the coordination problems associated with the previous GPT.

This argument is consistent with what Olsen et al. (1997) noted, that "institutional resistance never produced a climate conducive for cooperation and coordination

36. See Steine (1992), p.11.

among the relevant institutions” within the ‘National Plan for Improved Utilization of Information Technology in the Norwegian Industry 1992–95’. Institutional resistance and inertia was also a basic problem in the implementation of the National Program for Information Technology and an important reason why the heading committee of the program was reorganized twice during the four years it lasted. The previously mentioned report to the Parliament discussing research programs more generally³⁷, suggests that the problem of sluggish institutional changes in new technological and scientific fields have been quite pervasive. The problems and discussions leading up to the recent establishment of the Norwegian Research Council underscores this point, cf. footnote 35.

In other terms, even though coordination problems suggest that Pareto improvements are possible, widespread institutional resistance show that policy reforms create ‘winners’, but also ‘losers’ which, although they could be compensated *in principle*, makes it difficult to implement desirable policy changes even when we disregard the information problem discussed above.

Coordination through the market: The optimistic view

Coordination problems illustrated by game theoretic analysis are based on non-cooperative behavior as an assumption. However, it is not obvious that firms in the same industry or firms that are vertically related are unable to implement cooperative solutions through negotiations and contractual relationships. This view has been most forcefully stated in the classical paper by

Coase (1960), where he claimed that coordination problems associated with complementary activities often will be solved through such market mechanisms. This optimistic view appears to be orthogonal to Matsuyama (1997) and the cited argument in Bresnahan and Trajtenberg (1995), but it leads to a similar conclusion about the limited role for governments to act as a coordinator. Coase has argued that the market mechanism will tend to incorporate or compensate for external effects if transaction costs are not high³⁸. His point is that – in the presence of positive external effects – there are strong incentives to sign a contract or organize a compensation arrangement between e.g. a firm receiving a positive external effect and a firm providing the source of this effect. Coase also argued that economists tend to ignore such options for compensation through the market. A rhetorical remark by Matsuyama (1997) echoes this argument:

If the coordination problem were simple enough for even the outsider, such as the economists or the bureaucrat, to know how to solve it, it would have been taken care of a long time ago by those directly involved with the problem.’

The ability of the market itself to facilitate coordination, has to a large extent been ignored in economic studies of technical change and in recent research on ‘new’ growth theory³⁹. However, when we examine the Norwegian IT-industry, it is clear that the firms are involved in a large set of coordinating arrangements organized through contracts and other private institutions. According to Aakvaag et al.

37. Ch. Ministry of Church, Education and Research (1992).

38. See Coase (1988) where he has elaborated on this argument.

39. See, however, the recent literature on research joint ventures, e.g. Kamien et al. (1992).

(1996), about 60 percent of the Norwegian electronics firms report that they participate in technological cooperation schemes. Partner firms often have a partly integrated ownership structure, which is one important market arrangement to internalize this type of externalities. A different example of coordination through private institutions is given by Steine (1992), who argues that an important contribution to the early success of Norsk Data was its close contact with demanding customers. Norsk Data organized a formal user group in order to coordinate the development of their minicomputers and software with organizational and other innovations developed by its customers. Similar user groups and other coordinating relationships are well known throughout the computer industry. Formal contracts coordinating the development of new technologies in the primary innovating firm and 'partner' firms using the new technology are regularly announced in the business press. To take a recent case, the Norwegian electronics company MRT Micro, which has developed PC-cards to digitalize pictures, has announced that they have signed collaboration contracts with four firms using these PC-cards⁴⁰. These four firms are quite different; one is e.g. making identification system for the police and defence, while another is making measurement instruments for opticians and eye-doctors. Industry associations are another set of private institutions which are important in facilitating coordination of innovative activities⁴¹. In a theoretical study, Romer (1993) has examined new institutional

arrangements to improve the coordinating function of such organizations. However, it must be left for future research to examine the empirical performance of such organizations in coordinating R&D activities and privately funded research joint ventures more generally. Our point here is only to illustrate the widespread coordination of complementary innovative activities across independent firms through contracts and other private institutions.

Conclusions

The motivation for the IT programs in Norway in the 1980s and 1990s seem to a large extent to accord well with the coordination problems identified in the new growth theory and especially the recent theory on 'General Purpose Technologies' introduced by Bresnahan and Trajtenberg (1995). Having studied the Norwegian IT industry, we have no reason to doubt that innovative complementarities associated with such technologies can be pervasive phenomena, and that these complementarities create a number of coordination problems. A major question we have addressed in this study is to what extent the considerable public funds spent on coordinating and promoting the R&D activities in the Norwegian IT industry have been successful in overcoming such coordination problems and stimulated the performance of this industry and closely related industries. Our findings suggest that the results have been very modest and that the IT programs were largely unsuccessful⁴².

40. Dagens Næringsliv, 13.11.97, p.8.

41. The industry association for IT firms in Norway (ITF) reports a large number of coordinated research projects and research joint ventures in its annual report (The IT-Industry's Association, 1996).

42. Wicken (1994, pp. 271-2), summarizing a number of studies on the history of Norwegian technology policy from World War II onwards, draw a similar conclusion.

Why did not these technology programs succeed, despite their appeal *ex ante* and according to economic theory? In contrast to the situation with illustrative and simplistic game theoretic models, in real coordination problems, information is a serious obstacle; what is the nature of the game, which players are involved, what do the pay-off structure look like and how rapidly is it likely to change? Or in less formal terms; exactly which firms and what activities should be coordinated and in what way? These serious questions are very hard to answer in a rapidly developing field such as information technology and might be particularly hard to solve in a small open economy where a large majority of the innovations take place abroad. We believe that industrial innovation is an activity where coordination problems and 'market failure' often are pervasive, but it is probably also an activity where policy makers and bureaucrats often lack the information needed to improve on the market solution.

The coordination problems created by complementary innovative activities across different firms seem in many cases to be at least partly resolved by private institutions such as industry associations, privately funded research joint ventures and other cooperative research agreements. In future research it could be interesting to examine more directly the role of such cooperative activities⁴³.

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Chapter 3



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Do subsidies to commercial R&D reduce market failures? Microeconomic evaluation studies¹

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Abstract

A number of market failures have been associated with R&D investments and significant amounts of public money have been spent on programs to stimulate innovative activities. In this paper, we review some recent microeconomic studies evaluating effects of government-sponsored commercial R&D. We pay particular attention to the conceptual problems involved. Neither the firms receiving support, nor those not applying, constitute random samples. Furthermore, those not receiving support may be affected by the programs due to spillover effects which often are the main justification for R&D subsidies. Constructing a valid control group under these circumstances is challenging, and we relate our discussion to recent advances in econometric methods for evaluation studies based on non-experimental data. We also discuss some analytical questions, beyond these estimation problems, that need to be addressed in order to assess whether R&D support schemes can be justified. For instance, what are the implications of firms' R&D investments being complementary to each other, and to what extent are potential R&D spillovers internalized in the market? © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The theoretical literature on market failures associated with R&D and technological innovations is

vast, and there is also a steadily growing empirical literature verifying the importance of spillovers in R&D and innovative activities. There is consequently little controversy among economists about the desirability of governmental support to these activities², and all OECD countries have over sev-

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¹ We have benefited from comments by Tore Nilssen, John van Reenen and participants at the NBER productivity meeting in December 1998. This project has received partial financial support from the Research Council of Norway.

² See, however, the heated and wide-ranging debate on this issue in *Research Policy*, starting with the review by David (1997) of Kealey's book on economic issues of scientific research (Kealey, 1997). See also the exchange between Friedman (1994) and Griliches (1994).

eral decades spent significant amounts of public money on programs intended to stimulate innovative activities. However, compared to the size of the programs and the emphasis put on technology policy by politicians, the effort to evaluate in quantitative terms the economic benefits and costs of R&D subsidies has been rather modest.

In this paper, we review some recent contributions to this evaluation literature that use econometric techniques based on microdata, in particular firm-level data. More specifically, we review the microeconomic literature evaluating the effects of government sponsored commercial R&D. This kind of government support to commercial R&D projects is supposed to target projects with large expected social benefits, but with inadequate expected returns to private investors. An important question is whether the government agencies are able to choose projects with high social returns that the private sector would not undertake on its own.³

Evaluating the effects of government sponsored projects, one has to face the question of what would have taken place without the subsidies, and it is important to realize that evaluating large scale subsidy programs is an exercise in counterfactual analysis. Neither the firms receiving support, nor those not applying, can be considered random draws. Constructing a valid control group in this setting is quite challenging and we relate our discussion to the recent advances in econometric methods for evaluation studies based on non-experimental data.

Most of the available evaluation studies of R&D programs have not been based on microeconomic techniques, but instead on case studies and interviews with program and project managers.⁴ These key persons are typically asked to report the payoff from the projects, and similar questions might be asked also to downstream users of innovations emerging from the R&D program in question.⁵ It is

easy to conceive an upward bias in the payoff reported by project managers, not least because a high estimate typically increases the chances that the R&D program will be considered successful and continued or replaced by a similar program. Also, one should not underestimate the problems for the project managers in constructing an estimate of the payoff from individual projects, since such estimates are based on counterfactual questions similar to those faced by the econometrician.⁶ Another disadvantage of the case studies is that they have high costs per case (project) considered, and case studies consequently tend to be quite selective and suffer from the objection that they may not be representative. Finally, evaluation studies not based on 'objective data' may more easily be biased, e.g., by prior beliefs, which is a problem because evaluation studies typically are done by 'professional evaluators' who are part of the political process that formulates the programs, and who "are dependent on those commissioning the evaluation studies for further projects and studies, and risk losing future clients if they voice strong criticism" (Luukkonen, 1998).

It is outside the scope of this paper to discuss in detail evaluation studies based on interviews and case studies. Our study focuses on microeconomic studies of firm level data or similar data sources, as we pointed out above. It is also narrowly focused on the impact on manufacturing performance of direct government support to commercial R&D-projects, and it largely ignores closely related issues such as the impact of research in governmental labs, defense related R&D-contracts, support to basic research in universities and tax-breaks for R&D.⁷ Furthermore, we do not review the literature that exclusively considers to what extent R&D subsidies crowd out privately financed R&D investments⁸, but our discussion addresses this issue in the context of the more wide-ranging studies that we consider.

³ See, e.g., Yager and Schmidt (1997) for a detailed and skeptical discussion of the government's ability to reduce market failures in R&D activities.

⁴ Mansfield (1996) surveys this methodology and gives references to the previous literature.

⁵ Cf., e.g., Link (1996) and Link et al. (1996). The 1996 book by Link is reviewed by Averch (1997).

⁶ Notice that the project manager might have less information than the econometrician about economic results of competing projects or firms.

⁷ See the survey by Hall and van Reenen (1999) on taxes and R&D, and Mowery and Rosenberg (1998) for a wide ranging discussion of the other issues and further references.

⁸ See David et al. (1999) for a survey.

We start in Section 2 by considering five microeconomic studies that directly try to evaluate the effects of government sponsored commercial R&D, and we refer to these studies at several points in the rest of the paper. Section 3 discusses some general issues considered in the recent econometric literature on evaluation studies when only non-experimental data are available, which is typically the case for R&D programs. Section 4 discusses more narrowly how the five studies and related studies address the essential issue of R&D spillovers. In Section 5, we discuss some analytical questions related to market imperfections and spillovers that need to be addressed to decide whether the R&D support schemes can be justified. Our suggestions for future research are summarized in the last section.

2. Five microeconomic studies of government-sponsored R&D

2.1. The SEMATECH research consortium in the US

Irwin and Klenow (1996) evaluated the SEMATECH program in the US, which was a research consortium established in 1987. SEMATECH was set up to promote US manufacturing's role in the development of technology for production of semiconductor products.⁹ The consortium was initiated with fourteen firms but has since been somewhat restructured with a few of the initial firms pulling out. About half of the consortium's annual budget (about US\$200 Mill.) was financed through government subsidies in the period 1987–1996.¹⁰

In their study based on annual firm-level data for the period 1970–1993, Irwin and Klenow (1996) found that SEMATECH was successful in eliminat-

ing excessive duplication of R&D, which was a major objective of the consortium. At the same time, the SEMATECH firms had on average a more rapid growth in sales than non-member firms. Irwin and Klenow also compared the SEMATECH firms' performance in terms of physical investment, returns on assets and sales, and labor productivity growth, but found no systematic difference from non-member firms for these variables. Their analysis was based on running a set of similar regressions of the form

$$Y_{it} = \alpha_i + \beta_1 Y_{i,t-1} + \beta_2 D_i^{\text{SMT}} + \text{Dummies} + e_{it}, \quad (1)$$

where Y_{it} is the performance measure of interest, e.g., private R&D to sales ratio, for firm i in year t , while D_i^{SMT} is a dummy which is one if the firm was a member of SEMATECH and zero otherwise. Their regressions include firm-specific parameters, α_i , which are treated as so-called firm fixed (or correlated) effects.¹¹ The dummies include time dummies and firm age dummies, while e_{it} is an error term. The 'experiment' in the data allowing Irwin and Klenow to identify the interest parameter β_2 , is the observations for non-member firms in the same industry as the SEMATECH members (i.e., the electronic components industry, SIC 367). The presence of observations prior to the establishment of SEMATECH is useful to add precision to the estimates of the auxiliary parameters.

Irwin and Klenow focus on their estimate of β_2 , which, according to their computations, suggests savings in R&D around US\$300 Mill. But this estimate does not account for the dynamic effects captured by the lagged dependent variable in their model. The long run effect of R&D membership is given by $\beta_2/(1 - \beta_1)$, which is about 75% higher, and their estimated model consequently indicates that the R&D saving from SEMATECH was substantially higher than US\$300 Mill.

The study by Irwin and Klenow convincingly suggests that SEMATECH has been a profitable

⁹ Link et al. (1996) evaluate the returns to SEMATECH projects through interview studies.

¹⁰ The government support to SEMATECH was ended in 1996, but the consortium has continued with private funding only. In August, 1998, it was announced that SEMATECH and the government jointly will sponsor new university-based research centers to "study new methodologies in designing, testing and connecting microchip components".

¹¹ However, their regressions do not account for the bias created by the presence of these fixed effects in combination with a lagged dependent variable. See Nickell (1981).

project in terms of social costs and benefits, as the consortium has managed to eliminate wasteful duplication of R&D, while preserving the same or perhaps even better R&D output despite the cut in R&D spending. It would seem useful to repeat their exercise with a sample covering also the period after 1993. As recognized by Irwin and Klenow, the most important reservation one could raise against their analysis is probably the validity of the control group. 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. Irwin and Klenow try to account for the differences by incorporating the fixed effects, but even when they condition their analysis on such permanent differences, it remains questionable whether the non-members of SEMATECH in the same industry reveal what the members would have experienced without SEMATECH in place. We will return to this issue when we discuss methodological questions in evaluation studies based on non-experimental data in Section 3 below.

2.2. *The Small Business Innovation Research program in the US*

While SEMATECH largely targeted large and leading high-tech firms, the Small Business Innovation Research (SBIR) program was intended to stimulate innovation in small, high-tech firms. The SBIR-program was initiated in 1982 and the program mandated all federal agencies spending more than US\$100 million annually on external research, to set aside 1.25% of these funds for awards to small businesses. The percentage was increased to 2.5 in 1992, and this amounted to US\$1.1 billion in 1997. SBIR awardees must be independently owned, for-profit firms with less than 500 employees and a majority of shares must be owned by US citizens.

A recent study by Lerner (1998) has evaluated the performance of the firms receiving SBIR awards in the period 1983 to 1985. His study shows that SBIR awardees grew significantly faster, both in terms of sales and employment, than similar, non-supported firms from 1985 to 1995. These findings are based

on an econometric analysis of a sample where the SBIR awardees are matched with similar firms.¹²

The first part of Lerner's analysis presents various statistics (mean, variance and various percentiles) from the distribution of growth rates separately for the supported firms and the non-supported firms. The second part considers regressions similar to Eq. (1), but without firm fixed effects and with observations for only two years that are ten years apart (i.e., with 1985 corresponding to $t - 1$ and 1995 to t). Lerner explicitly stresses the need to assess the long-term impact of the awards, and he also states that he ideally would have liked to examine the relationship between program participation and firms' valuation. Using firms' valuation as the dependent variable was not possible, however, because only a small fraction of the SBIR awardees was publicly held. He chose instead growth in sales and growth in employment as proxies, referring to Gompers and Lerner (1997) who have shown that these measures are highly correlated with the valuation that venture capitalists assign to private firms.

Lerner considers different interpretations of his results including capital market imperfections and regulatory capture. It is well known that small R&D intensive firms may have difficulties raising capital due to informational asymmetries, and there is also an extensive literature suggesting that government involvement may be affected by distorted incentives for politicians and government decision-makers. With respect to the latter group, program managers may target anticipated winners so that the SBIR "can claim credit for the firms' ultimate success, even if the marginal contribution of the public funds was very low". Lerner argues that picking winners should be easier in low tech than in high tech industries, whereas a signal to investors about project quality should be particularly valuable in high tech indus-

¹² To be more specific, Lerner analyses two samples, one where each of the SBIR awardees is matched with a firm of similar size from the same industry and another where each of the awardees is matched with a firm of similar size from the same region. Note, that even though Lerner uses matching to construct the comparison group, he does not proceed using a formal matching estimator in the analysis. We will discuss various aspects of matching as a method for constructing the counterfactual outcome in Section 3.

tries where traditional financial measures are of little use. He finds that the superior performance of SBIR awardees is particularly significant in high-tech industries, and furthermore that the first award to a firm plays a significant role, while the marginal value of subsequent awards declines sharply. Based on these findings, Lerner concludes that the SBIR program seems to have played an important role in certifying firms' quality and the technological merits of the firms' projects, thereby alleviating capital market imperfections. However, he also finds evidence of distortions in the award process. Interviews with program managers revealed that they had faced political pressure to make geographically diverse awards, and this may explain why the SBIR program seems to have been less effective in regions with few high-technology firms.

2.3. Japanese research consortia

The SEMATECH program was inspired by the success of Japanese research consortia in the semiconductor industry and other high-tech industries. Branstetter and Sakakibara (1998) have examined the performance of the Japanese research consortia in these industries, combining econometric techniques with an interview study. The Japanese research consortia were heavily subsidized by the Japanese government; government subsidies covered on average two thirds of the research costs for the projects carried out within the consortia. Branstetter and Sakakibara argue that the Japanese research consortia were primarily aimed at bringing together complementary R&D projects, thereby making the R&D projects more productive and also more profitable.¹³ In this view, the research consortia have raised the learning opportunities and thereby stimulated to more R&D. Notice that this situation is different from the SEMATECH case discussed above, where the consortium eliminated excessive duplication of parallel research rather than promoted complementary research. Branstetter and Sakakibara's

econometric results show that a membership in the Japanese research consortia typically stimulated private R&D spending, and also made the research effort more productive.

Branstetter and Sakakibara's result on R&D spending is obtained by estimating a model slightly different from Irwin and Klenow's non-structural model (cf. Eq. (1) above):

$$\log(\text{R\&D}_{it}) = \alpha_i + \beta_1 \log(\text{Capital}_{it}) + \beta_2 S_{it} + \text{Dummies} + e_{it} \quad (2)$$

The left hand side variable is private R&D spending in firm i in year t , while the first explanatory variable on the right hand side is physical capital added to control for size effects. S_{it} is the number of research consortia in which the firm is involved in year t and β_2 is the parameter of interest. Branstetter and Sakakibara present estimates where they make different assumptions concerning α_i , assuming α_i to be either random effects or firm fixed effects. The dummies include both time and industry dummies as their sample covers several high-tech industries. The equation is estimated on an unbalanced sample of 226 firms over the period 1983–1989, with 141 firms participating in at least one research consortium during the sample period, while the remaining 85 firms did not. As pointed out above, their results revealed a positive and statistically significant value for the interest parameter β_2 .

To examine whether the research consortia created spillovers and thereby made the research effort more productive, Branstetter and Sakakibara estimated several patenting equations. Using data on patents granted to Japanese firms in the US, Branstetter and Sakakibara started by estimating an equation with the log of patents as dependent variable¹⁴:

$$\log(P_{it} + 1) = \alpha_i + \beta_1 \log(\text{R\&D}_{it}) + \beta_2 \log(\text{Capital}_{it}) + \beta_3 S_{it} + \text{Dummies} + e_{it} \quad (3)$$

Their point estimate of the consortia coefficient β_3 suggests that membership in an additional consor-

¹³ They motivate this focus with a reference to Cohen and Levinthal (1989), who emphasize that firms typically undertake R&D to learn about competitors' innovative activities. See Section 5.1 for further remarks on this issue.

¹⁴ Branstetter and Sakakibara follow the patent literature by dating each patent according to the patent's year of application.

tium tends to raise patenting by 5%, and this effect is statistically significant irrespective of whether α_i is treated as a random firm specific effect, or as a firm fixed effect. Branstetter and Sakakibara consider several alternative specifications of Eq. (3) and conclude that the positive effect of membership in research consortia is robust.

The final part of Branstetter and Sakakibara's analysis focuses more closely on the R&D spillovers associated with membership in a research consortium. This analysis is carried out by augmenting Eq. (3) with two additional terms representing spillovers. The basic spillover variable is constructed as a weighted sum of other firms' R&D, where the weights reflect the 'technological distance' between the firm in question and each of the other firms. The primary additional term representing spillovers in Branstetter and Sakakibara's analysis is this spillover variable interacted with a dummy variable reflecting membership in research consortia. Their parameter estimate for this interaction term is positive and statistically significant when α_i is treated as a random effect, and Branstetter and Sakakibara conclude that membership in research consortia augments knowledge spillovers.

One final, interesting aspect of Branstetter and Sakakibara's study is their use of interviews to supplement the econometric analysis. The responses in their interview study are consistent with their finding that government funds did not substitute for private R&D spending, but rather tended to increase the firms' own R&D spending. Interestingly, the interviews also suggested that selection into the research consortia was not biased towards the best projects; firms which are technology leaders in a field tend to be reluctant to participate in projects which will spread their superior knowledge and where they have little to gain. We will discuss how this selection issue affects the interpretation of the estimated parameters in Section 3.

2.4. Government support to commercial R&D projects in Israeli firms

The study by Griliches and Regev (1998) illustrates how the production function framework widely used to study returns on R&D, can easily be adapted to study the effects on private firm performance of

government-funded R&D.¹⁵ Their study covers the overall effort by the Israeli government to promote R&D related to manufacturing activities, incorporating a number of governmental programs.¹⁶ They estimate the private returns accrued to the supported manufacturing firms, created by the government-funded R&D. Their preliminary results suggest that there are large private benefits to the firms carrying out these government-funded R&D projects, and their estimate of the rate of return on these R&D investments is high. The social rate of returns is even higher if these R&D programs in addition generated any spillovers as presumably was expected.

Griliches and Regev estimate production functions incorporating R&D capital (K_{it}), allowing for a separate coefficient on the share of R&D capital accumulated with government funding (s_{it})¹⁷:

$$\ln(Q/L)_{it} = \alpha_i + \beta_1 \ln(C/L)_{it} + \beta_2 \ln(M/L)_{it} + \beta_3 \ln(K/L)_{it} + (\beta_3 \delta) s_{it} + \text{Dummies} + e_{it}, \quad (4)$$

where Q , L , C and M are output, labor, physical capital and materials. As above, the subscripts refer to firm i in year t . The dummies include a number of control variables in addition to year and industry dummies. The parameter of interest is δ , which can be interpreted as the effective premium or discount on government supported R&D. As mentioned above, their preliminary results suggest quite a high,

¹⁵ See Griliches (1979). The production function approach has previously been used to study the impact of government funded R&D in US manufacturing firms in Griliches (1986). A very large share of this R&D in the US has, however, been related to defense contracts and there are a number of reasons why it is hard to measure the real effects of defense related R&D projects, as discussed by Griliches (1979).

¹⁶ This governmental support to R&D includes commercial R&D projects, support to consortia engaged in 'generic' technologies (Magnet-program), National S&T Infrastructure program, USA-Israel binational program, and defense related contracts.

¹⁷ This specification is based on the observation that

$$[K_1 + (1 + \delta)K_2] = [K_1 + K_2 + \delta K_2] \\ = \ln K + \ln(1 + \delta s) = \ln K + \delta s,$$

where K_1 and K_2 are two types of capital with different efficiency, and $K = K_1 + K_2$. δ is the efficiency premium of the second type, while s is the share of this kind of capital. The last approximation is good if δs is small.

positive and statistically significant premium on government supported R&D, based on a sample of more than 11 000 firm-year observations covering the period 1990–1995. One suspects that the high premium is due to the government picking the best firms, and that the estimated rate of return therefore is upward biased. However, this does not seem to be the case. The premium is particularly high when fixed effects are accounted for, suggesting a *negative* selection bias where firms with a high share of R&D capital accumulated with government funding typically have low average productivity levels. We will return to this issue in Section 3.

Their finding of a high premium on R&D projects funded by the government suggests that these projects should have been profitable also for the firms themselves.¹⁸ According to their estimates, the government picks good projects in commercial terms, but the projects seem to be too profitable to justify government support. The question then emerges in what way a study is useful for evaluation of governmental support to commercial R&D, given the ambiguity of the interpretation of rate of return estimates. That is to say, a low rate of return estimate suggests that the projects might have been unsuccessful, while a high rate of return estimate suggests that the firms should have been able to fund the R&D activities themselves, unless there are significant capital market imperfections affecting R&D investments. One or two additional steps are consequently required to draw any conclusions about the social value of these R&D programs. First, their study should be supplemented by a study of how private R&D spending tends to respond to R&D subsidies and, second, spillover benefits should be estimated, as we will discuss in Section 4.

2.5. Government support to commercial R&D projects in Norwegian high-tech firms

Klette and Møen (1999) study the impact of a series of governmental programs aimed at supporting

commercial R&D projects in Norwegian manufacturing related to information technology. These IT programs were intended to stimulate complementary R&D activities, especially in high-tech manufacturing, and the effort peaked in the four years 1987–1990. The econometric analysis reveals few significant differences between the supported firms and the non-supported firms in the same industries, despite the large amounts of R&D support provided. Similarly, at a more aggregated level, the study finds that targeted industries did not show any outstanding performance compared to the rest of the manufacturing sector in Norway, nor in comparison to the same industries in other OECD countries.¹⁹ The study concludes that the effort to promote IT-related manufacturing has been largely unsuccessful, and the study proceeds by examining why the IT programs had such a poor coordinating performance.

In terms of the performance measure used by Griliches and Regev (1998), i.e., total factor productivity growth, Klette and Møen (1999) find that the supported firms did significantly worse than the non-supported firms. Considering this performance measure alone, one is led towards the conclusion that governmental support is associated with significantly poorer performance. However, the systematic difference between supported and non-supported firms disappears when a broader set of performance measures is considered. It is difficult to conceive that there is a *causal* relationship between government support and poor performance in terms of total factor productivity growth, and it seems more plausible that the relationship runs the other way; the government tried to save some of the main high-tech firms as they encountered problems when the IT industry was restructured towards the end of the 1980s. This possible interpretation illustrates why there might be a *negative* selection bias in the parameter estimates capturing the effect of government support, and we will discuss how this selection bias can be reduced or eliminated in Section 3.

The microeconomic part of the study by Klette and Møen is similar to Irwin and Klenow (1996) in

¹⁸ As discussed in Griliches and Regev (1998), a high premium does not necessarily imply a high *marginal* rate of return on the supported projects, as the support typically went to R&D intensive firms and their model assumes diminishing marginal returns to R&D capital.

¹⁹ The Norwegian governmental support to R&D in the targeted industries seems to have been high in relative terms also in an international perspective. See below.

that the estimating equations are reduced-form equations with a number of different performance measures as left hand side variables: private R&D spending and physical investment, growth in sales, employment and productivity, and returns on assets and sales. The estimating equations do not include lagged dependent variables in contrast to Eq. (1), but the main results are based on models including fixed, firm level effects. The first, microeconomic part of the analysis is based on firm and plant level data for the period 1982–1995.

As mentioned, the study also contains a more aggregated analysis, based on industry-level data for Norway and other OECD countries. This part of the analysis examines the overall performance of the targeted high-tech industries.²⁰ The motivation for this is that some of the benefits from the program could spill over to non-supported firms with the result that the comparison between the supported firms and the non-supported firms would underestimate the effect of the program. To the extent that these spillover effects were important, these effects should show up in the performance at a more aggregated level. At the more aggregated level, it is, however, difficult to identify a control group, i.e., a similar non-supported industry, and Klette and Møen consider two alternatives. The first comparison is between the targeted high-tech industries and the rest of the manufacturing sector as a whole. This is clearly not a clean quasi-experiment, but it is nevertheless interesting to compare, e.g., the profit rates and the returns to investments (R&D and physical) in the targeted industries to other industries in a cost-benefit perspective. The second comparison at the industry level is based on OECD data for the targeted high-tech industries in Norway and in other OECD countries. Once more, the contrast between industry performance in Norway and the other OECD countries is far from a clean quasi-experiment, as the same high-tech industries also received considerable governmental support in the other OECD countries. As far as the OECD data go, they suggest that the

increase, and perhaps also the level (relative to private R&D spending), of governmental support to these industries was significantly larger in Norway than in most of the other countries in the second half of the 1980s.

In a companion study, Klette and Møen (1998) examine more closely the effect of the R&D subsidies on private R&D spending in the supported firms. The first part of their analysis uses a non-structural econometric approach similar to Branstetter and Sakakibara (1998), as specified in Eq. (2) above. The analysis suggests that governmental R&D support did not crowd out private R&D spending, but nor did the firms increase their own R&D spending as was expected in the ‘matching grant’ contract scheme that was widely used. In the second half of their study, they introduce a structural model for R&D investment which incorporates a ‘learning-by-doing effect’ in R&D, where accumulated R&D capital (past R&D effort) has a positive impact on the productivity of current R&D.²¹ This framework suggests that temporary R&D grants might have had a more lasting, positive effect on private R&D spending after the support had expired, but the empirical results at this point are more suggestive than conclusive.

3. Estimating counterfactual outcomes from non-experimental data

As we will clarify below, the results in the studies presented in Section 2 are based on the assumption that R&D subsidies to a large extent are allocated randomly to firms and projects. With enough randomness in the allocation process, data for the firms receiving R&D subsidies as well as for similar non-supported firms provide us with quasi-experiments and a basis for causal, econometric analysis. Given the many factors involved in the political economy process that determines the allocation of R&D subsidies, random allocation may not be too

²⁰ Two alternative definitions of the targeted industries were considered: a widely defined group ISIC 382, 383 and 385, and a more narrowly defined group; ISIC 3825 and 3832.

²¹ The same framework is also used in Klette (1996) and Klette and Johansen (1998).

misleading in some cases. However, assuming that governments' deliberate selection process is largely random is clearly dubious and there might be a significant bias involved in the estimated impact parameters. This section tries to clarify the potential biases involved and explain how the methodology can be improved by drawing on some recent advances in econometrics associated with evaluation of labor market programs.²²

3.1. Selection and the problem of the counterfactual

Both Irwin and Klenow (1996), Lerner (1998) and Klette and Møen (1999) use the outcome of the non-supported firms to estimate what the supported firms would have experienced had they not been supported, and the two studies from Japan and Israel use their econometric models as devices to generate similar counterfactuals.²³ The difference in performance between supported and non-supported firms is the estimated gross impact of the R&D support schemes. The performance of the non-supported firms may, however, differ systematically from what the supported firms would have experienced in the absence of the support schemes, and this is the selection bias problem that we referred to above.²⁴ As we shall argue below, such a systematic difference does not make the evaluation results uninteresting, but it limits the kind of counterfactual questions the evaluation results can answer.

To aid the discussion, let us address the selection issue somewhat formally, and assume that the perfor-

mance of a firm i in period t , denoted Y_{it} , is given by

$$Y_{it} = \alpha_i + \lambda_t + \beta_i D_i + u_{it} \quad (5)$$

where D_i is a dummy variable which is one if the firm has received R&D support and zero otherwise²⁵, α_i is a firm specific intercept, λ_t reflects shocks common across firms, and u_{it} represents temporary fluctuations in unobservables. We have abstracted from other (observable) regressors for simplicity. To be concrete, α_i represents permanent differences in firm performance while u_{it} represents temporary fluctuations in performance around the firm specific means, due to effects specific for individual R&D-projects. Eq. (5) incorporates heterogeneous responses to the R&D support (ex post) as indicated by the subscript i on the β -coefficient, and the distribution of these coefficients may differ systematically between the supported and the non-supported firms. Indeed, the agency allocating the R&D support might try to allocate their funds on the basis of anticipated differences in the β_i 's.

Most of the studies above present estimates where α_i is treated as a firm specific parameter, i.e., where α_i is allowed to be correlated with D_i . In this way, the estimated impact parameter is not biased even if the supported firms are non-randomly selected, as long as the selection is based on firm characteristics that are largely invariant over time. Assuming that data are available before and after the supported firms have received their support, i.e., at times t_0 and t_1 , this gives the estimator

$$\begin{aligned} \hat{\beta}_{\text{did}} &= (\bar{Y}_{t_1}^s - \bar{Y}_{t_0}^s) - (\bar{Y}_{t_1}^n - \bar{Y}_{t_0}^n), \\ &= \Delta \bar{Y}^s - \Delta \bar{Y}^n \end{aligned}$$

where $\Delta \bar{Y}^s$ and $\Delta \bar{Y}^n$ are the average changes in performance from before to after the R&D support scheme was operating, and the superscripts s and n refer to the supported and the non-supported firms, respectively. In the econometric literature, this esti-

²² See Angrist and Krueger (1998) and Heckman et al. (1998) and references cited there. Blundell (1998) gives a simple introduction to the econometric literature.

²³ We will not consider the evaluation literature on estimating 'treatment effects' with various levels of 'treatment', as this complicates the analysis considerably. This literature is surveyed in Angrist and Krueger (1998).

²⁴ An interesting analysis of the choice of comparison groups when evaluating technology innovation programs is Brown et al. (1995). They suggest that the counterfactual outcome should be constructed using the performance of firms with rejected applications only, and not the performance of all non-supported firms. The rejected project applications are hardly a random group of projects, but they may in some settings be as close to a control group as it is possible to get.

²⁵ We have ignored the time subscript on D_i for simplicity, and we will focus the discussion on situations where the econometrician compares outcomes from before and after the program has taken place.

mator is now commonly referred to as the ‘*difference-in-differences*’ estimator.²⁶ Assuming that D_i and u_{it} are uncorrelated, we have that

$$\text{plim}_{n \rightarrow \infty} \hat{\beta}_{\text{did}} = E(\beta_i | D_i = 1) \equiv \beta^S$$

which is a parameter of interest, representing *the average impact of the R&D-support on the supported firms*.²⁷ This is the parameter of interest if we want to do a cost-benefit analysis of the R&D support scheme. Notice, however, that this parameter may not be informative of what would happen if the R&D support scheme was extended to previously non-supported firms, when there are systematic differences in the responses to R&D support between the supported and the non-supported firms.²⁸

As mentioned, most of the estimates presented in the four studies discussed above are based on the ‘*difference-in-differences*’ estimator or similar estimators, and the study by Heckman et al. (1998) suggests that this method is preferable to alternatives such as the widely-used parametric selection-correction method introduced by Heckman (1979) and the more recent matching methods discussed in Heckman et al. (1998).

The econometric evaluation literature has noticed that there may remain a serious problem due to correlation between the temporary shocks (u_{it}) and the probability of being selected into the program.²⁹ Discussing the results from the study by Klette and

Møen (1999), we observed above that the poor growth performance, in terms of total factor productivity for the supported firms, might have been due to the government supporting some large firms that were facing particularly severe problems when the IT industry was restructured towards the end of the 1980s. In such a case, there is a positive relationship between receiving R&D support and the prospect of growing more slowly than the average, and the growth performance of the non-supported firms is not very useful for estimating what the supported firms would have experienced had they not been supported. Consequently, the ‘*difference-in-differences*’ estimator underestimates the impact of the R&D-support on the supported firms. Similarly, in the Japanese case, Branstetter and Sakakibara (1998) find from their survey study, that firms with the most promising projects in a technological field were reluctant to participate in research consortia, which creates a similar downward bias in the ‘*difference-in-differences*’ estimator.

On the other hand, it is easy to conceive that the bias can go the other way in cases where firms apply for support because they have discovered particularly promising R&D projects. The screening of projects in the government agencies will also tend to create a selection bias in the estimated impact. More precisely, if there is a positive correlation between a firm hitting particularly promising projects that tend to generate above average performance growth in subsequent years, and the chance of the firm receiving R&D support, the ‘*difference-in-differences*’ estimator will overestimate the impact of the R&D-support on the performance of the supported firms. Previous studies of the effectiveness of R&D subsidies in stimulating private R&D spending have been criticized by Kauko (1996) along these lines, and among the studies we have reviewed in Section 2, this problem seems particularly relevant for the evaluation of the SBIR program by Lerner (1998). He concludes that the subsidies awarded under that program seem to have played a certifying role, helping the selected firms to attract venture capital. If, however, awards conveyed information to the market about the quality of recipient firms, this implies that the SBIR officials on average succeed in ‘*picking winners*’. If so, one would expect awardees to perform better than non-supported firms even without

²⁶ With observations for more than two years, a preferable estimator might be the ‘*within*’-estimator widely used in the panel data literature. The ‘*within*’-estimator is closely related to the ‘*differences-in-difference*’-estimator. It is possible to estimate the time profile of the impact by considering a number of ‘*difference-in-differences*’ estimates when observations for more than two years are available. See Heckman et al. (1998).

²⁷ In the econometric literature, this parameter is often termed the mean impact of the treatment on the treated. We have that $\beta^S = E(\beta_i | D_i = 1) = \bar{\beta} + E[(\beta_i - \bar{\beta}) | D_i = 1]$, where $\bar{\beta}$ is the population mean impact effect.

²⁸ One could, however, extrapolate the impact analysis to the non-supported firms also in this case by adding assumptions about the functional form for the β_i -distribution, along the lines in Heckman (1979).

²⁹ In studies of training programs, it has been observed that individuals tend to be selected into the program during periods when they perform particularly badly, i.e., have particularly low income. This is the so-called ‘*Ashenfelter-dip*’.

the awards, and the effect of the awards has to some extent been overestimated.

The econometric literature has suggested that such biases can be reduced or eliminated by augmenting the ‘difference-in-differences’ estimator, incorporating conditioning variables reflecting the pre-program performance.³⁰ That is, differences in longitudinal changes in performance between supported and non-supported firms should control for pre-program, temporary shocks that influence the probability of being supported, e.g., pre-program changes in R&D or firm growth. Similarly, one would also like to control for *anticipated* future temporary shocks that influence the probability of being supported by conditioning on forward looking variables, in particular physical and R&D investment and perhaps also hiring or firing.

In the review of the study of SEMATECH in Section 2, we raised the issue that the members and non-members in SEMATECH were to a large extent quite different firms in terms of size and closeness to the technological frontier. As emphasized in Heckman et al. (1998), such differences make the evaluation results critically dependent on assumptions about functional forms, both in terms of the performance equation and the selection equation, and Heckman et al. find that this tends to generate substantial biases in the case they examine. Exploring various matching-procedures as well as regression methods, Heckman et al. conclude that evaluation results are only reliable when they are based on ‘treated’ units (cf. supported firms) which are similar to some of the ‘non-treated’ units (cf. non-supported firms). For the supported firms that cannot be adequately ‘matched’, the comparison to non-supported firms can give quite misleading inference of the impact.

3.2. Spillovers and the counterfactual: ‘Catch-22’?

Using the non-supported firms to evaluate what would have happened to the supported firms if they had not been supported, assumes that there are no spillover effects of the R&D support scheme to the

non-supported firms, which is clearly a strong assumption. The question is whether the performance of the non-supported firms can be considered independent of the support given to the supported firms.³¹ One could argue both ways in terms of the bias this problem introduces in the estimated impact of the R&D program; the impact will be *underestimated* if the non-supported firms tend to benefit, e.g., from pure knowledge spillovers from the R&D in the supported firms, while the impact will be *overestimated* if the non-supported firms are hurt as they lose relative competitiveness to the supported firms.

This spillover issue is particularly problematic since spillovers to technologically related firms are often a major justification for such programs in the first place. This implies a ‘Catch-22’ 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 counterfactual outcome for the supported firms. This problem is particularly transparent if one tries to evaluate the performance of the supported firms by means of the matching procedure described in Blundell (1998, Section 5.4.2). The matching estimator suggested by Blundell is given by

$$\hat{\beta}_{mm} = \frac{1}{N_S} \sum_{i \in S} \left(Y_i - \sum_{j \in N} \omega_{ij} Y_j \right)$$

where Y_i and Y_j are the post-program outcomes for a supported and a non-supported firm, respectively, while N_S is the number of supported firms. S and N refer to the groups of supported and non-supported firms. ω_{ij} is a weight indicating the ‘similarity’ between the two firms before the R&D-support was provided. Our point is that similar weighting schemes have been used to identify ‘technologically related’ firms when estimating the impact of R&D spillovers,

³⁰ See Angrist and Krueger (1998), Blundell (1998) and Heckman et al. (1998) for details.

³¹ Manski (1993) considers a closely related problem; the assumptions required for identification of spillover effects, when we want to condition on regressors that tend to eliminate independent variations in the spillover variable. This is largely the reverse of the question we discuss in this section. See also Griliches (1998, ch. 12).

as in studies by Jaffe (1986), Branstetter and Sakakibara (1998) and others that we will discuss in the next section. This suggests that the better a firm seems to satisfy the conditions required to identify the counterfactual outcome in the absence of spillovers, the worse might this spillover problem be.

The motivation for introducing the matching estimator into the econometric tool box is that it requires only weak assumptions about functional forms, as we noted above (see Heckman et al., 1998). This argument suggests therefore that it might be difficult to identify the impact of R&D programs more generally, without imposing strong functional form assumptions.³² As is so often the case in economics, one does not get very far in causal inference with non-experimental data unless a significant amount of structure is imposed on the analysis. To conclude, we face the paradoxical situation that if an evaluation study finds little difference between the supported firms and the non-supported firms it could either be because the R&D program was unsuccessful and generated little innovation, or because the R&D program was highly successful in generating new innovations which created large positive spillovers to the non-supported firms.

3.3. *Focus on a few successes?*

[T]he economic value of one great industrial genius is sufficient to cover the expense of the education of a whole town (Marshall, 1920, p. 179).

It has been widely recognized that the economic benefits from research projects tend to have a highly skewed distribution, with a median return which might not be very high, but a few projects generate a high mean return; see, e.g., Scherer and Harhoff (1999).³³ This represents a further challenge to regression analysis of the impact of R&D subsidies,

and such skewness might be particularly pronounced for the outcome of government sponsored R&D projects to the extent that governments tend to support high-risk R&D. This observation raises the question of whether the main parameter of interest is the *average* impact of the R&D-support on the supported firms. More precisely, we might be interested in the average rate of return to the whole R&D subsidy program, but the weighted average estimates provided by the ‘difference-in-differences’ estimator or similar estimators will typically not apply the economically relevant weights to the individual observations, and we may want to pay more attention to the economically interesting outliers than such estimation procedures tend to encourage.

To the extent that the estimated impact parameter is driven by a few high-return observations, the confidence intervals for the impact parameter will be large and poorly approximated by the routinely reported intervals based on asymptotic normal distributions. Even if calculated correctly,³⁴ the confidence interval obtained will be large, reflecting the substantial uncertainty that prevails in trying to infer the impact parameter when the outcomes are characterized by a highly skewed distribution with long right tails. This suggests that we might need to consider a number of independent evaluation studies, say through meta-analysis, before we can provide an estimate of the impact of the R&D subsidies with much precision.

Recent econometric advances suggest that it might be possible to estimate the distribution of the subsidy impacts across firms,³⁵ but we believe that these methods should only provide a first step in a closer investigation of the economic benefits of the most important innovations generated by the R&D subsidy programs. It would be useful to merge econometric studies of the kind discussed in this paper with more detailed case studies of the most successful projects, and perhaps also some of the less successful projects.

³² See Manski (1993) for a formal analysis of the functional form assumptions required for identification in a closely related context, and within a regression framework.

³³ This observation is closely related to the finding that the distribution of the value of patents is highly skewed with a long right tail, see, e.g., Pakes (1986).

³⁴ Whatever that means, but say from bootstrap estimates for the argument’s sake.

³⁵ See Heckman et al. (1997) and Abadie et al. (1998).

4. Identifying spillovers and the social benefits of R&D projects

We noted above that spillovers tend to invalidate the non-participants as a control group. However, measuring the magnitude of the spillovers generated is by itself a crucial part of evaluating the programs. The studies discussed in Section 2 covered quite well the benefits to the private firms receiving the support, while in most of the studies the spillovers to non-supported firms and pecuniary externalities to customers and consumers were not extensively addressed.

A full cost benefit analysis of an R&D support scheme would involve estimating the expression

$$w(s) = \sum_{i \in S} \tilde{\Delta}\pi_i(s_i, \underline{s}) + \sum_{j \in N} \tilde{\Delta}\pi_j(s) + \sum_{l \in R} \tilde{\Delta}\pi_l(s) + \sum \tilde{\Delta}(CS) - d(s) \quad (6)$$

where $\tilde{\Delta}$ is used to indicate the (counterfactual) shift in the various variables as follows³⁶: The first sum covers the change in profits in the group of supported firms, S , due to the R&D support scheme. Note that the benefit for each firm belonging to S can be decomposed into a direct effect capturing the increase in profits due to the support they have received themselves, s_i , and an indirect effect capturing the change in profits due to the support received by other firms, \underline{s} . The latter component may be positive, negative or zero, depending on what kind of spillovers are present. The second summation term on the right hand side of (6) captures the change in profits in the group of non-supported firms, N , in the same industry as the supported firms.³⁷ The sign of this term is also ambiguous. We will refer to it as the indirect effect on the non-supported firms, and it may be a mixture of knowledge and rent spillovers. The next two terms represent rent spillovers alone. That is, the third sum captures the change in profits in firms in the rest of the economy, R , due, e.g., to pecuniary externalities as inputs become cheaper or

better. The fourth term is the increased consumer surplus in the economy. The last term represents the deadweight loss associated with the funding of the program.

4.1. The treatment of spillovers in the evaluation studies

Using Eq. (6) to fix ideas, we will now briefly discuss how far the various evaluation studies reviewed in Section 2 go towards incorporating the full welfare effects of the programs they examine. With respect to estimation techniques, the most ambitious attempt to estimate spillovers among these studies is Branstetter and Sakakibara (1998). Still, this study explores only the effect of the programs, i.e., the subsidized research consortia, on the participating firms and other firms in the same industry. In other words, they deal roughly with the first two sums in (6), while ignoring pecuniary externalities to firms in other industries and to consumers. With respect to the first sum, the change in profits for the supported firms, it is not relevant to distinguish between the direct and the indirect effect of subsidies, as the subsidies are given to consortia and not to individual firms.

Branstetter and Sakakibara find evidence that participation in research consortia rises research output, even after controlling for research input and firm specific effects. It seems reasonable to interpret this as a pure knowledge spillover, but comparing their framework to Eq. (6), we should note that they have not considered how the increased research output affects the consortia participants' *profits*. Depending on how close competitors the participants are in the output markets, there may be negative rent spillovers between them, and the innovative gains may partly accrue to customers and suppliers. However, focusing on innovative output seems like a reasonable strategy when the total welfare effect cannot be measured, since increased research efficiency necessarily increases total welfare. Turning next to the indirect effects of the program on non-supported but technologically related firms, they find clear evidence of general R&D spillovers, but they do not identify the extent of spillovers from the subsidized consortia to the non-members.

³⁶ All variables on the right hand side of (6) should be interpreted in terms of present values of current and future benefits.

³⁷ Our concept of industry is at this point loosely defined as firms which are technologically related.

Irwin and Klenow (1996) resemble Branstetter and Sakakibara in that they consider membership in a subsidized research consortium and not individually received R&D subsidies under a program. Referring back to Eq. (6), one could say that Irwin and Klenow sign the first term on the right-hand side, i.e., the effect of the program on the participants, as they find increased profitability for SEMATECH members. The level of profitability is obviously affected by other factors than SEMATECH membership, but their results suggest that members have increased profitability relative to non-members also when they control for such factors. The difference could in principle be due to non-members facing stronger competition after the introduction of SEMATECH, i.e., a negative pecuniary externality belonging to the second term on the right hand side of (6), but the authors' interpretation is that it is most likely due to increased research efficiency within the consortium.³⁸

Branstetter and Sakakibara (1998), like Klette and Møen (1999), try to capture both the effect on the supported firms and the effect on the non-supported firms in the same industry, but they ignore possible rent spillovers to other industries and to consumers. The empirical part of the study starts out estimating the effect of the support on the supported firms,³⁹ but find no significant impact neither in the short nor in the long run. This could, as mentioned in Section 2, be due to strong spillovers from the supported to the non-supported firms, and they investigate this issue by comparing the growth of the supported high tech industry (including the non-supported firms) both to growth in overall manufacturing, and to growth in similarly defined high tech industries in other OECD countries.

³⁸ Their interpretation is based on the finding that SEMATECH members significantly reduced their R&D-intensity relative to non-members, and the assumption that non-members' R&D spending was not affected by SEMATECH. This assumption is of course crucial, as we discussed in Section 3 under the heading of 'Selection and the problem of the counterfactual.'

³⁹ Since the subsidies in the programs they evaluate are given to individual firms, they could, in principle, have distinguished between direct and indirect effects of the support on the supported firms, but their focus is (implicitly) on the sum of the two effects.

Lerner (1998) concerns himself only with the effect of subsidies on the subsidized firms, but he states explicitly that his inability to assess the social return to the program is the most critical limitation of the study. Furthermore, he is well aware of the estimating problem that positive spillovers represent in that they, if present, reduce the difference in performance between subsidized and non-subsidized firms.

Like Lerner (1998), Griliches and Regev (1998) do not explicitly deal with spillovers. However, the framework Griliches and Regev use is one which easily lends itself to incorporating such effects the way they are usually treated in the more general literature on R&D spillovers. We will now turn to this larger literature as it is obviously of great relevance with respect both to methodology and to R&D policy. First, we take a closer look at the frameworks available to study R&D spillovers and then we briefly review the main findings and raise some concerns.

4.2. *Traditional approaches to the study of R&D spillovers*

There are two main strands of literature investigating the empirical importance of R&D spillovers. First, there are case studies that try to estimate the social return to particular research projects by extensively tracing the effects of the resulting innovations. This approach was first used to evaluate public investments in agricultural research, but private R&D investments have also been studied. The most famous example of the latter is Mansfield et al. (1977) finding a median social rate of return of 56%, more than twice the comparable median private rate of return.⁴⁰ The detailed information provided by case studies has been extremely valuable for understanding the mechanisms at work in technologically advanced industries and markets. However, as pointed out in the introduction, case studies always suffer from the objection that they may not be representa-

⁴⁰ More recent studies include Bresnahan (1986) on computers, Trajtenberg (1983; 1989) on CT scanners and the Bureau of Industry Economics (1994) on 16 innovations in Australia.

tive. This has motivated econometric work, which is the other main approach.

Most econometric studies have been performed within a production function framework where a ‘pool’ of outside knowledge is included in the production function of a firm or an industry. This is the idea utilized in the study by Branstetter and Sakakibara (1998).⁴¹ The R&D pool is constructed as a weighted sum with weights (ideally) representing the relevance of R&D undertaken elsewhere in the economy, i.e.

$$S_{it} = \sum_j w_{ijt} K_{jt} \quad (7)$$

where S_{it} is the spillover pool, and w_{ijt} is the effective fraction of knowledge in firm j which is freely available to firm i at time t . The weights are usually considered a measure of the proximity between the firms, and have been constructed in a number of ways. According to the survey by Mohnen (1996), both product fields, types of R&D, patent classes, input-output flows, investment flows and patent flows have been utilized,⁴² and he suggests other possibilities such as flows of R&D personnel, qualifications of R&D personnel, and R&D cooperation agreements.

As pointed out by Griliches (1979), there are two different concepts of spillovers behind these measures. First, a firm may benefit from research undertaken elsewhere to the extent that changes in the market prices of its inputs do not fully reflect the value of the innovations. From a production function point of view it is not really a spillover, but a measurement problem. If price indexes fully reflect quality adjustments, R&D embodied in inputs will not be relevant as a separate variable. Lacking quality-adjusted price indexes, however, one can try to

trace the effect of R&D rents not appropriated through the product prices by including the R&D investments of the producers in the production function of the buyers in proportion to the purchases done.⁴³ We follow several previous writers and use the term ‘rent spillovers’ for this effect. True knowledge spillovers, however, are ideas borrowed from other researchers, and one would think that these spillovers increase with the technical relatedness and geographical closeness of firms. According to this view, measures based on product fields, patent classes, types of R&D, R&D cooperation, or qualifications of R&D personnel seem most suited to constitute the weights in Eq. (7), maybe augmented with geographical distance.⁴⁴

4.3. Estimating knowledge and rent spillovers

It is widely acknowledged in the empirical literature that it is hard to distinguish knowledge spillovers from rent spillovers. The methodology of Jaffe (1986) is probably the one that comes closest to looking for the former type. Following suggestions in Griliches (1979), he links an outside pool of R&D to firm performance. Jaffe also extends the basic framework by controlling for differences in technological opportunities across different sectors and by allowing for the amount of spillovers received to depend on the firms’ own R&D investments. His key contribution, however, lies in the implementation of Eq. (7). To isolate pure knowledge spillovers, he uses the degree of overlap in the distribution of firms’ patents to construct the proximity weights, since patents are classified according to technological criteria. Furthermore, he uses the constructed spillover pool as an explanatory variable in a knowledge production function, utilizing count data on patents as a proxy for output. The coefficient on the spillover pool is therefore quite likely to represent pure knowledge

⁴¹ The basic idea is most completely spelled out in Griliches (1979) and Griliches (1995), but was first applied by Brown and Conrad (1967) at industry level data. Branstetter and Sakakibara (1998) build on Jaffe (1986) in their particular implementation of the framework.

⁴² Many of the studies reviewed by Mohnen (1996) use industry level data rather than firm data.

⁴³ Note that this way of getting around the lack of quality-adjusted price indexes will miss out on ‘spillovers’ in final-product markets, i.e., the increases in consumer surplus represented by the fourth term on the right-hand side of Eq. (6).

⁴⁴ Cf., e.g. Jaffe (1989), Jaffe et al. (1993), and Adams and Jaffe (1996) for the relevance of the geographical dimension.

spillovers. By studying the effect of the same spillover pool on profits and market value, he also sheds light on the effect of negative rent spillovers through increased competition, as the estimated coefficient then is likely to be a mixture of this effect and knowledge spillovers. Without underplaying the methodological difficulties associated with his work, Jaffe argues that the sum of ‘circumstantial evidence’ brought out is enough to make a good case for the existence of spillovers.

Positive rent spillovers from research embodied in intermediate inputs may best be investigated using a spillover pool whose weights are based on intermediate input flows. There are several weaknesses associated with this approach, however. First, as technical information may be exchanged between suppliers and customers, such a measure may pick up some pure knowledge spillovers as well. Second, data on firm-level input-output flows are extremely rare and we do not know any microeconomic studies of this type.⁴⁵ Finally, rent spillovers to final consumers, i.e., increased consumer surplus associated with new goods or production techniques, cannot be measured using this framework.

In theory, rent spillovers should be measured as the area under the final good’s demand curve. As noted by Bresnahan (1986), this may be done either by econometric techniques or by index-number techniques.⁴⁶ Bresnahan uses index numbers to measure the rent spillovers from the computer industry to consumers through the effect of computers as inputs in the financial sector. The computer industry is chosen because quality adjusted input prices are needed, and these have been estimated for this industry using hedonic techniques. However, hedonic techniques are not suited to handle large product changes, such as the introduction of qualitatively new product characteristics. Partly for this reason, Bresnahan only covers the period up to 1972 when traditional mainframes were challenged by software

advances and large mini computers.⁴⁷ The study of computer tomography scanners by Trajtenberg (1983; 1989), on the other hand, deals explicitly with the problem of measuring the welfare gain from the introduction of qualitatively new goods. The challenges involved in correctly measuring the welfare gains from new goods are also discussed in a recent book edited by Bresnahan and Gordon (1997). The evidence gathered there indicates that the increase in consumer surplus associated with the introduction of new goods may be substantial, and that ordinary price indexes are likely to underestimate the welfare gains.

4.4. *Surveying surveys and adding a grain of scepticism*

Griliches (1997, ch. 5) summarizes available econometric studies of social rates of returns to R&D, and he concludes that these social rates of returns tend to be several times larger than the private ones. Mohnen (1996), listing more than 50 studies, concludes that ‘‘spillovers exist and have to be taken into account when evaluating the returns of government-financed R&D’’. Other surveys, such as Griliches (1992), Nadiri (1993), the Australian Industry Commission (1995), Hall (1996), and Jaffe (1996), agree, and their conclusions are not controversial.

There is no reason to doubt the existence of positive spillovers, but considering first the difficulties involved simply in constructing a measure of the stock of knowledge and next the uncertainty over what is an appropriate lag length, it is somewhat remarkable that almost all studies trying to estimate something as intangible as knowledge spillovers actually report significant results.⁴⁸ There are at least

⁴⁵ Note, however, that there exist a large number of studies based on industry level data which use input–output matrices to construct the weights.

⁴⁶ Cf. Mansfield et al. (1977) for an early study utilizing this idea.

⁴⁷ Another reason was that the regulation regime in the financial sector changed about that time.

⁴⁸ Cf. Geroski (1991) and Geroski et al. (1998) for studies that do not find significant spillovers. These studies differ from others in that they base the spillover pool on innovation count data rather than on R&D investments. The Bureau of Industry Economics (1994) also finds rather modest spillovers in its 16 case studies.

three possible pitfalls that justify some concern. First, the results may be subject to what Griliches (1992) calls a publication filter, self-imposed by researchers working in the field or imposed by editors and referees considering non-significant coefficients to be of little interest. Second, some of the effects interpreted as spillovers may actually be knowledge transfers that are internalized in the market, e.g., through cooperative agreements. Third, the reported significant coefficients could to some extent be spurious, reflecting correlated unobservables across technologically related firms. Griliches (1998, p. 281) mentions in particular common technological opportunities, but correlated productivity shocks or measurement errors would have the same effect. This potential bias is closely related to the problem of estimating the counterfactual outcome in the presence of spillovers, discussed in Section 3.

5. R&D spillovers and the case for governmental support

As emphasized already, the concerns raised above do not imply that we have doubts about the existence of spillovers, but there remain some questions concerning the existing estimates. In this section, we raise another set of questions concerning R&D spillovers, now taking a closer look at what policy implications can be drawn, given that spillovers exist. If spillovers can be received costlessly, it is quite obvious that the arguments in favor of subsidies are valid. Firms performing R&D do not reap the whole benefit, and as they equate marginal cost to marginal *private* benefit, their investments will be below the social optimum. There is, however, a number of reasons why this argument is incomplete, and below we will discuss four issues that deserve further attention in the evaluation of the net welfare gains associated with R&D subsidies. In Section 5.1, we consider how private investment in R&D is affected by spillovers when a firm cannot receive such spillovers without incurring own R&D activity, and Section 5.3 discusses some of the recent insights from studies of R&D spillovers when such spillovers affect foreign as well as domestic firms and consumers. In Section 5.4 we give some remarks on coordination

through R&D joint ventures and similar market arrangements, while Section 5.5 considers implications of spillovers transmitted through the mobility of research workers. Discussing these issues, we hope to make clear why and how evaluation studies often need to go beyond the topics reviewed in Sections 2 and 4.

5.1. Costless spillovers vs. complementary R&D activities

Geroski (1995) points out that, even if one accepts that involuntary diffusion of knowledge happens and that this knowledge has commercial value to some of the recipients, it is still one thing to argue that spillovers exist and another to argue that they undermine incentives to innovate. Geroski's point is that firms must typically invest in research themselves in order to benefit from external knowledge pools. This argument is emphasized in Branstetter and Sakakibara (1998), cf. Section 2 above, and is perhaps most forcefully stated by Cohen and Levinthal (1989).⁴⁹ Cohen and Levinthal discuss in detail how a firm's own R&D activity tends to enhance the absorptive capacity of R&D results produced in other firms. If such a complementary relationship exists, "the analogy between spillovers and manna from heaven" is misleading and it is "not clear exactly what 'bits' of knowledge have been produced by one's own learning efforts and which have spilled over from rivals" (Geroski, 1995). In this situation, spillovers may actually stimulate R&D.⁵⁰ The returns to own R&D increase in the size of the spillover pool, and this creates a positive feedback mechanism between the R&D investments in technologically related firms.⁵¹ A negative effect due to imperfect appropriability still exists, but it is counteracted by an 'absorption' incentive, and conse-

⁴⁹ Important empirical evidence is presented by Mansfield (1981), finding that imitation costs on average are about 65% of the original innovation costs.

⁵⁰ Cf. Cohen and Levinthal (1989) for a formal analysis.

⁵¹ It has been argued that a similar complementarity exists between the knowledge stock and new investments in R&D within individual firms, cf. Klette (1996), Klette and Johansen (1998), and the references cited therein.

quently the net effect of spillovers on R&D investments is ambiguous.⁵²

The empirical evidence regarding the relationship between own and others' R&D suggests that complementarities in R&D are important in many cases. In addition to the empirical results presented by Cohen and Levinthal (1989) and Branstetter and Sakakibara (1998), Jaffe (1986) and Geroski et al. (1993) find a complementary relationship between own and others' R&D.⁵³ Despite the rapid growth in the theoretical literature on R&D investment, spillovers and welfare, however, little attention has been paid to the role of such complementarities and no results seem to be available discussing to what extent a market equilibrium will lead to too little investment in R&D in this case.⁵⁴ A rather bold suggestion is that technology policies may be too focused on sectors such as aircraft, semi-conductors, computers, electronics components and communication equipment, where innovations tend to be complementary according to Levin (1988). The apparent paradox, that one observes coinciding high spillovers and high R&D investments in industries like these (Spence, 1984), may indicate that these are industries where spillovers do not undermine the incentives to innovate, and where rivalry and strategic interaction may even lead to excessive R&D investments.

5.2. Is 'a big push' from government R&D subsidies needed?

Complementarity in R&D activities, as discussed above, is related to the discussion of governmental support to emerging industries. A significant portion of the support to commercial R&D is targeted towards new, high-tech businesses and emerging tech-

nologies, and it seems to be based on infant industry arguments. That is, support to targeted high-tech sectors is often rooted on the view that government support is needed to get emerging industrial activities to 'take off' and reach 'a critical mass'.

Perhaps surprisingly, this view might be entirely consistent with the discussion of complementary R&D activities above, where it was argued that such complementary spillovers may encourage investments in R&D. The point is, as emphasized by Matsuyama (1995), that complementarities tend to create multiple equilibria where, e.g., one equilibrium corresponds to little or no R&D activity in each of the firms, while another equilibrium corresponds to high R&D activities in several or all firms.⁵⁵ That is, with an emerging industry or new technology, the firms might get trapped in a low-level equilibrium where the lack of complementary spillovers renders R&D unprofitable in all firms with the result that the emerging industry never reaches 'the critical mass' and 'takes off'. This suggests that the government might play a coordinating role by triggering higher activity, e.g., through an R&D program, until the firms and the industry have reached the high R&D-activity equilibrium.

Klette and Møen (1999) argue that the rationale for government funding of IT-related research programs in Norway can be well understood in these terms. As pointed out in Section 2, their findings suggest, however, that the Norwegian IT programs were not very successful in initiating new manufacturing activities related to IT, and their case study elaborates on the informational difficulties involved. Inspired by Matsuyama (1997), they conclude:

In contrast to the situation with illustrative and simplistic game theoretic models, in real coordination problems, information is a serious obstacle; what is the nature of the game, which players are involved, what does the pay-off structure look like and how rapidly is it likely to change? Or in less formal terms; exactly which firms and what activities should be coordinated and in what way?

⁵² Note, however, that if R&D investments can be divided into innovative research on one hand and imitation costs on the other, it may be that only imitation costs are complementary to the spillover pool. If this is the case, there will be no positive feedback, i.e., it might be that firms with a deliberate imitation strategy contribute little or nothing to the spillover pool.

⁵³ Bernstein (1988) finds a complementary relationship in R&D intensive sectors while firms in sectors performing little R&D tend to substitute spillovers for own R&D.

⁵⁴ A study that comes close is Kamien and Zang (1998), which contains a model emphasizing the complementarities in R&D activities across firms.

⁵⁵ Klette and Møen (1999) elaborate on this point and give further references.

These serious questions are very hard to answer in a rapidly developing field such as information technology and might be particularly hard to solve in a small open economy where a large majority of the innovations take place abroad. We believe that industrial innovation is an activity where coordination problems and ‘market failure’ often are pervasive, but it is probably also an activity where policy makers and bureaucrats often lack the information needed to improve on the market solution.

Hence, even though complementarities make it possible, in theory, to improve on the market solution, it is necessary to analyze whether the government, in practice, has the necessary capabilities to do so before initiating coordination programs.

5.3. *International spillovers and high-tech policy*

Complementarity between firms in R&D and other activities is a central idea in the ‘new trade theory’ and ‘new economic geography’ literature of the last two decades. Much of the policy debate over support for R&D and innovation is concerned with international competition and ‘dynamic comparative advantage’, and those in favor of public technology programs are clearly inspired by the infant industry arguments discussed above. The work of Grossman and Helpman (1991) is of particular relevance to technology policy. Grossman and Helpman (1991, ch. 8) show that if spillovers are geographically bounded, then history matters, and countries with a head start in accumulation of knowledge can widen their lead over time. Moreover, they show that governments of lagging countries can improve their growth prospects by offering a temporary R&D subsidy. This may eliminate these countries’ disadvantages in high-tech industries. Similar results are obtained by Krugman (1987) in the context of learning-by-doing spillovers. However, as demonstrated by Grossman and Helpman (1991, ch. 7), the scope for national policies disappears if knowledge spillovers are perfectly international, i.e., if ideas flow as easily between nations as they do within nations. The extent to which spillovers are ‘intra-national’ or ‘international’ is therefore an important

empirical question. Inspired by these findings, Branstetter (1996) presents a microeconomic investigation using panel data for US and Japanese firms, and he finds evidence that spillovers are stronger within each of the two countries than between them. These results are supported by Narin et al. (1997), finding substantial ‘excessive’ self-citation when comparing citations across countries, and by Eaton and Kortum (1994), finding that technology diffusion is considerably faster within than between countries.⁵⁶ Branstetter concludes that ‘the idea that promotion of R&D can have an impact on comparative advantage is one that trade economists should take more seriously’.

Trade economists working on growth and development are, naturally, focused on export oriented and import competing sectors. However, it is not obvious that these are industries where the case for government support is particularly strong. The total gain from national R&D investments includes not only knowledge spillovers, but rent-spillovers to customers and buyers of intermediate goods as well. As argued in Section 3, these may be considerable, and in the extreme case of monopolistic competition, often assumed in theoretical models, all profits are competed away such that only rent spillovers are relevant for policy. If a substantial part of the spillovers created through R&D subsidy programs is to the rest of the world, e.g., because the targeted R&D intensive industries are highly export oriented, one may question why the government of the source country should bear the financial burden. This reservation seems particularly relevant to small open economies, but it has also been emphasized by several commentators in the debate over the funding of the ATP-program in the US.⁵⁷

At a general level, it is not difficult to outline the implications of international R&D spillovers. Governments should only subsidize R&D up to the point where the marginal cost equals the marginal social benefit accruing to its own nationals. When evaluating the marginal social benefit, potential negative repercussions from increased competition due to un-

⁵⁶ Cf. Mohnen (1998) for a recent review of the literature on international R&D spillovers.

⁵⁷ See, e.g., Yager and Schmidt (1997).

intentional spillovers received by foreign firms should be included,⁵⁸ but also potential positive effects of economic growth abroad.⁵⁹ Such positive effects could, e.g., be larger export markets and increased political stability in developing countries. Empirical results have obviously not been accumulated to a level which makes it possible to determine what amount of subsidies is optimal according to this theoretical criteria.

Empirical results suggest, as noted above, that spillovers to some extent are geographically bounded.⁶⁰ This may justify national technology programs, but the point we want to emphasize is that a careful analysis of the likely distribution of spillovers is necessary as the share of spillovers accruing to non-nationals may be substantial in some sectors. Note also that the existence of international spillovers gives scope for increased *global* efficiency through R&D cooperation between countries. The fact that technology policy and R&D programs within the European Union to some extent have been moved from individual member states to the union level since the 1980s, can be interpreted as a response to this understanding.⁶¹

⁵⁸ This effect need not be negative, as increased competition in the home market benefits consumers and other industries through input linkages.

⁵⁹ There is a large theoretical literature on optimal R&D policies, exploring what may happen under various assumptions regarding degree of competition, degree of intra- and interindustry spillovers, degree of openness, degree of international spillovers, whether there is strategic behavior or not, whether there is R&D cooperation or not and whether R&D of the firms in question are strategic complements or substitutes. Cf. Leahy and Neary (1997) and Neary (1998) for recent reviews of this literature. The not surprising policy advice in this literature, as we read it, is that it all depends on the assumptions. An important challenge for empirically minded economists, therefore, is to sort out what assumptions are the relevant ones. Alternatively, one can follow Neary (1998) and many others and conclude that the detailed information required to improve on the market solution is unlikely ever to be available to the policy maker.

⁶⁰ This is not only a finding of the literature on international spillovers. There is also a literature utilizing national data which strongly supports the view, cf., e.g., Jaffe (1989), Jaffe et al. (1993), and Adams and Jaffe (1996).

⁶¹ Well known examples of such programs include ESPRIT, EUREKA, and TSER, among others.

5.4. R&D joint ventures and the Coase theorem

Klette and Møen (1999) argue that firms seem to internalize spillovers through various market arrangements largely ignored in many of the theoretical models of R&D investment.⁶² One aspect of this is that the empirical findings emerging from the literature reviewed in Section 4 might be quite misleading, since some of the effects interpreted as spillovers may actually be knowledge transfers that are internalized in the market, e.g., through cooperative agreements. It seems reasonable to believe that firms know who their customers, suppliers, and rivals are, and according to the 'Coase theorem', firms would tend to sign contractual arrangements governing the knowledge flows between them.⁶³ A large number of cooperative agreements observed in the market indicate that this may be an aspect of the externality issue which has been grossly underemphasized. Freeman (1991) reports that "almost all of the top 20 information technology (IT) firms in US, EU and Japan made more than 50 cooperative arrangements of various kinds in the 1980s and some made more than a hundred". With respect to smaller companies, Aakvaag et al. (1996) report that about 60% of Norwegian electronic firms participate in technological cooperation schemes. Partner firms often have an interrelated ownership structure, and this is obviously a simple and basic market mechanism for internalizing externalities.⁶⁴

Related evidence is provided in the two studies by Zucker et al. (1998a) and Zucker et al. (1998b). In the (1998b) study, Zucker et al. demonstrate that the location of academic experts at the leading edge of basic bioscience strongly influenced the location of new biotechnology enterprises in the US. Further exploring this in the (1998a) study, it was revealed that firms and star scientists were not merely located in the same area, but that the scientists were deeply

⁶² See Leahy and Neary (1997) and references cited in that study for a review of recent theoretical studies of R&D joint ventures.

⁶³ More precisely, firms will perfectly internalize externalities in the absence of information and transaction costs. See Usher (1998) for a critical view.

⁶⁴ See Klette (1996) for a study of spillovers between firms with an interlocking ownership structure.

involved in the operations of the firms. Hence, what might have been interpreted as localized knowledge spillovers using standard methodologies and data sets (cf., e.g., Jaffe, 1989), was to a large extent a matter of market exchange.

Our point is not that spillovers are fully taken care of by contracting, and we recognize that it is notoriously hard to write complete contracts for uncertain and unpredictable activities such as R&D. What we argue is that both in theoretical and empirical analysis, more attention should be paid to the many contractual arrangements utilized and invented by the firms to overcome the potential spillover problems generated in innovative activities.

5.5. *Spillovers and the mobility of research workers*

We will end our review of spillover issues related to R&D policy by turning to the labor market. A number of authors have pointed to mobility of labor as an important mechanism for knowledge diffusion,⁶⁵ and it is most often thought of as a spillover mechanism. Jaffe (1996), making a clear distinction between rent spillovers and knowledge spillovers, considers mobility of researchers to be of the second type, writing that “[k]nowledge spillovers also occur when researchers leave a firm and take a job at another firm”. Defining knowledge spillovers as “benefit leakages that occur in absence of a market interaction between the innovator and the spillover beneficiary”, this seems a bit inconsistent since mobility of researchers takes place in the labor market. Jaffe implicitly acknowledges this point, writing that “important innovative successes are likely to increase the incentive for researchers to capitalize on their tacit knowledge by moving to another firm or starting their own”. We will argue below that, from a theoretical point of view, it is not entirely clear to what extent labor mobility really is a spillover, but if it is, we believe it is most correct to analyze it as a market (i.e., rent) spillover.

⁶⁵ Cf., e.g., Geroski (1995), Jaffe (1996), Almeida and Kogut (1996) and Zucker et al. (1997) for some recent statements on the importance of labor mobility. Almeida and Kogut (1996), studying patent holders, are particularly interesting, showing empirically that ideas are spread through the mobility of key scientists.

Our point of departure is that R&D investment not only increases the firms’ stock of innovations, it also increases the human capital of the research workers. After all, research is a learning process. This perspective introduces two interesting questions. First, who captures the value of the human capital from R&D activities, and second, how is the firms’ investment incentives affected by the possibility that research workers may quit? With perfect labor and credit markets, the answer to the latter question is that the investment incentives are not affected. To the extent that research work has a ‘general training’ element and increases the researchers’ future marginal product, they can look forward to corresponding future wage increases (cf. Becker, 1964). This gives the research workers incentives to bear the cost of the training through lower wages in the beginning of their career, and consequently, a research worker who quits does not impose a cost on his or her employer.⁶⁶ If the fairly steep wage profile thus associated with a research career does not suit the researchers’ consumption preferences, they can borrow for current consumption towards future wage increases. With respect to the question about who captures the value of the human capital from R&D, this analysis implies that it is the research workers, but they also pay the investment costs. The flip side of this conclusion is that labor mobility is not a mechanism that causes underinvestments in R&D, and should not be considered a spillover channel either.

A first objection to the analysis above is that credit markets are not likely to deliver all the necessary services given the moral hazard problems involved in borrowing on future income. This market failure will, evaluated in isolation, cause underinvestment in R&D.⁶⁷ If there is larger uncertainty over the future gains from research work than there is over future income from alternative career paths,

⁶⁶ See Pakes and Nitzan (1983) for a related, formal analysis.

⁶⁷ The utility loss associated with low consumption in the beginning of the career will shift the supply-of-research-labor curve downwards, increase the equilibrium wage of research workers and thereby the price on R&D investments. This will result in R&D investments below the level associated with a perfect credit market.

risk aversion at the individual level will magnify the underinvestment problem.⁶⁸ Imperfections in the labor market may, on the other hand, increase firms' incentives to invest in research work by reducing the mobility of researchers across firms. Such labor market imperfections include search costs and asymmetric information about the human capital of the employees. These effects will result in wages being below marginal product, and hence give firms an incentive to invest in workers' general (i.e., non-firm specific) human capital.⁶⁹

Determining the total effect of the 'training aspect' of R&D on investments and wages is in the end an empirical task, and little can at this moment be said. In order to investigate the issue, a framework explicitly linking R&D investments of firms with human capital accumulation in research workers, must be developed. Given the increasing number of matched employer-employee data sets now becoming available, we think future research in this direction will prove fruitful. It might be essential, however, that these data sets are able to trace the mobility of researchers across establishments, as such mobility and entrepreneurship can be a major component of the pay-off for successful researchers.

6. Conclusions

We have not succeeded in answering all our problems. The answers we have found only serve to raise a whole set of new questions. In some ways we feel we are as confused as ever, but we believe we are confused on a higher level and about more important things (Øksendal, 1985).

Estimates of the economic returns to R&D projects have gone a long way since this line of research

started more than 40 years ago (cf. Griliches, 1958). We have in this paper focused on a relatively small number of recent studies that try directly to evaluate the social returns from subsidies to commercial R&D activities. Four of the five studies suggest that the subsidy schemes have had a positive effect on performance in the targeted firms. We have, however, pointed out some of the shortcomings in the available studies and raised some questionmarks about the conclusion that these subsidy schemes have reduced market failures. Discussing similar shortcomings related to causal inference from observational studies, Cochran (1965) notes that a reader, "if later asked for a concise summary of the paper, may quite properly report: 'He said it's all very difficult'." We recognize that our paper may leave the same impression on our readers, but we also believe, as Cochran emphasizes, that "[a] listing of common difficulties is... helpful in giving an overall view of the problems that must be overcome if this type of research is to be informative." Furthermore, we have tried to emphasize that many of the unresolved questions are ready for further research with tools and data sets within our reach.

On the methodological side, a more careful inference of the magnitude of the impact parameters of interest can be made, drawing inspiration from the recent advances in the evaluation literature in labor market econometrics. A more ambitious approach would be to go beyond these largely non-parametric techniques and try to merge the model of performance and subsidy impact with a structural model of how the government allocates the R&D subsidies. A structural model of the allocation of R&D subsidies should address the question of how the government can construct operational procedures to identify R&D projects with high social returns,⁷⁰ and the empirical analysis based on such a structural model can help us to identify to what extent the government agencies succeed in implementing these procedures. These are clearly interesting and worthwhile research tasks in

⁶⁸ It might be the individual's aversion towards high skewness rather than high variance which is the more important issue here. Notice that risk-neutrality at the firm level is irrelevant for the argument.

⁶⁹ Cf. Acemoglu and Pischke (1999) for a review of some relevant literature.

⁷⁰ The practical difficulties in selecting R&D projects with high social returns are discussed in some detail in Yager and Schmidt (1997). The ongoing ATP/NBER project is particularly noteworthy in its attempt to draw on the insights from the econometric literature to resolve some of these difficulties.

themselves, and if completed successfully they will give us an alternative handle to eliminate the potential selection biases that we discussed at some length in Section 3.

A large number of research papers on R&D and spillovers have emerged over the last decade, but we have argued that several theoretical and empirical aspects of spillovers deserve more attention before conclusions about R&D policy can be drawn. Many of the issues we have raised seem to require a more detailed investigation of the nature of the spillovers and also a more detailed investigation into the various contractual arrangements that prevail in the market between firms and between the researchers and their firms.

Finally, evaluation of the economic returns to R&D subsidy programs seems to require a combination of empirical investigations at different levels of observation. We have argued that the microeconomic approach that has been the focus of this paper should be supplemented with detailed case studies to get a more precise estimate of the economic returns from the few, outstanding innovations that might typically generate a very large share of the economic benefits emerging from risk-oriented R&D subsidy programs. On the other hand, in order to estimate the impact of an R&D subsidy program in the presence of knowledge spillovers, we need to look beyond the direct impact of the subsidies on the performance of targeted firms and consider changes in performance of the industries or 'technological clusters' to which the supported firms belong. This may lead us to a more aggregated, industry-level analysis. It is encouraging to observe that economic researchers already have many of these elements in their tool box, but they have not yet been fully tied together.

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Chapter 4

Is mobility of technical personnel a source of R&D spillovers? *

by
Jarle Møen ‡

ABSTRACT: Labor mobility is often considered to be an important source of knowledge externalities, making it difficult for firms to appropriate returns to R&D investments. In this paper, I argue that inter-firm transfers of knowledge embodied in people should be analyzed within a human capital framework. Testing such a framework using a matched employer-employee data set, I find that the technical staff in R&D-intensive firms pays for the knowledge they accumulate on the job through lower wages in the beginning of their career. Later they earn a return on these implicit investments through higher wages. This suggests that the potential externalities associated with labor mobility, at least to some extent, are internalized in the labor market.

JEL classification: J24, J31, J62, O32

Keywords: Labor mobility, Compensating differentials, Human capital, R&D-capital, R&D spillovers, Matched employer-employee data

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“Don’t let your employees do to you what you did to your former boss.”

The golden rule of protecting trade secrets,
as defined by Intel general counsel Roger
Borovoy (Jackson; 1997)

1 Introduction

Labor mobility is likely to be a very important source of knowledge *diffusion*. Surveying one hundred founders of companies on the 1989 *Inc.* ‘500’ list of the fastest growing companies in the United States, Bhide (1994) finds that 71 percent “replicated or modified an idea encountered through previous employment.” With respect to technical employees, Almeida and Kogut (1999), demonstrate by an analysis of patent data from the semiconductor industry that ideas are spread through mobility of key engineers. Evidence of this kind, however, does not justify the common proposition that labor mobility is an important source of knowledge *spillovers*. Such spillovers (or externalities) are thought to cause underinvestment in private R&D because workers have incentives to exploit their employers’ research results by setting up or joining a competitor.

The aim of this paper is three-fold. First, I want to clarify how labor mobility can affect R&D investments. I will argue that there are market mechanisms that may internalize the potential externalities involved. Second, I present a framework to test the existence of such market mechanisms. Third, I present empirical findings suggesting that these mechanisms actually exist. My results are, however, not entirely conclusive with respect to the exact mechanism.

The link between labor mobility and knowledge spillovers dates back to Arrow’s (1962) article on the public good aspect of knowledge. Arrow writes that “no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information” and adds that “[m]obility of personnel among firms provides a way of spreading information” (p. 615). Following Arrow’s seminal work, a large literature on R&D spillovers has evolved, and economists working in the field have continued to consider labor mobility an important spillover channel. Geroski (1995) expresses what appears to be a common view¹, writing that “[l]ast but not

¹Jaffe (1996) writes that “[k]nowledge spillovers also occur when researchers leave a firm and take a job at another firm”. Stephan (1996) writes that “[f]uture work should also focus on the role mobility within the industrial sector plays in facilitating spillovers”. Gersbach and Schmutzler (1997) write that “[s]pillovers arise because employees who change jobs take with them all their knowledge, some of which is not specific to their original firm.”

least, spillovers occur when a researcher paid by one firm to generate new knowledge transfers to another firm (or creates a spin-off firm) without compensating his/her former employer for the full inventory of ideas that travels with him or her.”

That workers do not make such compensations seems obvious since they already possess their employers’ knowledge when they decide to leave. The timing of events that Geroski implicitly suggest, however, is misleading. To the extent that research work has a general training element, workers may pay for knowledge as it is accumulated. Whether labor mobility actually reduces appropriability and R&D investments, therefore, is an empirical question. The approach I suggest to answer this question, is to test key implications of models that assume perfect markets. If using standard methodologies² for estimating R&D spillovers without first considering such a ‘benchmark’ case, the results of ordinary market exchange may mistakenly be interpreted as R&D spillovers, and public policy will be misguided³.

The basic implications of labor mobility follows from classical human capital theory, cf. Mincer (1958) and Becker (1962, 1964). To the extent that workers in R&D-intensive firms get access to valuable knowledge on the job, they will expect higher wages in the future. When holding jobs that give access to such knowledge, they should therefore be willing to pay for what they learn by accepting wages below their alternative wage. This hypothesis can be tested using extended Mincer (1974) wage regressions, which is the standard approach in the training literature.

Utilizing a large matched employer-employee data set from the Norwegian machinery and equipment industry, I find that the technical staff in R&D-intensive firms pay for the knowledge they accumulate on the job through lower wages in the beginning of their career, and that they later earn a return on these implicit investments through higher wages. Scientists and engineers have to accept a wage discount in the order of six percent in their first year after graduation if choosing an ‘R&D intensive’ career. This should be considered a conservative estimate, due to a likely ability bias. Towards the end of their career, they receive a wage premium in the order of seven percent. Similar results apply for workers with secondary technical education. The fact that I find as strong results for workers with secondary technical education as for scientists and engineers, indicates that R&D-intensity is not only a measure of learning associated with doing research, but also a proxy for the value of general work experience from high-tech firms. When estimating the

²Cf. e.g. Jaffe (1986) and Jaffe, Trajtenberg and Henderson (1993). See the concluding section for a short discussion of the problem with these methodologies in my context.

³Zucker, Darby and Armstrong (1998), Klette and Møen (1999) and Klette, Møen and Griliches (2000) elaborate on this point.

price paid for learning separately from the return to research experience⁴, I find that having work experience from R&D intensive firms is associated with higher wages, while the employers' *current* R&D intensity reduce wages for workers with less than 20 years experience. Furthermore, as predicted by human capital theory, the youngest workers appear to invest most heavily in on-the-job learning. These findings suggest that the potential externalities associated with labor mobility, at least to some extent, are internalized in the labor market⁵.

With respect to mobility patterns, I find a turnover rate of about 20 percent regardless of the firms' R&D intensity. Excess labor turnover, however, is less in R&D intensive firms. This effect is particularly pronounced for workers with secondary technical education. If changing employer, workers tend to move to a firm with an R&D intensity similar to their former employer. Consistent with the lower excess turnover in R&D intensive firms, research experience from the current employer appears to be more valued than research experience from previous employers.

The rest of the paper is organized as follows: The next section outlines some relevant theoretical models. Section three discusses the data. Section four derives empirical results regarding R&D investments and wages. Section five derives empirical results regarding R&D investments and labor mobility. Section six contains my concluding remarks.

2 R&D investments and human capital theory

Research is a learning process, and R&D investments, therefore, may not only increase a firms' stock of innovations, but also increase the human capital of research workers. In the literature, however, R&D capital (Griliches; 1973), and human capital (e.g. Becker; 1964) are rarely discussed together.

R&D capital is knowledge that can earn a monopoly rent, and this rent is what motivates investments in R&D. If the results of a research project can be perfectly protected by patents or other intellectual property right instruments, labor mobility is not a concern to firms when it comes to appropriating returns. However, often, the intellectual property rights cannot be effectively protected. The R&D capital of firms is then to a large extent embodied in the employees. Such knowledge is what Zucker, Darby and Brewer (1994, 1998) have called *intellectual human capital*⁶.

⁴I will use 'R&D experience' as a short term for experience from R&D intensive firms.

⁵This does not guarantee optimal R&D investments, however, as credit restrictions or risk averse preferences may reduce workers' willingness to 'co-finance' R&D. I will return to this in the concluding section.

⁶Intellectual human capital is human capital that can earn a monopoly rent because the knowl-

Under these circumstances labor mobility is potentially a threat to the firms. Pakes and Nitzan (1983) analyze the investment incentives of entrepreneurs facing such a situation, and conclude that it is possible to design labor contracts which solve the problem, see below.

As knowledge diffuses, intellectual human capital will become 'ordinary' human capital that can be acquired through schooling or on-the-job training. On-the-job training also has relevance for an analysis of labor mobility and R&D investments. There may be more to learn in firms conducting research because such firms are likely to use the most up-to date technology and frequently change their products and production processes. This training may be valuable to other firms. Furthermore, the distinction between intellectual human capital and on-the-job training does not constitute a clear dichotomy. Many innovations are incremental product and process improvements made at the factory floor, and in the limit they may as well be considered excellent craftsmanship as innovations. A case where different firms offer different opportunities for on-the-job training is analyzed by Rosen (1972).

The rest of this section will outline the theoretical models of Rosen (1972) and Pakes and Nitzan (1983). Although highly relevant for work on R&D-investments, training and labor turnover, these models have received modest attention in the literature. The main predictions of the models will be discussed and tested in the empirical part of the paper.

Rosen's 1972 model Rosen (1972) models on-the-job learning using a compensating differential framework, and turns it into "an economic theory of occupational mobility". Rosen thinks of jobs as tied packages of work and learning. Workers sell the services of their skills and simultaneously purchase an opportunity to augment

edge is not publicly available nor perfectly protected. This distinguishes it from 'ordinary' human capital which is widely diffused knowledge that can be acquired at a cost and earns a normal rate of return on the implied investment. How quickly intellectual human capital depreciates and becomes ordinary human capital depends both on the complexity and tacitness of the knowledge and on whether those who possess the knowledge try to keep it secret. Innovations that can be communicated at no cost represents a limiting case and will not add to anyone's human capital once the idea is in the public domain. Zucker, Darby and Brewer (1998) stress that scientific discoveries that create intellectual human capital is "characterized by natural excludability", and that this solves the appropriability problem. From the point of view of an individual scientist, this is correct, but not from the point of view of an investing firm or entrepreneur. Zucker, Darby and Armstrong (1998) recognize this within their setting, writing that "much of the fruits of the biotechnological revolution was much more appropriable by the star scientists than by the universities that (typically) employed them." They also recognize that universities indirectly appropriate returns through the wage mechanism, cf. footnote 42.

those skills. Some jobs provide more learning opportunities than others. The difference between the maximum market rental of a worker's existing skills and the wage that he or she receives in a given job, is the implicit price the worker pays for learning. Basic human capital theory suggests that a worker's incentive to accumulate human capital is largest at young age. As the worker grows older he or she will have fewer years to collect returns on a given investment, and obviously workers have no incentives to pay for increasing their human capital in the last year before retirement. This imply that the "optimal human capital investment program is implemented by a sequence of job assignments in which workers systematically move and are promoted across jobs that offer successively smaller learning opportunities" (Rosen; 1986).

The point of departure in Rosen's model is a net wage equation

$$y = \omega H - P(k) \quad (1)$$

where y is income, ω is the unit rental price of human capital and k is an index measuring potential learning-by-experience on the job, $k \in [0, \bar{k}]$. $P(k)$ is an implicit or shadow price function giving the market equalizing wage differential between a job with no learning potential and a job with learning potential k . The actual amount of learning by individual i is proportional to k and depends on individual i 's ability, $\alpha_i \in [0, 1]$ such that

$$\dot{H}_{it} = \alpha_i k. \quad (2)$$

The workers problem is then to choose a sequence of jobs, k_t , over his or her lifetime, T , to maximize the present value of income, i.e.

$$\max_{k_t} V = \int_0^T [\omega H_t - P(k_t)] e^{-rt} dt \quad (3)$$

subject to an initial stock of human capital, H_0 and $\dot{H}_{it} = \alpha_i k$. Optimization requires that at any time, $t \in [0, T]$,

$$\frac{P'(k_t)}{\alpha_i} = \frac{\omega}{r} [1 - e^{-r(T-t)}]. \quad (4)$$

The expression on the left hand side is the marginal cost of investing in human capital, and the expression on the right hand side is the discounted marginal return. It seems reasonable to assume that $P'(k) > 0$ and $P''(k) > 0$, i.e. that the marginal cost of learning is positive and increasing. Given this, optimality requires k_t to be largest at the time of entry into the labor market and then to decrease monotonically over time.

Note that the marginal cost of a given real investment in human capital decreases with ability. Hence, workers with higher ability will, all else equal, find it profitable to choose jobs with greater learning potential. In the words of Rosen (1972): “Economic incentives induce more ‘able’ workers to learn more and to accumulate knowledge more rapidly than the less ‘able.’” This will give rise to a potential selection problem (ability bias) in the empirical application of the model.

The Pakes-Nitzan model In Rosen (1972) firms differ with respect to learning opportunities, but they do not have market power. Pakes and Nitzan (1983) formalize learning in a different way, downplaying training, but emphasizing the strategical aspects of the innovation process. Their point of departure is Arrow’s (1962) reference to labor mobility as a source of R&D spillovers, and the observation that scientists get access to valuable information⁷. They argue that even though mobility of scientific personnel will spread knowledge produced in industrial laboratories, it need not be a mechanism which reduces the profitability of research projects and employment in such projects. Both scientists and firms are aware of the fact that working on a research project gives access to valuable information⁸. Once such information is disclosed or developed, scientists, if they are to stay with the firm, will have to receive a wage increase reflecting their new market value. Thus, scientists expect that accepting a research position implies a future wage increase, and consequently they accept an initial wage below their alternative wage⁹.

Next, Pakes and Nitzan notice that if the innovation makes the firm a true monopolist, it will never be profitable for the firm and the scientist to split, since the sum of rents in a duopolistic market will be less than the monopoly rent¹⁰.

⁷Note that Pakes and Nitzan (1983) is, strictly speaking, not a model about human capital. Research scientists learn about research results, but do not increase their generic productivity. Hence, the model lack the training perspective crucial in Rosen (1972).

⁸Pakes and Nitzan (1983) explicitly model the uncertainty involved in research. This feature of the model does not alter the simple intuition given here, however, because they assume that utility functions are linear in income. Discussing this assumption, they acknowledge that both risk aversion and a lower bound on wages will affect R&D investments.

⁹Cf. Anand and Galetovic (2000) for a model where the firm cannot commit *ex ante* to share profits with the researcher. In this setting underinvestment in R&D may occur.

¹⁰Pakes and Nitzan (1983) model only a situation with one entrepreneur and *one* scientist. If several scientists have equal access to the same critical information, this will complicate the analysis because of potential strategic interaction among the scientists. Cf. Combes and Duraton (2000) for a game theoretic model where a continuum of workers share the same (exogenously given) strategic knowledge. They show that the ‘joint profit’ effect driving the result in Pakes and Nitzans’ model is not robust to this variation. Pakes and Nitzan dismiss the case with a large number of workers sharing exactly the same strategic knowledge about a firm as being of little relevance. They do

Mobility, therefore, should only be observed when it increases the joint profit of the firm and the scientist. This may happen if the firm cannot avoid that other firms get access to valuable information and enter the market¹¹. The scientist, by setting up a rival, will then break into profits which otherwise accrue to third parties, and since this profit will be part of the scientists alternative wage in 'period two', it is possible for the firm to extract this rent when setting the 'period one' wage. Another situation which may induce the scientist to join or set up a rival is when the research project create 'spin-offs', some of which are better exploited in a separate firm due to coordination costs¹². Summarizing the insight of their model, Pakes and Nitzan writes that

mobility of scientific personnel is not, in itself, a source of concern to entrepreneurs. ... [A]n optimizing entrepreneur who is free to choose among alternative contracts will always choose one which only induces the scientist to leave and join a rival if the sum of the benefits to the two agents increases as a result of the scientist's leaving. Contracts which specify labor payment in the form of a flat wage and stock option (or other profit sharing agreement) ought to be able to induce close approximation to this behavior.

Balkin and Gomez-Mejia (1985) provide empirical evidence in support of Pakes and Nitzans' prediction. Surveying 105 companies in the Route 128 region around Boston, they find that incentive pay programs are far more common in high-tech firms than in other firms, and that such programs are used for broad levels of technical employees. In addition, key scientists and engineers who help form the companies at an early stage, are given long term stock options.

not present strong arguments, but it seems reasonable to assume that if several scientists work on the same project, their knowledge is more often complimentary than substitutable. Cf. Rajan and Zingales' (2001) 'horizontal hierarchy' for a model with this flavor.

¹¹Note that spillovers at this point enter the story, but mobility will be a consequence of spillovers, not a source of spillovers. Information can leak out to third parties by reverse engineering, inspection of patent documents, independent research on the same technological problem, etc. Cf. Levin, Klevoric, Nelson and Winter (1987) for a survey of the importance of various information channels. Labor mobility receives a middle score in their study.

¹²Cf. Franco and Filson (2000) for a model focusing particularly on spin-off firms, but looking at process innovations in a homogeneous product industry. Franco and Filson get results similar to Pakes and Nitzan in that knowledge spillovers are internalized in the labor market, but they do not endogenize mobility by considering the potential 'joint profit' resulting if a spin-off firm is not established.

3 Data

The data used in this study comes from three main sources: Governmental administrative records prepared by Statistics Norway, the annual manufacturing census of Statistics Norway, and the biannual R&D survey of Statistics Norway supplemented with other surveys of immaterial investments and innovation done by the same bureau. The Norwegian data are extraordinary in the sense that the entire working population can be followed over a number of years, and in the sense that extremely rich information is available both about the workers and about their employers. When analyzing wage profiles and labor mobility, the extensive coverage offered by the Norwegian data is a great advantage.

I have chosen to focus on the technical staff¹³ in the machinery and equipment industries as these industries have many high-tech firms and have a fairly complete coverage in the R&D surveys. The matched employer-employee data set covers the years 1986 to 1995, and I have only included men employed full time in the analysis below. Women do not constitute a large share of the labor stock in these industries, and they are known to have different career patterns and preferences than men. Roughly speaking, the main sample has annual observations of about 30,000 workers in 750 plants.

Both the (normalized) length of the highest attained education, and the type of education, is recorded in the data. Occupation, however, is not available. Hence, it is not possible to look specifically at researchers, and workers' learning will be proxied by the employers' R&D intensity. I measure R&D intensity as R&D man-years per employee at the three-digit line of business level within firms¹⁴. If all workers within a firm participate equally in the firm's R&D efforts, R&D man-years per employee will measure the share of time that each worker uses to perform R&D. Since R&D work obviously is not shared equally among the employees, R&D intensity is a noisy proxy for what we want to capture. Measurement errors in the R&D variable add to this noise.

Further information about the data is given in the data appendix and in Tables A1-A6.

¹³I define the technical staff as workers with secondary technical education and workers with higher technical or scientific education. I refer to the latter group as scientists and engineers.

¹⁴This means that R&D intensity is measured at a level 'in between' the firm and the plant. I will use the term firm level R&D intensity in what follows. If R&D man-years were not reported, the value has been imputed based on the firms' R&D spending. I have censored the R&D intensity variable at 0.8 in order to reduce the influence of outliers. This affects 0.4 percent of the observations with positive R&D intensity.

4 The effect of R&D investments on wages

Pakes and Nitzan (1983) predict lower starting wages and higher wage growth for workers doing research, and Rosen (1972) predicts the same pattern more generally for workers having jobs with a high learning potential¹⁵. A key assumption behind both models is that workers mainly acquire general human capital on the job. Testing these models, i.e. testing to what extent different firms offer different learning opportunities, and to what extent workers pay for their knowledge accumulation, we would like to estimate equation (1) which is Rosen's point of departure. In principle this is possible. Human capital, H , can be decomposed and the price or relative weight of its various components can be estimated using a standard log-linear hedonic wage regression. Furthermore, potential learning-by-experience on the job, k , may be proxied by the employer's R&D intensity as it seems reasonable to assume that workers in 'high-tech', R&D intensive firms learn more than workers in 'low-tech' firms. However, some problems are immediately evident. Work experience needs to be decomposed according to the training or research content of the jobs that workers have had at different stages of their career, but complete information about the workers' career histories is not available¹⁶. Furthermore, it is far from obvious how one can summarize what is known about the workers' experience from different firms into a good measure of human capital. In what follows, I will suggest several solutions to these problems.

A first look at the effect of R&D on the earnings profile One way to get around the missing career data, is to assume that workers career trajectories are such that the R&D intensity is constant over their career. Table 5 show that this assumption is valid as an approximation¹⁷. We can then utilize the structural relationship between k and H , given in equation (2) together with the optimal time path for learning investments implicit in (4). Under this assumption the R&D intensity will at each point of time reveal information both about k and about the component of H representing accumulated R&D experience. More specifically, the estimated joint effect will give the returns to R&D experience minus the cost of learning. Working for a highly R&D intensive employer should cause a large

¹⁵I will discuss the relationship between the two models more in detail towards the end of this section.

¹⁶Cf. the data appendix for details.

¹⁷The correlation coefficient between R&D intensity in year t and $t-1$ is 0.84. It falls somewhat when the time intervall is increased, but the coefficient is still 0.57 and highly significant between year t and $t-9$. This is the longest observable time span. Note that the correlation coefficients are downward biased due to measurement errors in R&D intensity.

negative wage premium early in the career, reflecting the implicit price paid for the R&D experience. At the same time, this experience has not had much time to affect the stock of human capital. As time goes by, workers' willingness to pay for human capital accumulation decrease and approaches zero, but differences in previous R&D experience will translate into differences in human capital. Workers who are in R&D intensive firms and have a long R&D intensive career behind them, will therefore have a large positive wage premium reflecting the human capital accumulated.

Table 1 reports the results of OLS wage regressions where cross-terms between experience and current R&D intensity are added to test the hypothesis that employees with a career in R&D intensive firms have a steeper experience-earnings profile than other workers. Additional control variables included are years of schooling, seven experience dummies¹⁸, a quadratic in plant number of employees and year dummies. In column 1 and 3 the experience dummies are interacted directly with R&D intensity while column 2 and 4 report the results of interacting the experience dummies with a dummy which is one if the R&D intensity is above 0.2¹⁹. An R&D intensity of 0.2 represents the 97th percentile for workers with secondary technical education, and the 82th percentile for workers with higher technical or scientific education. The dummy approach is used as an easy way to assess the magnitude of the effect of R&D intensity on wages. An alternative illustration is given in Figure 1, where earnings-experience profiles for workers in firms with no R&D and in firms with R&D intensity 0.2 is graphed, based on a specification continuous in experience.

The results support the main theoretical prediction of Rosen (1972) and Pakes and Nitzan (1983). Early in the career both workers with secondary technical education and scientists and engineers accept a significant wage *discount* when working for R&D-intensive firms, but over time this discount is changed into a significant wage *premium*. Note that both the discounts and the premia are biased towards zero due to measurement errors in the R&D variable. The pattern strongly suggests that R&D-investments of firms translate into general human capital, and that workers both pay and get paid for the knowledge they accumulate.

¹⁸I have chosen to use experience dummies rather than a higher order polynomial in the main specification because the tabulation of cross terms between R&D intensity and a higher order polynomial is difficult to interpret.

¹⁹In these regressions, workers in firms with medium R&D intensity have been excluded. Medium R&D intensity is defined as an R&D intensity between 0.05 and 0.2. The exclusion is done to facilitate a sharper comparison between workers in firms with high and low R&D intensity. Note also that average R&D-intensity is likely to be a poorer proxy for each individual's R&D exposure in firms with intermediate levels of R&D-intensity than in firms with high or low R&D-intensity. The results are, however, robust to including workers in firms with medium R&D intensity, and to using the 90th percentile for each group as a cutoff point instead of 0.2 R&D intensity.

It is evident from Table 1, columns 2 and 4, using the dummy variable approach, that the discounts as well as the premia are of economic significance. Scientists and engineers working in firms with an R&D intensity above 0.2, have on average 6.1 percent *lower* wages in their first year than scientists and engineers in firms with R&D intensity below 0.05. Scientists and engineers with more than 35 year experience and working in a firm with R&D intensity above 0.2, have wages that on average are 6.8 percent *above* the wages of scientists and engineers with similar experience in firms with R&D intensity below 0.05. The magnitudes of the discounts and premia are similar for workers with secondary technical education in R&D intensive firms. They have a 5.5 percent wage discount in the beginning of their career, and an 8.6 percent premium in the end of their career.

Figure 1, which is based on a specification with a quartic in experience interacted with a quadratic in R&D intensity, gives the same qualitative results as Table 1. In Figure 1, however, the premium late in the career is particularly evident for scientists and engineers. The wage discount early in the career, on the other hand, is most evident for workers with secondary technical education²⁰. Given that research is mostly performed by workers with higher education, the significant effect of R&D on wages for this group, brought out both in Table 1 and Figure 1, is somewhat surprising. I will return to this issue later, when discussing in depth the relationship between the Rosen and the Pakes-Nitzan-model. Presumably R&D-intensity measures not only direct research exposure, but works as a general proxy for technological training at all levels within firms.

One way to check the plausibility of the coefficients is to calculate the internal rate of return to choosing an R&D intensive career. For a worker with secondary technical education, the internal rate of return is 5.7 percent, and for workers with higher technical or scientific education it is 3.6 percent²¹. These numbers should be

²⁰Another slight anomaly in Figure 1, is the increase in the wage discount for workers with secondary education over the first ten years of their careers. Looking at the standard errors in Table 1, however, we see that the shape of the wage profile is not very precisely estimated in this interval. Furthermore, such an increase in the very first years is also found in Table 1-3, and is not inconceivable, as discussed in footnote 26. Whereas the dummy specifications are completely flexible with respect to the length of such an effect, the specification behind Figure 1 causes some interdependence in discounts and premia across time. This may explain why the effect is most visible there.

²¹The calculation is based on the regressions in Table 1, column 2 and 4. I assume that the workers are employed in a firm with 100 employees, and that the business cycle is as it were in 1995. Workers with secondary education are assumed to have 12 years of schooling and work for 45 years. Workers with higher education are assumed to have 15 years of schooling and work for 42 years.

considered rough estimates, but they are in a reasonable range.

Estimates based on earnings growth One major obstacle to identifying compensating differentials, whether associated with training or other job amenities, has been the potential correlation between job amenities and unobserved individual characteristics. In Rosen's model, an ability bias arises because highly talented workers have a lower cost of learning, and absorb more knowledge in a job with a large potential for learning, than less talented workers²². This implies a tendency for talented workers to self-select into R&D intensive firms, causing the wage discount in the beginning of the career to be underestimated, and the wage premium in the end of the career to be overestimated²³.

In addition to ability bias and the bias due to measurement errors in R&D already mentioned, there is another potential bias in Table 1 associated with workers switching between employment in 'high-tech' and 'low-tech' firms. Although Table 5 indicates that this kind of behavior is not very common, it clearly does happen. A bias then arises because the regressions in Table 1 assume that we can compare experienced workers in R&D intensive firms to experienced workers in less R&D intensive firms, and learn how much more human capital is accumulated in R&D intensive firms. Workers who transfer out of R&D intensive firms, however, will increase the wage level of the 'comparison group' in the less R&D intensive firms, and cause a downward bias on the estimated gain from working in R&D intensive firms. In the same way, workers who transfer from firms that do not invest much in R&D to firms that do, have less human capital than those who have been in R&D intensive firms for their entire career. Hence, they will reduce the average wage level in R&D intensive firms and add to the bias. The result is that the wage premia associated with the last periods of a 'high tech career' are underestimated, i.e. we will underestimate the steepness of the experience earnings profile²⁴.

A simple way to avoid the potential ability and 'switching' bias, is to estimate

²²Cf. Autor (2000) for a model with the same feature.

²³It is in this respect interesting to note that the estimated coefficients on R&D-intensity become smaller (more negative) if the share of scientists with post graduate degrees at the plant is included in the regression, despite this variable being strongly correlated with R&D intensity (not reported). One possible explanation is that the share of post graduate scientists also is correlated with unobserved worker ability. This would be consistent with the 'O-ring theory' of Kremer (1993).

²⁴By reducing the steepness of the experience earnings profile for workers with a high-tech career, this bias could explain why the estimated net return does not become positive until the workers have somewhere between 10-20 years experience. The bias is eliminated when current and previous R&D is included separately in the regression, cf. Table 3 below.

the wage equation in first differences, i.e. investigate how firms' R&D intensity affect wage growth directly. This is done in Table 2. The drawback of this specification is that we do not learn about the effect of R&D on the wage level²⁵. Given that ability is expected to bias results *against* finding support for the hypothesis that workers pay for R&D experience, however, this is not a serious problem.

The broad picture emerging from the upper part of Table 2 is that workers with technical or scientific education in R&D-intensive firms who do not change employer, have higher wage growth throughout their career²⁶. This is consistent with the previous finding that R&D translates into human capital that workers earn a return on²⁷. Wage growth also appears to level off towards the end of the career, consistent with workers having less incentive to accumulate human capital when getting closer to the retirement age.

Since the correlation between firms' R&D intensity and workers' learning investments is expected to be strongest for young workers, it should be possible to observe changes in 'payment' associated with transitions between firms with different R&D intensities. Moving from an R&D-intensive firm to a less R&D-intensive firm early in the career should induce a wage increase, and transitions the opposite way should induce a wage decrease. Both types of moves will contribute to a negative relationship between wage growth and change in R&D intensity. For old workers, a change in R&D intensity should not affect wages as much, since they are not expected to invest much in human capital. The estimated coefficients do not fully confirm these hypotheses. For old workers, the coefficients are small and not very significant as expected, and for young workers with secondary technical education the coefficient is negative and highly significant, but for young scientists and engineers the coefficient is positive and significant. A problem with the estimates, however, is that mobility cannot be considered exogenous²⁸.

²⁵The wage level is identified if using a fixed effects specification, but such a specification does not perform well. This may be due to its more restrictive assumption regarding the dynamics of unobserved worker characteristics.

²⁶Note, however, that wage growth for workers with secondary technical education is negatively correlated with the employers' R&D intensity in the first two years of the career. This is also evident in Table 1, column 1, Table 3, columns 1-2 and in Figure 1. It may reflect that it takes some time to 'absorb' the complexity of R&D intensive firms, or that workers due to imperfect information about the quality of the training, are unwilling to pay the full cost of the training at once, but that firms are able to extract this premium through lower wage growth during the very first years of the workers' career.

²⁷Cash flow before wage payments per worker, is included to control for the rent sharing effect of successful innovations found by van Reenen (1996). Such a rent sharing effect is present in the data, but it does not dominate the effect of R&D.

²⁸If e.g. young scientists and engineers who perform well tend to move to more R&D intensive

Estimating the price of learning and the return to R&D experience separately Table 1 utilize cross sectional information only, and estimates in one coefficient the return to previous R&D experience *minus* the price paid for current learning opportunities. Utilizing the longitudinal dimension of the data set it is possible to specify these two components separately. The learning opportunity that a worker faces depends only on *current* R&D intensity, while average R&D intensity in *previous years* reveal information about the workers' R&D experience. Note, however, that the stability in R&D intensity over the workers careers, evident in Table 5 and footnote 17, makes current and previous R&D intensities somewhat collinear. A high level of precision can therefore not be expected when including both variables.

Table 3, columns 2 and 4, reports the results of interacting current R&D intensity and the average of previously observed R&D intensities separately with experience dummies. The first thing to notice is that the coefficients on the average of previously observed R&D intensities, i.e. the return to R&D experience, are mostly positive, while the coefficients on current R&D intensity, i.e. the implicit price paid for learning opportunities, are mostly negative. Note also that current R&D intensity has a more negative impact when previous R&D experience is included, cf. column 1 and 3.

The price paid for learning decreases over time as predicted by theory, but the data do not bring out the expected wage increase over time that should be associated with R&D experience. Furthermore, the coefficients on current R&D, i.e. learning, does not go to zero, but becomes positive late in the career. These two features seem connected. The employer's current R&D intensity appears to be a better proxy for old workers' human capital than the average of previously observed R&D intensities. This could be due to some selection process where workers whose technological experience has become obsolete, move out of or are displaced from R&D intensive firms.

In order to assess the importance of learning for the industry on an aggregate level, I have summarized the estimated wage discount for all R&D firms. This sum amounts to 0.7 percent of the total wage bill for technical personnel in all R&D performing firms and 2.6 percent of industry R&D investments. Looking only at firms with R&D intensity above 0.2, the wage discount represent 3.0 percent of their total wage bill and 2.5 percent of their R&D investments. These numbers are not very big, but nor are they negligible.

firms, while young scientists and engineers who do not perform well tend to move to less R&D intensive firms, this may explain the positive coefficient.

The value of R&D experience from the current employer vs. previous employers Lengermann (1996) and Loewenstein and Spletzer (1998, 1999) who study the effect of formal on-the-job training, find that the return to training received from previous employers exceed the return to training received from the current employer. Loewenstein and Spletzer argue that this may reflect that employers extract some returns to general training, and that workers do not realize the full returns until they change jobs. If something similar applies to the value of experience from R&D intensive firms, it would imply that the potential R&D spillovers involved when workers in R&D intensive firms change employers, is only partially internalized in the labor market. In order to investigate this possibility, I have for each employee where sufficient career information is present, calculated the average observed R&D intensity in previous years when working for the current employer and the average observed R&D intensity in years working for previous employers.

With a smaller sample size and three R&D measures, an extension of the specification with experience dummies interacted with R&D-intensities, used in Tables 1 and 3, is not feasible. It is necessary to put more restrictions on the specification and I have chosen to approximate the price paid for learning opportunities with current R&D intensity and its interaction with years of overall work experience. R&D experience built up with the current employer is proxied with the average observed R&D intensity in previous years working for this employer times years of tenure with this employer. R&D experience built up with previous employers is proxied with the average observed R&D intensity while working for previous employers times years of experience prior to the current employment relationship. These measures, resembling sums of R&D intensities, are consistent with equation (2).

Table 4, column 1 and 3, reports the results. Column 2 and 4 report a slightly less restrictive specification where non-linear interactions with experience and tenure are allowed. All regressions confirm the previous finding that current R&D intensity have a significantly negative impact on wages early in the career. The positive cross-term with experience also confirm that this negative impact, interpreted to be the price paid for learning opportunities, diminishes over time. With respect to the R&D experience built up over the career, both R&D experience from the current employer and R&D experience from previous employers have a positive and significant impact on wages. R&D experience from the current employer, however, seems to be more highly valued. Unfortunately, this result is more suggestive than conclusive. In order to construct the variables needed, all years working with the current employer must be included in the sample, while information about previous employers can be less complete. Hence, the average R&D intensity in years working

for previous employers is measured with greater error than average R&D intensity in years working for the current employer, and coefficients on variables involving the former measure will therefore be more biased towards zero²⁹. In addition, the coefficient on R&D experience with the current employer could be upward biased. This would happen if recent R&D experience shows that knowledge accumulated earlier in the career has not become obsolete. The results for old workers in Table 3 indicate that this may be the case.

Robustness and econometric issues A number of alternative specifications have been tried to assess the robustness of the results³⁰. In one specification, more than 30 additional control variables were included, such as proxies for hours worked³¹, the capital to labor ratio, the Herfindal index, the market share of the firm, the union density³² and four-digit industry dummies. This did not change the quantitative results. The results are also robust to including firm size, years of education and union

²⁹If the sample is restricted to workers whose complete career is known, the return to R&D experience from previous employers appears to be above the return to R&D experience from the current employer for workers with higher education, while both coefficients become insignificant for workers with secondary education. For these workers the coefficient on previous R&D experience even has a negative sign.

³⁰In addition to trying out different specifications within the sample of workers with technical education, I have also run the basic regressions on workers with non-technical education. The effect of R&D experience on workers with non-technical secondary and higher education resembles the effect on workers with technical education in that they seem to have a steeper experience-earnings profile if working in R&D-intensive firms. The results are fairly strong for workers with secondary non-technical education, but less evident for workers with higher non-technical education. It is not clear why these workers should be affected by the R&D-intensity of their employers, but several explanations are possible. First, many workers with a general secondary degree are in fact production workers, and hence quite comparable to those with secondary technical education included in the main sample. Second, R&D intensive firms may be advanced along many dimensions, and offer valuable work experience also to the non-technical staff. Third, R&D intensive firms also appear to be intensive in formal training. In years where the dataset includes measures of both R&D investments and formal training, these measures are significantly, positively correlated. Fourth, it is possible that not only the technical staff, but also administrative managers in R&D intensive firms have access to sensitive technological information. Then the Pakes and Nitzan (1983) model applies to this group as well as to the technical employees, and it is in any case conceivable that R&D intensive firms to a larger extent than other firms use stock options and similar compensation schemes for their managers, e.g. due to cash constraints. Finally, the Norwegian economy is strongly unionized. Unions often demand similar earnings plans for all employees in a firm.

³¹The following measures are available: Average hours per week worked at the plant, number of part time jobs and number of months unemployed.

³²The union density is only available after 1990. In 1990 and before, I have used the 1991 value, since union density as a firm characteristic is fairly stable over time.

density in interaction with experience. Dividing the sample into different time periods, however, reveals that the effect of R&D on the wage-experience profile is more pronounced in the 1980s than in the 1990s. This may be related to the severe recession in the Norwegian economy starting in the late 1980s, causing a restructuring of, and a decline in, some of the most innovative subindustries³³. The decline in the profitability of high-tech firms is likely to have affected both the returns to previously accumulated human capital and workers' willingness to pay for access to new knowledge.

All regressions reported in Tables 1, 3 and 4 allow for correlated error terms across observations of the same individual in different years. However, one could also argue that error terms for workers belonging to the same firm may be correlated. Allowing for such correlations when computing the standard error of the estimated coefficients, reduce their significance, but the qualitative results are even robust to including firm specific fixed effects in the regressions.

Rosen (1972) versus Pakes and Nitzan (1983) It has not been an objective of this paper to test the two theoretical models that motivated the empirical specification against each other. It may, however, be worthwhile to reflect on the conceptual differences between them.

Narrowly interpreted, as a two period model about information, Pakes and Nitzan predict a wage discount when a scientist enter a research firm and a wage rise thereafter, regardless of when in the career this happens. The wage profile is driven by a rent which exists as long as the research results are not completely diffused in the industry. In Rosen's model, on the other hand, a steeper wage profile is associated with high-tech or research *experience* rather than research *results*.

Since the experience gained by working on a new technology may be of value after the rent associated with the technology is competed away, the human capital investments in Rosen's model is likely to depreciate more slowly than the 'intellectual' human capital investments in Pakes and Nitzans' model. While young workers thus have a stronger incentive to invest in ordinary human capital than old workers, workers of different age may have more similar incentives with respect to investing in access to research results. In principle, the two models could be tested against each other based on this difference. However, when going beyond stylized versions of the models, the effects of research experience and research rents are complementary rather than alternative explanations for finding a steeper wage profile in research firms. Clearly, doing research has a training element in addition to giving workers

³³Cf. Klette and Møen (1999).

insight in particular research results, and given that R&D is a cumulative process where detailed knowledge about the current technology is an important input in the development of the new technology, it is highly unlikely that an old worker will get a 'high-tech' job without being on a high-tech career track already. Taking account of this cumulative aspect of R&D, and thinking in terms of a 'multi period' Pakes and Nitzan model, a worker who continuously invests part of his or her wage in relatively short term R&D projects is likely to have a steadily increasing wage profile over the whole career³⁴. This is because R&D investments on average should have a higher return than financial savings due to the higher risk, and because workers may become exposed to more and more valuable research results as they gain general research experience.

Rather than testing the models of Rosen (1972) and Pakes and Nitzan (1983) against each other, it seems natural to ask about the relative importance of research rents versus research experience. A rough decomposition of the difference in observed wages between firms with high and low R&D intensity can be based on the assumption that early in the career an estimated effect of R&D on wages will reflect both ordinary human capital and intellectual human capital investments, while late in the career a wage discount and subsequent wage growth associated with R&D would primarily reflect intellectual human capital investments. Hence, the effect of current R&D should not go to zero or become insignificant late in the career as they seem to do in Tables 2 and 3. There should be a positive effect on wage growth and a negative effect on the wage level although significantly smaller than the effects earlier in the career³⁵.

Based on this reasoning, it may seem like the estimated coefficients in my analysis are driven mostly by the long term value of high-tech experience, i.e. accumulation of ordinary human capital as modelled by Rosen. Given the broad categories of technical personnel used and the weak identification of the separate 'Pakes-Nitzan effect', this is perhaps not very surprising. Identifying a separate effect of research rents is probably more difficult than estimating the training effect of high-tech experience. First, measurement errors present in the R&D data bias the coefficients towards zero, and the collinearity of current and previous R&D add to the difficulty of identifying a possible small effect of current R&D late in the career. Second, the importance of intellectual human capital or research rents for wages vary between workers according to how close they are to the innovative core of the firm. In order

³⁴Changes in R&D intensity within a research career will, however, reduce the smoothness of such a wage-profile.

³⁵Estimating a separate 'Pakes-Nitzan effect' based on workers who moved between firms with different R&D-intensities does not succeed either, cf. the bottom part of Table 2.

to identify how involved each worker is in the actual research process, occupational data is necessary. Such data is not available, and R&D-intensity, even if measured correctly, will be an imprecise measure of the amount of research done by individual workers within firms. R&D-intensity may, on the other hand, be a fairly precise proxy for firms' technology level, and hence perform reasonably well as a measure of training in the Rosen (1972) sense. In order to make a separate evaluation of the Pakes and Nitzan model, I believe detailed survey data on wage contracts for key scientists is necessary. Gathering and analyzing such data are left for future work. The significant finding in this study, is that workers seem willing to do intertemporal wage trade-offs that can internalize potential R&D spillovers.

A comparison with the training literature It may be worthwhile to compare the overall results of my analysis to similar analyses of 'on-the-job training'. Although this paper, as far as I know, is the first to look at the effect of R&D on wages, there exists a large literature on the effect of formal training. In this literature, a number of authors have found training to be correlated with wage growth, but finding support for a negative effect on starting wages such as human capital theory predicts, is unusual, cf. e.g. Barron, Black and Loewenstein (1989), Lynch (1992) or Barron, Berger and Black (1999)³⁶. Common interpretations are that workers do not pay for general training, or that the implicit price is masked by a positive ability bias. In this perspective, the strong negative effect of R&D on starting wages present in this sample, is remarkable. It suggests that firms' technology levels are more important to wages than formal on-the-job training. One explanation for this could be that while most formal training is short term, working in a technologically challenging environment affects human capital accumulation for the entire duration of a job.

5 R&D investments and labor mobility.

At first sight, Rosen (1972) and Pakes and Nitzan (1983) seem to have specific predictions not only with respect to wage profiles, but also with respect to mobility patterns. A main prediction of Rosen's model is that workers consistently move to jobs with less learning opportunities. In my context, that may imply that workers move from more to less R&D intensive firms, but as pointed out by Rosen himself,

³⁶One exception is Autor (2000). Studying temporary help firms, he finds that "[w]ages are lower at firms offering training by a modest, but statistically significant magnitude". Lynch (1992) find a negative effect of uncompleted training for workers with less than high school education, but not for workers with a high school degree or some college education.

there is heterogeneity with respect to the learning content of jobs not only across, but also within firms. Hence, a clear prediction cannot be deduced.

Pakes and Nitzan (1983) predict that R&D firms are able to avoid turnover, and thereby spillovers, by sharing the monopoly rent at stake with the workers. In the presence of spin-off innovations or sources of spillovers other than labor mobility, however, they show that mobility actually can be a way of appropriating returns. The model, therefore, like Rosen's, fails to give clear predictions with respect to worker mobility between firms. Furthermore, Pakes and Nitzan (1983) do not consider firm specific knowledge. If firms with different levels of R&D intensities differ with respect to firm specific human capital, this will also influence the relationship between turnover and R&D investments³⁷.

In lack of strong predictions, empirical mobility patterns cannot be used directly to test the theories. A descriptive analysis of mobility patterns still has interest, however, as it will give insight into the outcome of the different forces at play. The extent to which technically educated workers change employers also illuminate how important labor mobility may be as a source of knowledge diffusion and hence indicate the size of the potential externalities involved.

R&D investments and worker flows Based on Rosen's model, despite the lack of a clear prediction, one would expect a tendency for workers to move from more to less R&D intensive firms as a way of reducing their learning in accordance with an optimal human capital investment plan. To investigate this I have calculated a transition matrix of job changes for technical employees between plants with known R&D intensities. The matrix is reported in Table 5. The most striking result is that workers tend to move between firms with *similar* levels of R&D intensity. 65.5 percent of workers leaving a firm that does not conduct R&D (within the plant's line of business) move to another firm that does not conduct R&D, even though jobs in such firms account only for 34.6 percent of all jobs. 64.0 percent of workers leaving a firm with R&D intensity above 0.2 move to another firm with R&D intensity above 0.2, although such firms only account for 5.9 percent of all jobs. The pattern is the same for workers leaving firms with intermediate levels of R&D intensity.

One explanation for the observed stability in R&D intensity across jobs may be that there is some specificity associated with a given technology level within

³⁷In the training literature, the effect of training on turnover propensities has been used to assess whether the human capital built up is general or firm specific, cf. e.g. Loewenstein and Spletzer (1999) and Parent (1999). For a theoretical model of knowledge diffusion with partly firm specific human capital, see Fosfuri, Motta and Rønde (2001) who analyse a firm's decision to invest in production facilities abroad.

the industry. As workers grow older, they will then prefer jobs with less learning, within firms at the same level of R&D intensity as those they have previously worked for. Another explanation may be that workers have preference for work at a given technology level³⁸.

R&D investments and labor turnover As explained above, Pakes and Nitzan (1983) investigate the relationship between R&D and labor turnover theoretically without reaching a firm conclusion. Table 6 reports labor turnover for technical employees in firms with different levels of R&D intensity in my sample. The turnover rate is about 20 percent, and does not seem to vary much across firms with different levels of R&D intensity. What seems most relevant to explore, however, is how R&D investments affect ‘churning’, i.e. hires and quits over and above the level necessary to accomplish changes in the number of employees. Excess turnover, a measure of churning³⁹, lies between 5 and 10 percent and seems to decrease with R&D intensity both for workers with secondary technical education and for workers with higher technical or scientific education. A descriptive analysis of excess turnover is not sufficient, however, as a closer inspection of the data reveal that there are significant differences between firms having different levels of R&D intensity, with respect to other characteristics known to influence turnover such as workers’ experience. In order to isolate the effect of R&D on excess turnover, therefore, a regression framework is called for.

Table 7 reports regression results for both a tobit and a maximum likelihood

³⁸The work of Almeida and Kogut (1999), Stern (1999) and others suggests that scientists and technical personnel have preferences regarding the technological environment that they work in.

³⁹Cf. Burgess, Lane and Stevens (1996) and Barth and Dale-Olsen (1999). The excess turnover rate is half the churning rate. I have calculated the excess turnover rate as separations out of jobs that continue, divided by the number of continuing jobs.

grouped logit estimator⁴⁰. The estimated relationship is

$$excess\ turnover_{it} = f(R\&D-int. * D^{sec. edu.}, R\&D-int. * D^{higher edu.}, X) \quad (5)$$

The unit of observation is educational groups within plants. Control variables, X , include a quadratic in the educational group number of workers, a quadratic in their average experience, a quadratic in plant age and year dummies⁴¹.

In the tobit regression I have followed Barth and Dale-Olsen (1999) by excluding small units, limiting the sample to educational groups that consist of at least five workers, cf. footnote 40. Both the tobit and the grouped logit specification show that excess turnover is lower in R&D intensive firms. The effect is, however, particularly evident for workers with secondary technical education. One possible explanation is that human capital accumulated by workers with secondary technical education is more firm specific than human capital accumulated by workers with higher technical or scientific education. It may also indicate that the mechanisms related to spin-off innovations and other spillover channels, modelled in Pakes and Nitzan (1983), are relevant in the industries investigated. Workers with higher education would probably be most affected by these mechanisms which increase turnover.

The results in Table 7 is consistent with other findings in the empirical literature. Pacelli, Rapiti and Revelli (1998) who estimate the probability of worker firm separations in Italy, find that “more innovative firms cultivate more durable employer-employee relationships”, and Greenhalgh and Mavrotas (1996) analyzing

⁴⁰Barth and Dale-Olsen (1999) estimate the effect of employers' wage policies on excess turnover, and treat the excess turnover rate as a characteristic of the firm. This leads them to use a tobit estimator. Within such a framework, the observed excess turnover rate must be considered an estimate of a target rate implicit in the firms' personnel policy, and Barth and Dale-Olsen (1999) think in terms of a latent variable censored from below at zero. (One might add to this that the excess turnover rate is also censored from above at one.) As an estimate for the target rate, however, the observed rate is heteroscedastic with a variance proportional to the inverse of the number of employees. Barth and Dale-Olsen (1999) do not explicitly discuss this, but alleviate the problem by limiting the analysis to large firms. Grouped logit eliminates this heteroscedasticity problem. Thinking of the data in this way also changes the perspective from the firm unilaterally deciding an excess turnover rate to individual employer-employee relationships which may or may not continue, depending on both firm and worker characteristics. I find this to be a preferable perspective, as individual employer-employee relationships is the true unit of observation, and it makes sense conceptually to divide observed quits into two groups, those who are replaced, and those who are not replaced. The first type of quits constitute excess turnover while the second type of quits are due to job destruction. If we knew which of the workers who separate that belong to which group, we would no doubt use logit or probit. When we only know the proportion of workers belonging to each group, we can apply grouped logit or probit. cf. Greene (1997, chapter 19.4.3).

⁴¹A complete list is given in the subtext to Table 7.

the British labor market, find that sectoral R&D is negatively correlated with mobility. They attribute this only to the presence of firm specific human capital, however, claiming that “the skills acquired [in R&D intensive sectors] are rather more specific than average”.

6 Concluding remarks

Labor mobility is often considered to be an important source of knowledge externalities, making it difficult for firms to appropriate returns to R&D investments. Pakes and Nitzan (1983), however, analyze the problem formally, and find that labor turnover should not be a problem for R&D firms. Both scientists and firms are aware of the fact that working on a research project gives access to valuable information. Once such information is disclosed or developed, scientists, if they are to stay with the firm, will have to receive a wage increase reflecting their new market value. Thus, scientists expect that accepting a research position implies a future wage increase, and consequently they can accept an initial wage below their alternative wage, without experiencing a welfare loss.

Research firms are likely to use the most up-to date technology and frequently change their products and production processes. Because of this, one would think that even workers who don't have direct access to the results of the R&D projects, learn more in these firms. Rosen (1972) provides a model where different firms offer different opportunities for on-the-job learning, and derive implications with respect to wages that resemble those of Pakes and Nitzan (1983). Rosen thinks of jobs as tied packages of work and learning. Workers sell the services of their skills and simultaneously purchase an opportunity to augment those skills.

I have argued in this paper that inter-firm transfers of R&D-results embodied in people, should be analyzed within a human capital framework similar to the models of Rosen (1972) and Pakes and Nitzan (1983). Testing such a framework using matched employer-employee data from the Norwegian machinery and equipment industries, I find that the technical staff in R&D-intensive firms indeed pays for the knowledge they accumulate on the job through lower wages in the beginning of their career. Later in the career they earn a return on these implicit investments through higher wages. These results appear despite the existence of several biases against finding different experience-earnings profiles in R&D intensive and non-R&D-intensive firms. This suggests that potential externalities associated with labor mobility out of research firms, at least to some extent, are internalized in the labor

market⁴².

An alternative explanation for the steeper experience-earnings profile in R&D intensive firms has been suggested to me. Inspired by e.g. Freeman (1977) one may imagine that workers and firms are uncertain about the workers' ability⁴³, and that high ability workers have higher productivity in research firms than in firms using well known technologies demanding less problem solving⁴⁴. All workers are in this case willing to accept a lower wage in R&D firms because the expected wage growth, is higher. As information about ability is revealed, *ex post* high ability workers in research firms perform well while others, *ex post* low ability workers, exit having lost in the 'lottery'⁴⁵. Such a model, which does not involve any kind of human capital accumulation, is consistent with the results in Tables 1 and 2, but not with the results in Table 3 where previous R&D experience is introduced in addition to current R&D. In a model like the one sketched above, current R&D should be associated with a wage premium as soon as the firm and the worker have learned about the worker's ability and be stable thereafter, while previous R&D experience should not affect wages. This is not the case.

An important question that this analysis has not addressed is whether workers pay for the *full* value of the knowledge they accumulate in R&D intensive firms. The conceptual distinction between knowledge diffusion and true externalities motivated my analysis, but identifying possible true externalities is challenging. Building on previous methodologies such as Jaffe (1986) one could construct a spillover pool for each firm based on R&D conducted in other firms which the firm in question has recruited from. This measure could be inserted in a knowledge production function. The problem is that it is not possible to know whether the coefficient on such a spillover pool represents an externality or whether the knowledge is 'bought' in the labor market. Inserting the spillover pool in a profit function will not solve the problem, either. In equilibrium, labor mobility should affect the profit of all firms,

⁴²The only related finding I know of in the literature is Zucker, Darby and Armstrong (1998) who in an academic setting, claim that "competitive university salaries are lower, other things equal, in areas where faculty expect the possibility of receiving substantial outside income or wealth as a result of skills developed doing research at the university."

⁴³Freeman's point of departure is that "[n]ot all prospective research workers prove equally adept. Moreover, no individual can be certain in advance just how well he will do. As time passes, his capabilities become clearer to himself as well as to his employer."

⁴⁴An alternative formulation is that there is uncertainty about the quality of the match, cf. e.g. Jovanovic (1979), and that match quality is more important in research firms than in other firms with more 'routine jobs'.

⁴⁵Freeman (1977) focuses on risk averse workers' demand for a wage contract with insurance, but it follows from his model that if workers are not completely risk averse they will accept a beginning wage below their alternative wage in order to participate in the implicit 'lottery'.

and only by comparing different equilibria with exogenous variation in the degree of labor mobility, could an effect of mobility-induced externalities be identified. This is obviously difficult. I believe the best way to proceed is to model explicit mechanisms that might cause externalities, and derive testable implication from such specific models. Case studies of firms that have lost or hired workers with strategic knowledge would also be valuable.

From a theoretical point of view it is conceivable that labor mobility does create some externalities. If firms have limited ability to commit themselves to share future profits with their employees, or if several workers have access to exactly the same research results, this may undermine the ‘joint profit’ effect underlying optimal R&D investments in Pakes and Nitzans’ model⁴⁶. Furthermore, information asymmetries and other barriers to mobility may enhance the firms ability to appropriate rents, while at the same time reduce workers’ incentives to pay for knowledge accumulation⁴⁷. Mechanisms which induce employers to pay for general human capital accumulation create a positive externality to the worker’s future employer if the worker decides to quit or if the firm goes out of business. A complete welfare analysis must also incorporate that, even if workers pay for all the knowledge they accumulate, this ‘solution’ to the spillover problem does not guarantee optimal R&D investments. If workers co-finance R&D through lower wages, and if the value of the knowledge they accumulate depend on the outcome of the R&D project, they become exposed to the risk associated with the project. Risk aversion among workers may then become a new source of distortion since human capital investments cannot be diversified⁴⁸. Liquidity constraints making workers unwilling to trade off current wage for future wage on a large scale, may also create problems⁴⁹.

⁴⁶Cf. footnote 9 and 10.

⁴⁷Cf. Acemoglu and Pischke (1999) although these authors do not write with reference to R&D investments. A particularly important kind of imperfection may be distortions in the wage structure which makes a wedge between wages and marginal productivity increase with the workers’ human capital. Firms then have an incentive to invest in R&D producing general human capital because they get a share of the return. A simple mechanism which could cause such wage compression, is that firms receive a *fraction* of the productivity of the workers as profit due to matching, search costs or other sorts of labor market friction. If the employer receives a fraction of the workers’ productivity, the employers level of profit will increase with the workers’ productivity and therefore with their human capital. Another possible mechanism is complementarity between firm specific and general human capital. In this case, the alternative wage for the scientist will increase less than his or her productivity as he or she receives training.

⁴⁸Cf. footnote 8.

⁴⁹Cf. Fosfuri et al. (2001) for a model emphasizing this in a developing country context.

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Appendix on data issues

Information about individual workers comes from a number of governmental administrative records, which are prepared by Statistics Norway for research use. Barth and Dale-Olsen (1999), appendix 2, give some details on the various registers included in the data base. I have taken great care to improve the data quality by checking for consistency across years and across related variables for the same individual. Missing values are imputed where possible. The available registers cover the years 1986 to 1995.

Plant level information about employers comes from the annual manufacturing census of Statistics Norway⁵⁰. Microdata are available from 1972⁵¹. Information about R&D at the line of business level within firms are collected from R&D surveys and other surveys of immaterial investments and innovation. Prior to 1991 the R&D surveys were conducted by the Royal Norwegian Council for Scientific and Industrial Research. Thereafter the surveys have been conducted by statistics Norway⁵². Microdata is available for 1970, biannually 1975-81, annually 1981-85 and biannually 1985-95. The 1970 survey has been linked to the 1972 manufacturing census. In the machinery and equipment industries utilized in this study, the R&D surveys have close to full coverage for firms with more than 20 employees. For years and firms not covered by the R&D surveys, three other data sets has been utilized. A survey of immaterial investments was conducted by Statistics Norway in 1988, covering the years 1986-88, and in 1990 covering the years 1988-90⁵³. Furthermore, an innovation survey was conducted by statistics Norway in 1993 for the year 1992⁵⁴.

I have used the following procedure when constructing the R&D database: First, I have linked the R&D surveys to the manufacturing census. Next, for firms and

⁵⁰The census is documented in the series *Manufacturing statistics*, Official Statistics of Norway, Statistics Norway, Oslo.

⁵¹The microdata are documented in a mimeo from 1991 by Halvorsen, Jensen and Foyn in Statistics Norway.

⁵²The R&D surveys are documented in the series *FoU-statistikk Forsknings- og utviklingsarbeid Utgifter og personale* (1970-1991 by Forskningsrådenes samarbeidsutvalg and Norges Forskningsråd); *FoU-statistikk og indikatorer* (1995 by Utredningsinstituttet for forskning og høyere utdanning); and *Det norske forskningssystemet - statistikk og indikatorer* (1997 by Norges forskningsråd). More details are given in the series *FoU virksomhet Utgifter og personale i næringene industri, bergverksdrift og anleggsvirksomhet*, by NTNf and in Report 96/14 from Statistics Norway by Skorge, Foyn and Frengen. All publications have summaries in English.

⁵³These surveys are documented by Frenger in *Interne notater 90/11* and *Notater 93/14* from Statistics Norway.

⁵⁴This survey is documented in the reports 95/7 and 95/26 from Statistics Norway by Frengen, Foyn and Ragnarson. Report 95/26 is in English.

years not included in the R&D surveys I have used R&D information from the surveys of immaterial investments, and from the innovation survey. For firms and years where R&D information is still missing, I have used survey information about planned R&D one and two years ahead, and information about previous R&D. In the final stage, missing R&D variables were imputed by linear interpolation, and by extrapolating the first observed R&D intensity backwards in time and the last observed R&D intensity forward in time, firm by firm. Firms' R&D investments are known to be stable over time. Imputing missing information when possible, therefore, seems preferable to deleting the observations. 80 percent of the worker-year R&D variables are from surveys, 5 percent are imputed by interpolation and 15 percent are imputed by extrapolation. 65 percent of the imputed R&D intensities are zero.

Even though the data set is rich, I do not have complete information about the workers' careers. First, the individual records start in 1986. Second, despite my effort to collect R&D information as described above, small firms are not necessarily covered. Third, the match between the different data sources is not perfect. Due to the second and third problem, R&D information is missing for approximately 20 percent of the worker-year observations. On the positive side, however, I can extract some information about workers' careers prior to 1986, the first year included in the matched data set. I know when the workers started the job they held in 1986⁵⁵, and this can be combined with information about the employers' R&D investments, in some cases dating as far back as 1970.

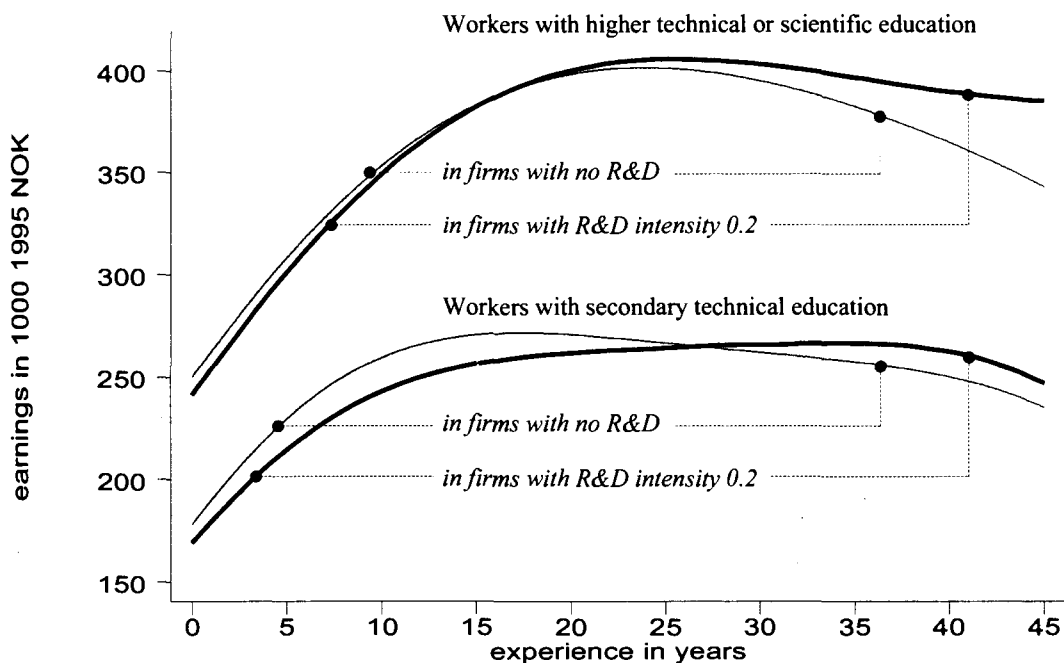
Earnings is measured as taxable labor income. I have often referred to this as the workers' wage. Experience is measured as real work experience for the youngest cohorts, years since graduation for older cohorts, and potential work experience for cohorts graduating before November 1970. Potential work experience is age minus schooling minus seven. Real work experience is measured as years since graduation adjusted for pre graduation work experience, part time employment and unemployment within the sample years 1986-1995. Both experience and tenure are measured in years (with decimals) completed at the beginning of the calendar year. Dummy variables for experience are based on the integer of experience.

In the mobility analysis, all observations with complete information are used. In the wage regressions observations with unreliable earnings measures have been excluded. Information about trimming procedures is given in Table A1. Trimming based on earnings reduces the sample by 8 percent. Tables A2-A6 describe the

⁵⁵Note, however, that for 16 percent of the observations, the starting date is censored at April 30th 1978. I have used a dummy variable to resolve this problem in regressions where tenure is included.

sample and the main variables.

Figure 1. Estimated earnings-experience profiles



The graphs are based on regressions similar to those in Table 4, column (1) and (3) except that experience dummies interacted with R&D intensity is exchanged with a quartic in experience interacted with a quadratic in R&D intensity. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995. The graphs for workers with higher education are based on 15 years of education and a firm with 100 employees. The graphs for workers with secondary education are based on 12 years of education and a firm with 100 employees. Business cycle conditions are assumed to be like 1995.

Table 1. The effect of R&D on the experience-earnings profile

	(1)	(2)	(3)	(4)
	Secondary technical education		Higher technical or scientific education	
R&D				
* less than one year experience	-.207*** (.049)	-.055** (.024)	-.132*** (.044)	-.061*** (.014)
* 1-2 year experience	-.297*** (.052)	-.048** (.019)	-.097*** (.025)	-.044*** (.009)
* 3-5 year experience	-.163*** (.032)	-.029*** (.011)	-.049** (.021)	-.025*** (.007)
* 6-10 year experience	-.169*** (.026)	-.025*** (.009)	-.012 (.022)	-.018*** (.007)
* 11-15 year experience	-.083*** (.032)	.001 (.010)	.008 (.026)	-.009 (.009)
* 16-20 year experience	-.065* (.035)	.023** (.011)	.025 (.032)	.001 (.009)
* 21-35 year experience	.088*** (.029)	.045*** (.009)	.101*** (.029)	.031*** (.009)
* more than 35 year experience	.222*** (.048)	.086*** (.016)	.229*** (.055)	.068*** (.019)
R&D measure	Intensity	dummy	intensity	dummy
Sample size	244 657	207 776	71 372	50 216
R-squared	.20	.20	.28	.26

The dependent variable is ln (real annual earnings). Control variables included in the regression, but not reported are seven experience dummies, years of schooling, a quadratic in plant number of employees and year dummies. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within individuals, are given in parentheses. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. The R&D dummy is one if the R&D intensity is above 0.2. Observations with R&D-intensity between 0.05 and 0.2 are excluded from the regressions in column (2) and (4). The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995.

- *** Significant at the 1% level
- ** Significant at the 5% level
- * Significant at the 10% level

Table 2. The effect of R&D on biannual earnings growth

	Secondary technical education	Higher technical or scientific education
Stays with same employer from year $t-2$ to year t		
* 2 year experience * R&D-intensity	-.203** (.082)	.021 (.040)
* 3-5 year experience * R&D-intensity	.077*** (.027)	.065*** (.017)
* 6-10 year experience * R&D-intensity	.079*** (.016)	.048*** (.012)
* 11-15 year experience * R&D-intensity	.101*** (.016)	.039*** (.014)
* 16-20 year experience * R&D-intensity	.093*** (.018)	.049*** (.015)
* 21-35 year experience * R&D-intensity	.063*** (.011)	.007 (.011)
* above 35 year experience * R&D-intensity	.047** (.022)	.008 (.021)
Separates in year $t-1$		
* 2-10 year experience * Δ R&D-intensity	-.232*** (.057)	.097*** (.037)
* 11-20 year experience * Δ R&D-intensity	.044 (.045)	.037 (.033)
* above 21 year experience * Δ R&D-intensity	-.076* (.045)	-.021 (.040)
Sample size	139 108	42 466
R-squared	.09	.13

The dependent variable is the first difference of ln (real annual earnings) between year t and year $t-2$. Control variables included in the regression, but not reported are cash flow before wage payments per employee, seven experience dummies, a dummy for being a separator in year $t-1$ interacted with dummies for the three levels of experience used for separators, a quadratic in the change in plant size measured by number of employees and year dummies. The coefficients are estimated using ordinary least squares. Standard errors are given in parentheses. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. R&D intensity for stayers is the average over year t , $t-1$, and $t-2$. The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995.

*** Significant at the 1% level

** Significant at the 5% level

* Significant at the 10% level

Table 3. The effect of current R&D and previous R&D experience on earnings

	(1)	(2)	(3)	(4)
	Secondary technical education		Higher technical or scientific education	
Current R&D-intensity				
* less than one year experience	-.204*** (.050)	-.204*** (.050)	-.134*** (.044)	-.130*** (.044)
* 1-2 year experience	-.314*** (.062)	-.342*** (.073)	-.131*** (.030)	-.266*** (.038)
* 3-5 year experience	-.190*** (.031)	-.233*** (.039)	-.058** (.023)	-.123*** (.027)
* 6-10 year experience	-.177*** (.028)	-.208*** (.032)	.010 (.023)	-.097*** (.025)
* 11-15 year experience	-.080** (.032)	-.084** (-.037)	.014 (.027)	-.062** (.069)
* 16-20 year experience	-.069* (.036)	-.079* (.041)	.031 (.034)	-.022 (.038)
* 21-35 year experience	.089*** (.029)	.038 (.030)	.094*** (.030)	.039 (.032)
* more than 35 year experience	.234*** (.048)	.285*** (.053)	.222*** (.056)	.265*** (.062)
Average R&D-intensity over previous career				
* 1-2 year experience		.055 (.093)		.261*** (.051)
* 3-5 year experience		.094 (.057)		.142*** (.038)
* 6-10 year experience		.070 (.055)		.186*** (.036)
* 11-15 year experience		.010 (.062)		.167*** (.038)
* 16-20 year experience		.028 (.059)		.134*** (.052)
* 21-35 year experience		.171*** (.060)		.165*** (.053)
* more than 35 year experience		-.158** (.072)		-0.149 (.103)
Sample size	227 418	227 418	65 422	65 422
R-squared	.19	.19	.28	.28

The dependent variable is ln (real annual earnings). Control variables included in the regression, but not reported, are seven experience dummies, years of schooling, a quadratic in plant number of employees and year dummies. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within individuals, are given in parentheses. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995. Workers, for whom no R&D information from previous years is available, have been excluded.

*** Significant at the 1% level

** Significant at the 5% level

* Significant at the 10% level

Table 4. The effect of current R&D, R&D experience from the current employer and R&D experience from previous employers

	(1)	(2)	(3)	(4)
	Secondary technical education		Higher technical or scientific education	
current R&D intensity	-.316*** (.042)	-.480*** (.063)	-.104*** (.034)	-.157*** (.052)
* experience	.017*** (.002)	.038*** (.008)	.003 (.002)	.008 (.007)
* experience ²		-.001*** (.0002)		-.0001 (.0002)
mean R&D intensity in previous years with current employer				
* tenure	.028*** (.008)	.124*** (.018)	.032*** (.007)	.089*** (.014)
* tenure ²		-.014*** (.002)		-.008*** (.002)
mean R&D intensity in years with previous employer(s)				
* (experience – tenure)	.008** (.003)	.005 (.008)	.005** (.002)	.013** (.006)
* (experience – tenure) ²		.0001 (.0003)		-.0004 (.0003)
Sample size	62 243	62 243	17 675	17 675
R-squared	.23	.24	.33	.33

The dependent variable is ln (real annual earnings). Control variables included in the regression, but not reported, are years of schooling, a quadratic in plant number of employees, a quartic in experience, a quadratic in tenure, a dummy for having changed employer at least once, year dummies and a dummy variable for job relationships whose starting date is censored at April 30th 1978 together with its interactions with all tenure variables. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within individuals, are given in parentheses. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. Mean R&D intensity is calculated over the years where information about the R&D intensity is available. The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995. Workers in firms where R&D information is not available in the sample year and in at least one prior year, and workers who have had previous employment without R&D intensity being known in at least one year, have been excluded.

- *** Significant at the 1% level
- ** Significant at the 5% level
- * Significant at the 10% level

Table 5. Worker mobility between plants with known R&D intensity

	with no R&D	with R&D- intensity $\in (0,.05]$	with R&D- intensity $\in (.05,.2]$	with R&D- intensity $> .2$	Total number of separa- tions
left a non R&D-plant and joined a plant	65.5	27.3	5.7	1.5	3 168
left a plant with R&D-intensity $\in (0,.05]$ and joined a plant	27.8	61.1	8.9	2.2	3 330
left a plant with R&D-intensity $\in (.05,.2]$ and joined a plant	11.9	42.6	40.4	5.1	2 841
left a plant with R&D-intensity $> .2$ and joined a plant	12.9	9.3	13.9	64.0	497
percentage of jobs in plants	34.6	42.3	17.2	5.9	

The numbers are percentage shares of total separations from each category of plants and sum to 100 horizontally. The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995 at a plant where the R&D-intensity is known. Transitions out of the sample have been excluded. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms.

Table 6. Labor turnover by education and R&D intensity

	Turnover rate	Excess turnover rate	Number of job-year observations
Secondary technically educated in a plant			
with no R&D	.194	.095	110 091
with R&D-intensity $\in (0, .05]$	.210	.091	84 886
with R&D-intensity $\in (.05, .2]$	.211	.072	37 280
with R&D-intensity >0.2	.208	.059	7 246
Higher technically or scientifically educated in a plant			
with no R&D	.191	.074	14 806
with R&D-intensity $\in (0, .05]$	.210	.075	20 444
with R&D-intensity $\in (.05, .2]$	.211	.071	20 782
with R&D-intensity >0.2	.216	.065	11 838

The turnover rate is separations in year t as a share of employment in year t . The excess turnover rate is separations out of jobs that continue as a share of continuing jobs. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995.

Table 7. The effect of R&D intensity on excess turnover

R&D-intensity		
* secondary technical education	-0.119*** (.030)	-2.041*** (.416)
* higher technical or scientific education	-.042 (.030)	-.721* (.376)
Estimator	Tobit	Grouped logit
Sample size	6 904	266 173
Pseudo R-squared	.42	.01

The dependent variable is the excess turnover rate within plant educational groups. The excess turnover rate is separations out of jobs that continue as a share of continuing jobs. Control variables included in the regressions, but not reported are a dummy for higher technical or scientific education, plant job destruction rate, plant job creation rate, a quadratic in the educational group number of workers, a quadratic in their average experience, a quadratic in plant age and year dummies. The sample sizes in the tobit regressions refer to the number of within plant educational groups. Educational groups with less than five workers have been excluded from the tobit regressions due to the turnover estimates being uncertain when based on few workers. The sample sizes in the grouped logit regressions refer to the number of workers. Standard errors are given in parentheses. In the grouped logit regressions, the standard errors are adjusted for heteroscedasticity and correlated error terms within plants. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. The sample consists of men with technical or scientific education employed full time in the machinery and equipment industry in Norway 1986-1995.

*** Significant at the 1% level

** Significant at the 5% level

* Significant at the 10% level

Table A1. Sample size and trimming procedures

Total number of observations in the machinery and equipment industries 1986-1995	810 559
– Women	125 111
– Part time workers	11 314
– Workers with unknown education	8 968
– Workers with primary education	141 216
– Workers with secondary or higher non-technical/non-scientific education	94 325
Total number of observations of full time working male technical staff	429 625
– Workers in firms that cannot be matched to the time series files of the manufacturing statistics	39 527
– Workers in firms where R&D information is not available	46 744
Total number of observations of full time working male technical staff in the matched sample	343 354
– Workers not working for the whole year because they are entering the labor force	9 982
– Workers not working for the whole year because they are leaving the labor force	14 044
– Workers with secondary technical education and earnings below NOK 75.000 (1995 value)	2 723
– Workers with higher technical or scientific education and earnings below NOK 150.000 (1995 value)	566
Main sample (trimmed)	316 029

Each entry refers to the number of observations deleted among the observations left after the deletions in the rows above have been conducted. Workers with secondary technical education and earnings below NOK 75.000 (1995 value), and workers with higher technical or scientific education and earnings below NOK 150.000 (1995 value) have been excluded because such low earnings suggest that they have not worked full time for an entire year. Tables 5-7 are based on all observations of full time working male technical staff in the matched sample, whereas the wage regressions in Tables 1-4 are based on the trimmed 'main sample'.

Table A2. Observations in main sample by year and education

	Number of workers	Secondary technical education	Higher technical or scientific education
1986	29 256	75.0 %	25.0 %
1987	30 329	75.8 %	24.2 %
1988	29 450	76.0 %	24.0 %
1989	29 952	76.2 %	23.8 %
1990	31 576	77.1 %	22.9 %
1991	31 482	79.6 %	20.4 %
1992	33 857	79.2 %	20.8 %
1993	33 261	78.8 %	21.2 %
1994	35 315	78.3 %	21.7 %
1995	31 551	77.4 %	22.6 %
Observations	316 029	77.4 %	22.6 %

Table A3. Observations in the main sample by experience and R&D intensity

	Observations	No R&D	R&D-intensity ∈ (0,.05]	R&D-intensity ∈ (.05,.2]	R&D-intensity >.2
Less than one year experience	7017	36.6 %	42.9 %	16.5 %	4.0 %
1-2 year experience	18446	36.8 %	40.3 %	16.9 %	6.0 %
3-5 year experience	36167	37.7 %	37.7 %	17.6 %	7.0 %
6-10 year experience	57802	42.1 %	32.8 %	17.5 %	7.5 %
11-15 year experience	44545	41.0 %	32.3 %	19.3 %	7.4 %
16-20 year experience	37563	42.9 %	32.0 %	18.6 %	6.4 %
21-35 year experience	86846	40.6 %	33.9 %	19.3 %	6.2 %
More than 35 year experience	27643	41.4 %	35.7 %	17.8 %	5.1 %
	316 029	40.6 %	34.4 %	18.4 %	6.6 %

R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms.

Table A4. Worker characteristics by education

	Secondary technical education	Higher technical or scientific education
Years of education		
mean	11.2	14.5
st.dev.	(.9)	(1.7)
10 th percentile	10.0	13.0
90 th percentile	12.0	17.0
Years of experience		
mean	16.8	17.4
st.dev.	(11.9)	(11.6)
10 th percentile	3	3
90 th percentile	34	35
Years of tenure [‡]		
mean	6.3	6.0
st.dev.	(5.6)	(5.1)
10 th percentile	.9	.9
90 th percentile	13.2	12.5
Wage in 1995 NOK		
mean	245 400	353 500
st.dev.	(71 000)	(125 900)
10 th percentile	176 500	240 200
90 th percentile	336 100	479 700
Union membership		
share	44%	27%
Working at R&D performing plant		
share	54%	78%
R&D-intensity if at R&D performing plant		
mean	.057	.125
st.dev.	(.085)	(.134)
10 th percentile	.002	.006
90 th percentile	.152	.278

The numbers are based on all worker-year observations in the machinery and equipment industry included in the main sample, cf. Table A1. An R&D plant is a plant belonging to a firm that conducts some R&D within the plant's three-digit ISIC industry. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. Wage in 1995 NOK is rounded to the nearest 100.

[‡] 16 percent of the observations have the job starting date censored at April 30th 1978.

Table A5. Plant characteristics by plant size

Number of employees:	Less than 50	50-200	more than 200	All plants
Number of employees				
mean	18.3	96.2	483.3	83.3
st.dev.	(12.9)	(38.6)	(347.7)	(169.9)
10 th percentile	4	54	221	6
90 th percentile	39	158	906	185
Average experience of technical staff				
mean	16.9	17.1	17.2	17.0
st.dev.	(6.6)	(4.4)	(4.4)	(5.9)
10 th percentile	9.3	12.0	12.2	10.2
90 th percentile	25.3	23.0	22.5	24.1
Average tenure of technical staff[‡]				
mean	5.7	6.0	6.1	5.8
st.dev.	(3.3)	(3.0)	(3.3)	(3.2)
10 th percentile	1.9	2.3	2.1	2.0
90 th percentile	10.0	9.8	10.7	10.0
Average education of technical staff				
mean	11.7	11.7	12.0	11.8
st.dev.	(1.1)	(0.8)	1.0	(1.1)
10 th percentile	10.7	10.8	11.2	10.8
90 th percentile	13.0	12.9	13.4	13.0
Share of work force with higher technical or scientific education				
mean	10%	10%	13%	10%
st.dev.	(16)	(11)	(12)	(14)
10 th percentile	0	1%	2%	0
90 th percentile	32%	23%	31%	29%
R&D performing firm				
share	34%	54%	63%	42%
R&D man-years per employee if R&D performing firm				
Mean	.14	.07	.08	.10
st.dev.	(.18)	(.09)	(.10)	(.15)
10 th percentile	.007	.005	.003	.006
90 th percentile	.39	.17	.21	.26
Capital per employee in 1995 NOK				
Mean	805 800	831 700	977 100	828 900
st.dev.	(1 137 600)	(682 300)	(746 400)	(995 100)
10 th percentile	245 700	268 300	233 700	262 000
90 th percentile	1 359 600	1 575 200	1 838 500	1 472 800
Union density among technical staff				
Mean	23%	33%	41%	27%
st.dev.	(36)	(39)	(43)	(38)
Market share				
Mean	2%	6%	19%	5%
st.dev.	(8)	(12)	(25)	(13)
Part of multi-plant firm				
Share	37%	47%	64%	42%
Plants founded before 1972				
Share	44%	64%	66%	52%
Number of plant-year observations	4 728	2 195	697	7 620

The numbers are based on all plant-year observations in the machinery and equipment industries included in the main sample, cf. Table A1. An R&D plant is a plant belonging to a firm that conducts some R&D within the plants three-digit ISIC industry. R&D man-years per employee and R&D sales ratio are measured at the three-digit line of business level within firms. Market share is measured at the five-digit line of business level for the firm that the plant belongs to. Capital per employee is rounded to the nearest 100.

[‡] 16 percent of the underlying employee observations have the job starting date censored at April 30th 1978.

Table A6. Aggregate growth from 1986 to 1995 and R&D intensity by sub-industries

ISIC	Number of plants			Number of observations			R&D intensity	
	1986	1995	Δ	1986	1995	Δ		
38210	Engines and turbines	9	11	2	939	856	-9 %	.03
38220	Agricultural machinery	52	33	-19	514	597	16 %	.04
38230	Metal and wood-working machinery	37	26	-11	200	183	-9 %	.04
38241	Oil and gas well machinery and tools	92	104	12	4709	8270	76 %	.02
32249	Other industrial machinery	73	104	31	607	878	45 %	.06
38250	Computers and office machinery	50	28	-22	1052	334	-68 %	.26
38291	Household machinery	11	8	-3	95	92	-3 %	.04
38292	Repair of machinery	709	458	-251	480	594	24 %	.11
38299	Other machinery	339	351	12	4132	3197	-23 %	.09
38310	Electric motors and eq. for el. production	139	153	14	2428	2010	-17 %	.07
38320	Radio, TV and communication apparatus	190	135	-55	3335	2858	-14 %	.17
38330	Electrical household appliances	32	20	12	251	187	-25 %	.12
38391	Insulated cables and wires	12	17	5	689	627	-9 %	.12
38399	Other electrical apparatus and equipment	124	100	-24	596	282	-53 %	.04
38411	Building of ships	163	188	-25	3738	4350	16 %	.01
38412	Building of boats	438	232	-206	535	400	-25 %	.04
38413	Ship and boat engines and motors	36	29	-7	557	353	-37 %	.04
38414	Components and fixtures for ships/boats	53	55	2	590	981	66 %	.02
38421	Railway and tramway equipment	1	1	0	136	178	31 %	-
38422	Repair of railway and tramway eq.	18	8	-10	1258	1015	-19 %	-
38430	Motor vehicles	174	80	-94	740	1207	63 %	.06
38440	Motor cycles and bicycles	1	2	1	114	77	-32 %	-
38450	Aircraft	28	20	-8	1167	1173	1 %	.01
38490	Other transport equipment	6	12	6	11	52	373 %	.02
38510	Professional and scientific instruments	57	109	52	306	749	145 %	.11
38520	Photographic and optical goods	10	8	-2	77	51	-34 %	.22
382-385	All machinery and equipment industries	2 854	2 292	-562	25 863	30 698	19%	.10

The number of plants is taken from the manufacturing census. The number of observations refers to the technical staff in the main sample, cf. Table A1. The growth in the technical staff does not imply that there has been employment growth in these industries, but is a result of old workers with primary education not included in the sample, gradually being replaced by workers with secondary education. R&D-intensity is the weighted average R&D man-years per employee, measured at the three-digit line of business level within firms, for the plants in the sample over the years 1986-1995.

Chapter 5

Spin-offs and spillovers: Tracing knowledge by following employees across firms *

by

Jarle Møen[‡]

ABSTRACT:

Most R&D projects fail from a commercial point of view, and technological shifts may quickly turn even successful innovations into failure. It is, however, possible that projects which fail commercially produce knowledge with some social value. Such knowledge is likely to be embodied in workers or teams of workers, and in order to evaluate the social returns to research, it is desirable to trace workers as they move across firms and industries. In this paper I utilize a large matched employer-employee data set and test for the existence of potential knowledge spillovers transmitted through the labor market. The specific case analysed is a series of Norwegian IT-programs so far considered unsuccessful, but which recently have been linked to the rise of a new generation of successful IT-firms. It has been argued that know-how and networks built up in leading companies during the programs still 'fertilize' the Norwegian IT-industry. I find little support for this claim. Workers with experience from companies that received R&D subsidies were largely re-employed in IT-industries, but they have not outperformed similar workers without such experience. An analysis of firms that are spin-offs from formerly subsidized IT-firms reveals that they perform below, rather than above average.

JEL classification: J24, J31, J62, O32

Keywords: R&D-subsidies, Knowledge spillovers, Human capital, Labor mobility, Displaced workers, Spin-off firms, IT-industry, Program evaluation, Matched employer-employee data

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1 Introduction

Most R&D projects fail from a commercial point of view¹, and technological shifts may quickly turn even successful innovations into failure. This reflects the high risk associated with research, but also that it is difficult to appropriate the returns to knowledge. For this reason it is possible that projects and firms that fail commercially still produce knowledge with some social value. This possibility seems particularly relevant for subsidized R&D, since subsidies are aimed at projects with high risk and large externalities. The substantial amount of money spent by OECD governments on R&D subsidies makes it important to test this hypothesis². A possible 'scrap value' associated with unsuccessful projects and firms may significantly influence the social returns to R&D and reduce the overall risk associated with technology programs³. This issue has so far not been investigated in the technology program evaluation literature, nor has there been much empirical analysis of labor market knowledge flows or spin-off firms in general.

This paper analyzes a series of Norwegian IT programs so far considered unsuccessful. Recently, however, it has been argued that knowledge built up in the subsidized firms has been transmitted to a new generation of successful firms through labor mobility. Using matched employer-employee data, I test this hypothesis. Scientists and engineers with experience from the subsidized IT-firms have to a much larger extent than other scientists and engineers in high-tech industries migrated to the rapidly growing IT service industry. There is no evidence, however, indicating that these scientists and engineers have played a particularly prominent role in the growth process. Nor do spin-off firms from the subsidized firms perform particularly well. One possible explanation for these discouraging results is that the technology shift in the late 1980s rendered much of the intellectual human capital built up under the programs obsolete.

The rest of this paper is organized as follows: The next section discuss labor market knowledge flows in more detail. Section three discuss the data, the empirical

¹Cf. e.g. Scherer and Harhoff (2000). Analyzing several samples of innovations they find that the top ten percent most valuable innovations capture from 48 to 93 percent of the total value.

²According to Guellec and Pottelsberghe (2000) the OECD average share of governments in the funding of R&D performed by private firms was 10 percent in 1998. The share of government funding in total R&D was 30 percent.

³Scherer and Harhoff (2000) find that the estimated distributions of the returns to innovations are so skewed that instability may extend to the level of a whole economy. The risk aspect seems particularly relevant for small economies. While a large country like the US can be fairly confident that it will host at least a few major successes like Microsoft, IBM or Intel, chance probably plays a large role when a small country like Finland becomes the host of a giant like Nokia. Furthermore, even if a small country succeed in breeding a major company, there is always the risk that the company will be wiped out by a future technology shock. The extent to which knowledge built up in high tech firms can be applied elsewhere in the economy and generate spin-offs, therefore, is particularly important for small countries spending money to subsidize commercial R&D.

approach and the definition of key variables. Section four gives a brief description of aggregate subsidies and growth in the Norwegian IT and high-tech industries, and analyzes the flow of scientists and engineers out of subsidized and non-subsidized firms. Section five analyze the value of experience from subsidized IT-firms using wage regressions on a sample of scientists and engineers with experience from high-tech and IT-industries. Section six analyze the performance of spin-off firms, while section seven concludes.

2 The importance of analyzing knowledge flows

Since research is a learning process, knowledge built up through failed projects and firms is likely to be embodied in workers or teams of workers. In order to assess the value of such knowledge, it is necessary to trace workers as they move across firms and industries seeking to maximize the returns to their human capital. Consider the early days of the semiconductor industry as an example of the potential importance of this approach. If evaluating the social returns to R&D contracts awarded pioneering firms such as Sprague Electric, Shockley or Fairchild based on the performance of these firms alone, it seems clear from historical accounts that the return would appear modest. Yet, it is well documented that key technologies later utilized in the semiconductor industry by tremendously successful companies like Intel, was developed in these early entrants and transferred by employees to new firms better suited to exploit the technologies commercially, see e.g. Holbrook et al. (2000), Jackson (1997) or Saxenian (1994).

The recent availability of large matched employer-employee data sets makes it possible to analyze statistically the importance of human capital and employee mobility suggested by such case studies⁴. Furthermore, tracing knowledge flows by following employees is not only relevant when firms fail. It can also be useful when analyzing particularly successful firms and technologies, since entrepreneurs often 'cash out' on their investments by selling their company to larger, established firms. In conventional, firm-level data sets, such companies disappear without there being any indication of what happened. This problem may be particularly important when evaluating programs targeted at start-up firms and small businesses⁵. Analysis of the opposite process, i.e. the formation of spin-off firms, is also facilitated within a framework where employees are followed over time and across firms. Employee mobility and spin-off firms are closely related phenomena. Again, consider the semiconductor industry as an example. According to Saxenian (1994, p. 31), writing about Silicon Valley,

⁴An alternative approach is illustrated by Almeida and Kogut (1999) analysing patenting and patent citation patterns among engineers that change employers.

⁵The Small Business Innovation Research (SBIR) program in the US would be an example of such a program, cf. e.g. Lerner (1999) and Wallsten (2000).

“Many of the region’s entrepreneurs and managers speak of Fairchild as an important managerial training ground. ... To this day a poster of the corporate genealogy of the scores of Fairchild spin-offs, hangs on the walls of many Silicon Valley firms.”

In the present paper, I illustrate how the ideas outlined above can be implemented and analyzed. Matched employer-employee data are used to ‘re-evaluate’ a series of Norwegian technology programs in the 1980s that subsidized IT manufacturing firms. A previous evaluation by Klette and Møen (1999) concluded that “the IT-programs were largely unsuccessful”. Recently, however, claims have been made that the growth of the Norwegian IT-industry in the late 1990s was stimulated by knowledge built up in formerly subsidized firms. In particular, employees of the fallen industry leader, Norsk Data, have been pointed to as key contributors in a new generation of successful firms. Norsk Data was a ‘national champion’ and a leading minicomputer company⁶. It was the second largest company on the Oslo Stock Exchange in the mid 1980s, but had considerable difficulties in adapting to the technology shift in the late 1980s represented by the introduction of PCs and open standards. In 1989 mass layoffs were unavoidable and in 1991 it closed down its manufacturing plants⁷.

One expression of the idea that Norsk Data had a lasting impact on the industry, can be found in a publication from the Research Council of Norway (2000) presenting IT (ICT⁸) firms and technologies that have benefitted from R&D subsidies. In the introduction the Council states that⁹

“[t]he bankruptcy in Norsk Data received much attention, and left the impression that the Norwegian ICT industry was severely injured. This was not the case. Know-how was embedded in the employees, and these employees were rather quickly absorbed by other Norwegian ICT-firms.”

It may not be very surprising that the Research Council in this way tries to improve upon the public impression of Norsk Data, given that the firm had received

⁶The company experienced a 40 percent average annual sales growth from 1973 to 1986, and 50 percent average annual growth in profits during the same period. It was considered the third most profitable computer company in the world, and the stocks were traded in Oslo, Stockholm, Frankfurt, London and New York. Cf. Steine (1992) and articles published in the business press for more information about the history of this company.

⁷What little was left of the company went bankrupt in 1993.

⁸I do not make any distinction between the concepts IT - information technology - and ICT - information and communication technologies. The latter abbreviation is of more recent origin, and its use seems to be associated with the growth of the IT service sector.

⁹In my translation.

massive subsidies¹⁰. A similar, but even stronger statement, however, was made by Norway's leading engineering magazine, *Teknisk Ukeblad*, one year earlier. In the fall of 1999, this bulletin of the Norwegian Engineering Association wanted to elect the 'engineering achievement of the century'¹¹. Second of ten nominees was Norsk Data. The magazine argued that this 'industrial adventure ... left behind a thousand professionals whose knowledge still fertilize Norwegian information technology'¹².

It seems that the statements quoted above are based on knowledge about a handful of cases. Both the Research Council and *Teknisk Ukeblad* mention e.g. Dolphin Interconnect Solutions, a company that came out of the R&D department in Norsk Data when it closed down. In 2000 a part of Dolphin was sold to Sun Microsystems and in the business press, the price was pictured as sensational. Such 'spin-off returns' from previous investments cannot be captured by ordinary microeconomic program evaluation methodologies which focus on the performance of the subsidized firms¹³. In order to evaluate whether Dolphin and similar cases are representative, a quantitative framework utilizing matched employer-employee data is called for.

3 Data and empirical approach

3.1 Data

The data used in this study come from four main sources: Governmental administrative records prepared by Statistics Norway, the biannual R&D survey conducted by the Royal Norwegian Council for Scientific and Industrial Research and Statistics Norway, the manufacturing statistics of Statistics Norway, and the statistics of accounts for non-financial joint-stock companies prepared by Creditinform and Statistics Norway. The Norwegian data are extraordinary in the sense that the en-

¹⁰Norsk Data was the largest recipient among firms subsidized by the National Program for Information Technology lasting from 1987 to 1990, and received more than 12 percent of the budget allocated to commercial R&D under the program. Given the size of the company, this does not necessarily imply that the subsidies were large relative to Norsk Data's private R&D investments, but money from the National Program for Information Technology came on top of subsidies from preceding programs and substantial public procurements which were used actively to help the company develop new technology throughout its history. Cf. Harlem et al. (1990) and Bjerkan and Nergård (1990).

¹¹Cf. Valmot (1999). A list of all nominees is given in the same journal (*Teknisk Ukeblad*), August 12th 1999, pp 10-11.

¹²My translation. Spelled out in more detail: "All over Norway we see spin-off effects from the Norsk Data era; thousands of people that worked in or with Norsk Data built up know-how whose existence it is hard to imagine without this company. Many of these people started new firms together with old colleagues or business contacts, others have contributed with their experience in other sectors of the economy." The article was titled "The lighthouse of the Norwegian IT-industry".

¹³Cf. Klette, Møen and Griliches (2000) for a review.

tire working population can be traced across employers over more than a decade, and in the sense that extremely rich information is available both about the workers and about their employers. The data appendix gives further details and descriptive statistics.

3.2 Hypothesis

The hypothesis under consideration is whether the boom in R&D subsidies and R&D investments in the Norwegian IT manufacturing industry in the mid and late 1980s, later caused growth in this or other sectors of the economy. Establishing such a causal link is demanding and involves constructing a counterfactual situation for the firms and workers involved.

Compared to the standard program evaluation literature, cf. e.g. Heckman, Lalonde and Smith (1999), several complications are present. First, the ‘treatment’ is not dichotomous. R&D investments have both an intensity dimension and a time dimension. Moreover, there is no clear-cut start of the program as various technology programs have replaced each other for several decades prior to the period that can be observed¹⁴. Also, the selection problem, fundamental to all program evaluation where participation is not randomized, has a peculiar twist. There is a ‘double selection’ process where firms are selected into programs, and workers self-select into firms. Deciding on a relevant and valid comparison group under these circumstances is difficult.

My responses to the problems listed above will be as follows: First, with respect to the intensity and time dimension of treatment, I will use a regression framework so that continuous variables can be utilized in addition to a dichotomous classification, based on cut-off values. Next, with respect to missing data for previous programs, little can be done. I will, however, argue below that this is not a severe obstacle. Finally, my response to the potential selection problem will be to allow for individual fixed effects. A more explicit approach to the selection problem does not seem necessary. Negative selection is not particularly relevant since R&D programs are meant to stimulate high quality research¹⁵, and positive selection creates a bias against my conclusion that the programs were not successful.

3.3 How to define ‘treatment’

Defining high-tech, R&D firms and IT R&D-firms Treatment, in the context of this paper, is having experience from a subsidized R&D firm in the IT

¹⁴Cf. Klette and Møen (1999) for details.

¹⁵This is not to say that negative selection could not exist. Various political economy processes may lead the subsidies to troubled firms, cf. Klette and Møen (1999) for a discussion. Then, however, the programs would not look successful, nor be successful.

manufacturing industry. In principle, therefore, we would like to compare similar workers with experience from IT-firms with and without subsidies. However, it is difficult to define an IT-industry since information technology does not constitute a separate class in standard industrial classification schemes¹⁶. Too narrow a set of classes will leave out a lot of true IT-firms, whereas a broader set will include a lot of non-IT firms. I get around this problem by utilizing a unique variable in the R&D surveys which identify the IT-content in each firm's R&D investments. Using this variable in combination with R&D man-years, I define IT R&D-firms in the manufacturing sector as firms with an intensity¹⁷ of IT-related R&D above 10 percent¹⁸. This definition is designed to exclude a large number of firms that perform small IT projects without having information technology as their main focus or being technologically advanced. Almost without exception, units classified as IT R&D-firms according to this criteria belong to ISIC 382-385, i.e. the machinery, electronics, transportation equipment and technical instruments industries¹⁹. I will hereafter refer to these industries together as 'high-tech'. Out of 1173 plants (constituting 957 firms) with known R&D in the high-tech industries in the period 1986 to 1991, 197 plants belong to 'R&D firms' having an intensity of total R&D²⁰ above 10 percent. Out of these, 108 belong to 'IT R&D-firms', i.e. firms having an intensity of IT-related R&D above 10 percent. There are on average 4.0 observations of each plant in the years 1986 to 1990²¹.

Defining subsidized firms Since subsidies are awarded unevenly among recipients, there is also a problem of how to define a subsidized IT R&D-firm (hereafter referred to as a subsidized firm). For a subsidy to have an effect on a firm's research activities, it must be of some significance. Hence, any subsidy should not qualify, and I define the treatment group as IT R&D-firms with an intensity of subsidized IT-related R&D above 0.5 percent. For a treatment firm with an intensity of IT-related R&D at the lower limit, i.e. 10 percent, this implies that at least 5 percent of the firm's IT-R&D must be subsidized²². The criteria is designed so that all large

¹⁶Cf. e.g. OECD (2000). The Norwegian industrial classification scheme was based on ISIC rev. 2 until 1993/94. Since then NACE rev. 1 (ISIC rev. 3) has been used.

¹⁷R&D intensity is measured as R&D man-years per employee (per year) at the three-digit line of business level within firms. Cf. the data appendix for more information. In the text, I will not distinguish between firms and lines of business within firms.

¹⁸These variables are not available, nor as relevant, for the IT service sector. This sector will be defined using the OECD definition based on industrial classification codes.

¹⁹The equivalent NACE classifications are NACE 29-35.

²⁰The sum of IT and non-IT R&D.

²¹Note that firms, and thereby plants, can change category between years. When giving the number of plants in different categories above, plants are counted as belonging to an R&D firm or IT R&D firm if it has this status in at least one of the years 1986-1991.

²²I know for each firm the share of R&D that is classified as IT, but not the share of subsidies used in IT-projects. However, since the government had IT high on its agenda, I assume that R&D-

subsidy recipients known from other sources, that can be identified in the data, are included²³. Out of 108 plants belonging to IT R&D-firms in the period 1986 to 1990, 79 belong to subsidized firms.

Defining the treatment period Data on individual workers start in 1986, and the era of large R&D subsidies ended in 1990, cf. Figure 1 below. Hence, I will consider the years 1986 to 1990 to be the ‘treatment period’. As mentioned, there were targeted IT-programs prior to 1986, but I do not believe the lack of data from these early years is a severe restriction. The largest R&D subsidy program were in effect from 1987 to 1990, and the largest IT R&D contracts were awarded in the years 1985 to 1987²⁴. Furthermore, with some stability in employment relationships, a certain persistence in program participation, and both a lag and some persistence in the effect of subsidies, there will be a positive correlation between the unobserved and the observed treatment. It is, however, somewhat unfortunate that workers cannot be observed in a pre-treatment period, so that a clean comparison of pre and post treatment wages can be undertaken as part of the program evaluation.

Categorizing workers I want to assess the value of the core technological know-how built up in the subsidized firms. This know-how is likely to be possessed by scientists and engineers, and my analysis will therefore focus on this group. With the treatment period lasting from 1986 to 1990, many scientists and engineers will have had several employers, and firms may also have changed subsidy status within this time interval. I categorize scientists and engineers as having ‘experience from subsidized firms’ if they are attached to a subsidized firm in at least one year. Similarly scientists and engineers are categorized as having ‘experience from IT R&D-firms’ and ‘experience from R&D-firms’ if they have at least one year experience from such firms in 1986 to 1990.

Using these definitions, there are 1755 scientists and engineers with experience from R&D-firms. Out of these 1290 have experience from IT-R&D firms. In this group 1095 have experience from subsidized firms. About a quarter of the workers in subsidized firms were employed by the industry leader, Norsk Data. The numbers are based on a sample of male scientists and engineers born after 1935 and employed

subsidies awarded firms that report to do IT R&D is related to their IT-projects. If subsidies exceed a firm’s IT R&D-investments, the excess subsidies are excluded.

²³The ten largest recipients received 35 percent of the funds. These firms were producing electronic products, telecommunication equipment, instruments and computers. According to Harlem et al. (1990), the ten largest recipients were Norsk Data, Autodisplay, EB Nera, Nordic VLSI, EB, LCD Vision, Seatex, Micron, Simrad Subsea and Alcatel/STK. The order reflects the size of the funding.

²⁴The implementation and organization of the National Program for Information Technology is extensively documented in Harlem et al. (1990) and Buland (1996).

full time in a high-tech firm at least one of the years 1986 to 1990²⁵. Altogether there are 3784 scientists and engineers in the sample. 3419 of these are in firms with known R&D-investments.

Continuous treatment variables The firm categories defined above are based on cut-off values for R&D intensities that are somewhat arbitrary, and that conceal a significant amount of variation in research and ‘program’ exposure. The intensity of R&D and subsidies varied between firms within each category, and within firms over time. Furthermore, workers may have stayed with several employers during the program years. In many of the analyses that follow it is possible to use such continuous variation in treatment, and therefore I construct a stock measure of experience in addition to the dummies. This is done by attaching to each worker information about his employers R&D investments, and adding up intensities in R&D, IT R&D and subsidized IT R&D over the years 1986 to 1991. I use these sums as measures of the human capital accumulated²⁶.

3.4 A description of workers and firms by treatment category

Descriptive statistics on workers and firms are given in the data appendix. IT R&D firms are concentrated in the following industries: Computer and office machinery, Other machinery, Radio, TV and communication equipment, Insulated cables and wires, Professional and scientific instruments, and Photographic and optical goods. Except for computers, non of these industries are dominated by IT R&D firms, however. Subsidized and non-subsidized IT R&D-firms coexist in all industries mentioned except in production of insulated cables and wires, where all workers belong to subsidized firms. Other R&D firms and non-R&D firms are represented in a wider set of subindustries than the IT R&D firms. These industries comprise the production of various types of machinery, electrical equipment and transport equipment²⁷.

An important thing to notice is that the larger part of the IT-industry received subsidies. There are 1095 scientists and engineers with at least one year of experience

²⁵I have excluded women because they are known to have different career patterns and preferences than men, and do not constitute a large share of the labor stock in these industries.

²⁶Since the intensities are measured in man-years per employee per year, the unit of the ‘experience stocks’ are years. This should not be interpreted literally, however. It will only be a precise measure of individual R&D experience if all workers participate equally in the firms’ R&D projects. This is obviously not the case, and one should rather think of R&D intensities as proxies for how much there is to learn in a firm at a given time. Summing the intensities over the time dimension then gives a measure of on-the-job learning.

²⁷About 82 percent of the worker-year observations are from firms with R&D information available. Out of the 26 subindustries listed, 19 have some IT R&D investments.

from subsidized IT-firms and 195 that only have IT experience from non-subsidized firms. Given that the authorities were determined to stimulate the IT-industry, this is perhaps not surprising, but it leaves a relatively small, and possibly non-random, control group. That being said, however, there are relatively few observable differences between workers in subsidized and non-subsidized IT R&D-firms. Scientists and engineers in non-subsidized IT R&D-firms are slightly younger, but appear otherwise similar to their colleagues in subsidized firms. Furthermore, my analysis is not dependent on this dichotomous classification, as I also utilize continuous experience variables as explained above²⁸.

Subsidized firms are somewhat larger, more unionized and more likely to have a rural location than non-subsidized firms. They are also more often foreign owned and younger. The most interesting difference, however, is that subsidized firms had significantly higher growth rates in the years preceding the awarded subsidies. Presumably, recent success must have been an important criteria when subsidies were awarded. With respect to intensity in R&D and IT-R&D the two group of firms are close to identical. 'Other R&D firms' are somewhat less R&D intensive than IT R&D-firms and have a slightly lower educational level, but they are on the other hand more capital intensive. Non-R&D-firms have an even lower educational level than R&D-firms and are more unionized and less often foreign owned. Non-R&D firms are clearly the oldest group of firms.

With respect to educational composition, subsidized firms are slightly more diversified with respect to the human capital they possess than non-subsidized firms. All R&D-firms, however, even non-IT firms, are highly intensive in various types of electrotechnical engineering skills. Non-R&D firms also employ many workers of this type, but mechanical engineers is the most dominant skill group in these firms.

Summing up the differences between subsidized and non-subsidized IT R&D-firms, the main impression left by the descriptive statistics is that workers in subsidized and non-subsidized firms are quite similar, although there are some differences between the two types of firms. In particular, the technology programs seem to have favored firms with rapid growth.

²⁸This creates substantial variation, as subsidies were very unevenly distributed across firms. This was part of a long tradition where 'national champions' were considered important catalysts for growth.

4 A closer look at investments, performance and labor mobility

4.1 Industry investments and growth

In the mid 1980s, the Norwegian economy was booming. At the same time, a large number of firms received R&D subsidies from public technology programs. Also, significant IT-related R&D contracts were given to the defence industry, and in connection with the restructuring and modernization of the public telephone company. The upper graph in Figure 1 shows total R&D investments in the high-tech industries, i.e. ISIC 382-385 in the years 1984 to 1997. The middle graph shows the share of these investments that were labelled information technology by the firms. The lower graph shows the share of the IT investments that was subsidized. The three graphs display a very similar pattern, with strong growth until 1987, and then a decline until 1991. Several developments are behind these movements. First, after the general expansion in the mid 1980s, the economy went into a downturn lasting from 1988 to 1993. Next, as mentioned in the introduction, the leading technology firm, Norsk Data, ran into trouble in the late 1980s and went out of business in 1991. Finally, the technology programs and large R&D-contracts came to an end.

An interesting feature in Figure 1 is that R&D investments in IT did not pick up in parallel with the increase in total R&D investments when the economy started to recover. This may be interpreted as an indication that the technology programs did not produce a basis for new growth, at least not within the manufacturing sector.

The development of the subsidized firms is more clearly drawn out in Figure 2, comparing employment growth in subsidized firms with employment growth in other categories of high-tech firms. There is a strong decline in employment in subsidized firms²⁹. Given this picture, the dismal conclusion of Klette and Møen (1999)³⁰, evaluating the technology programs based on firm level data, are not surprising. However, as discussed above and suggested by the quotes in the introduction, this interpretation may be misleading. A more positive way to read Figure 2 is to stress that workers were leaving the subsidized firms on a large scale, and that they may have contributed to growth elsewhere.

Figure 3 pictures the growth in the Norwegian IT industry, as defined by OECD,

²⁹Employment in non-subsidized R&D firms and other R&D firms appears to fluctuate more than the other two categories simply because there are fewer workers behind these graphs. The strong decline in employment for non-subsidized IT R&D firms from 1992 to 1993 is driven by one single firm that ran into trouble. Much of the subsequent growth is due to the same firm recovering. The negative employment growth in subsidized IT R&D firms is not driven by Norsk Data alone. Leaving out this company does not alter the picture significantly. Furthermore, looking at sales growth gives a very similar picture, but then I am not able to keep track of plants which change industry classification from manufacturing to services.

³⁰Cf. the introduction.

from 1995 to 1999. In these years the IT service industry grew considerably faster than the rest of the private sector. As suggested by the Research Council, workers from previously subsidized manufacturing firms may have played a role in this process.

4.2 Tracing workers out of the subsidized firms

A natural first step when analyzing R&D-spillovers brought about by labor mobility, is to see where the technical expertise in the subsidized firms became employed later on. The results of such an analysis are presented in Table 1. The first column shows the industry of occupation in 1997 for scientists and engineers with experience from subsidized firms. The main comparison group is scientists and engineers with experience from IT R&D-firms that were not subsidized. These are tabulated in column 2. Columns 3 and 4 give mobility patterns for scientists and engineers with experience from other R&D-firms in the high-tech industries, i.e. firms whose research activities were not strongly IT-related, and scientists and engineers without experience from R&D-intensive firms.

The main difference between subsidized and non-subsidized IT R&D-firms is that a much higher share of scientists and engineers from the subsidized firms has moved to IT-service industries³¹. 30 percent of scientists and engineers from subsidized IT-firms became employed in the IT-service industry³² versus 14 percent of scientists and engineers with experience from non-subsidized IT-firms. The other columns show that the less IT and R&D intensive the firms, the less likely are the scientists and engineers to move to the IT service sector. The table suggests that the subsidized IT-activities were service related, or at least that the IT-service industry offered the best opportunities for scientists and engineers from subsidized firms when these firms closed down.

³¹IT service industries are defined according to OECD and with a few further refinements added by Statistics Norway, cf. Statistics Denmark (2000). Included sub-industries are Wholesale of radio and television goods (NACE 51433), Wholesale of office machinery and equipment (NACE 5164), Wholesale of machinery and equipment for trade, transport and services (NACE 51654), Telecommunications (NACE 642), Renting of office machinery and equipment including computers (NACE 7133), Hardware consultancy (NACE 721), Software consultancy and supply (NACE 722), Data processing (NACE 723), Database activities (NACE 724), Maintenance and repair of office, accounting and computer machinery (NACE 725), and Other computer related activities (NACE 726). Corresponding ISIC codes are 61131, 61235, 7202, part of 833 and all of 8323 which correspond to NACE 72.

³²Looking separately at workers from Norsk Data, the share is as high as 46 percent.

4.3 A brief summary of some ‘non-wage’ labor market outcomes

The main message to take away from Table 1, is that *the possibility* of a link between R&D subsidies awarded in the 1980s and growth in the IT-service sector in the 1990s, is present in the data. Next, I investigate how workers from the subsidized firms actually performed in the labor market. Were e.g. workers from the subsidized firms “rather quickly absorbed” in the labor market, as claimed by the Research Council?³³. Some indicators that can throw light on this issue are reported in Table 2. Row 1 reports the share of displaced workers³⁴ that did not become re-employed in the same municipality³⁵. Row 2 reports the share of workers who participated in active labor market programs. Row 3 reports the average employment rate following the program³⁶, row 4 reports the share of workers who took further education and finally row 5 reports the share of workers that became self-employed³⁷. Taken together, the results do not suggest that workers from subsidized firms had any particular difficulties in finding new jobs. Having established this, I will move on to analyze earnings.

5 Wage regression analyses

If know-how built up in the subsidized firms was not firm-specific and thus provided a basis for growth in other firms later on, we would expect experience from subsidized firms to have higher value in the labor market than experience from other firms. This assertion can be tested using extended Mincer (1974) wage regressions. Lacking a ‘pre treatment’ period, I start out exploring scientists and engineers’ wage level during the program. Next, I investigate wage growth following the program and check the results obtained from these two analyses against the wage levels after the program. Given that know-how built up in the industry leader Norsk Data has been considered particularly valuable, and that about one quarter of all scientists and

³³Cf. quoted in the introduction.

³⁴I have defined a displaced worker as a worker with at least two years tenure who separated from a plant that downsized at least 25 percent in that year or over that year and next year.

³⁵Note that what is measured is a change in their home address municipality, not merely a change in municipality of employment. The low number for workers from non-subsidized IT R&D firms is due to one large firm that went through a mass lay-off, and then rehired many of the workers, cf. the ‘dip’ for employment in non-subsidized IT R&D firms in Figure 2.

³⁶Those not employed include everyone who are not employed and not under education, regardless of whether they are registered as unemployed or not. Part time workers are counted as part time unemployed.

³⁷These numbers may be artificially low. Presumably, they do not include workers who are employed in joint-stock companies that they own themselves. Self-employed are included in the wage analyses presented in the next section.

engineers with experience from subsidized firms have worked for this company, I investigate the robustness of all results with respect to leaving out these workers³⁸.

5.1 The effect of R&D and subsidies on wages during the program

Several mechanisms related to R&D, IT and subsidies may possibly have affected wages during the program period. First and foremost, if scientists and engineers expected to accumulate more general knowledge in subsidized firms (or in IT firms in general) than in other firms, they should be willing to pay for this through lower wages³⁹. To the extent that subsidized firms promoted more advanced technologies, and technologies considered to have a large future potential, such investments in general human capital are conceivable, although risk aversion and liquidity constraints may reduce the effect. Another mechanism, possibly affecting the wages, is that subsidized firms may have employed scientists and engineers of better (unobserved) quality. High-ability workers are necessary to develop frontier technologies, but high-ability workers may also have a preference for working in a technologically advanced environment⁴⁰. The net effect of this on wages is not obvious. On one hand, high-ability workers have better outside options, but workers with a preference for technologically advanced firms may, on the other hand, accept wages below their outside option⁴¹. A final possible mechanism is unions. The wage level in subsidized firms would be affected if the workers were able to negotiate higher wages and thereby extract some of the subsidies as rents.

Table 3 explores the wage level for prime aged male scientists and engineers in high-tech industries in the program years by including measures of R&D, IT R&D and subsidized IT R&D in a standard wage regressions. Both a dummy variable approach (column 1 and 3) and a specification with continuous variables (column 2 and 4) are reported. The dummy approach utilizes the dummies for R&D firm, IT R&D firm and subsidized IT R&D firm described in section 2. Note that these dummies are nested in the sense that a subsidized firm is also an IT R&D firm which is also an R&D firm. In specifications with continuous variables, I use intensities

³⁸This procedure is intended to avoid a detailed and explicit wage analysis of this single company and its employees.

³⁹This follows from classical human capital theory, cf. Becker (1962, 1964) and the discussion in Møen (2001).

⁴⁰The work of Almeida and Kogut (1999), Stern (1999) and others suggests that scientists and technical personnel have preferences regarding the technological environment they work in.

⁴¹Rosen (1986) provides a review of the theory of compensated differentials (equalizing differences). Stern (1999) shows that this mechanism has relevance for scientists in the private sector. This is, in the setting of my paper, supported by Steine (1992) who states that the company policy of Norsk Data was to pay the same as similar firms, or somewhat less. He adds, “[i]t was attractive to work in Norsk Data. so why be a wage leader?” (p. 50, my translation).

measured as the share of the work force doing R&D, IT R&D and subsidized IT R&D. These variables are also nested, so that in order to find the total effect of a marginal increase in IT R&D due to a subsidized project, all three of the reported coefficients should be added.

In all regressions, workers in non-R&D firms is the baseline comparison group. Non-reported control variables are listed in the subtext to the table. Among these variables are 15 dummies for different academic degrees, hence, scientists and engineers are compared within detailed educational groups.

In Table 3, column 1 and 2, I do not distinguish between subsidized and non-subsidized IT R&D, and from Part A of the table, using the full sample, we see that the wage level in IT R&D firms is significantly below the wage level in other R&D firms. The average discount is between 2 and 3 percent. Non-IT R&D, however, does not seem to affect wages. When distinguishing between subsidized and non-subsidized IT R&D, a puzzling pattern appears. The dummy approach suggests that the lower wage level is associated with work in subsidized firms while the specification with continuous variables suggests that the lower wage level is associated with work in non-subsidized firms.

A clue as to how these conflicting results can be reconciled can be found in Part B of the table where workers from Norsk Data are excluded. Column 1 and 2, suggest that the observed lower wage level in IT R&D firms is driven mainly by workers in Norsk Data. If Norsk Data received enough IT subsidies per worker to be classified as a subsidized firm, but had, relative to other firms, far higher total investments in IT R&D per worker, this may explain the observed coefficients in Part A, column 3 and 4. This is not inconceivable. When sources like Bjerkan and Nergård (1990) describe Norsk Data as a thoroughly subsidized company, they are not so concerned with direct R&D subsidies as with preferential public procurement, and Norsk Data is in this respect a special case⁴². The company is also special in a different respect relevant for my analysis. The company was famous for rewarding their employees with shares, something that received much attention in the business press. The discount that the employees received when buying shares was counted as taxable labor income and is therefore included in my wage measure⁴³, but the stock market price of the shares increased so rapidly and for so many consecutive years, that the employees were likely to value the opportunity to buy shares in the company highly and trade this off against ordinary wage compensation. Hence, some (but probably not all, cf. footnote 41) of the apparent discount associated with Norsk Data may be an artifact of the company's unusual compensation scheme and not a true compensating differential⁴⁴.

⁴²Cf. footnote 10.

⁴³Cf. Steine (1992, p. 54-55).

⁴⁴As far as I know, this wage policy was unique for Norsk Data at the time, as were their consistently rising stock price. I should also mention that stock options were not much used in

Looking at Table 3B, column 3 and 4, we see that even when workers from Norsk Data are excluded, there is to be a wage discount associated with workers in subsidized firms. Both the dummy specification and the intensity specification suggest that the discount is slightly less than 2 percent compared to non-subsidized IT R&D firms, although only the intensity specification produces a significant coefficient⁴⁵. Above I have mentioned several mechanisms that may be behind this. In order to distinguish between some of these possible mechanisms, the analysis in Table 4 can be extended by interacting R&D variables with experience, thereby examining wage profiles rather than average wage levels. If the wage discount in subsidized firms is due to workers investing in general human capital, one would expect it to be associated with young workers taking a wage cut when entering the firms and then experiencing stronger wage growth as their expectations about the value of on-the-job training become fulfilled⁴⁶.

Table 4 gives the results of including R&D, IT R&D and subsidized IT R&D, interacted with workers' experience. In column 1 and 2, we see that scientists and engineers have a steeper wage profile in IT R&D firms than in other firms. Consistent with the idea that IT is a general technology, cf. e.g. Bresnahan and Trajtenberg (1995), these firms appear to offer lower wages early in the career in exchange for higher wage growth thereafter. The beginning wages in IT R&D-firms are about 10 percent lower than in other R&D firms, and the annual wage growth is about 0.5 percent higher⁴⁷. Interestingly, there are no significant differences between R&D firms that don't specialize in IT and non-R&D firms.

Moving on to column 3 and 4, distinguishing between subsidized and non-subsidized IT R&D firms, one finds that the average wage discount associated with subsidies in Table 4 is due to the wage profile in subsidized firms being less steep

the sample years. Due to a very unfavourable tax treatment between 1991 and 1999, it was not much used in later years, either. For these reasons, I believe that labor earnings is a fairly accurate measure of monetary compensation in other companies than Norsk Data.

⁴⁵For the intensity specification, the discount is derived by multiplying the coefficient -0.488 with 0.036, the employers' average intensity in subsidized IT R&D, from table A2.

⁴⁶Workers may also pay for learning through lower wages later in their career, but that will be difficult to separate from the wage premia they receive on their previous human capital investments, cf. footnote 47 and Møen (2001). From a theoretical point of view, their willingness to invest in human capital should fall gradually towards retirement.

⁴⁷The dummy and the intensity specification give very similar results. Taking into account the special wage policy of Norsk Data discussed above, and looking instead at part B, it may seem as if 10 percent is rather on the big side. If the correct wage discount for entering workers is between 6 and 7 percent, and the wage growth between 0.4 and 0.5 percent, as suggested in Part B, this imply a pay-back period of about 15 years. Notice also that the firms' IT R&D-intensity times experience is used as a proxy both for how much the workers are learning, and how much they have learned on the job, cf. Møen (2001). IT R&D-intensity is a noisy variable, and as a proxy for human capital, it probably becomes increasingly noisy the further into the career a worker has reached. This implies that measurement errors may severely bias the coefficient on the interaction term towards zero.

than the wage profile in non-subsidized firms. Hence, there is nothing in the data suggesting that investments in general human capital were particularly large for workers in subsidized firms.

5.2 The effect of experience from subsidized firms on wages later in the career

Table 5 contains the results of an analysis of the effect of experience from R&D, IT R&D and subsidized IT R&D-firms on ten year wage growth from 1986 and 1987 to 1996 and 1997. The advantage of looking at wage growth is that potential differences in ability and preferences between workers are accounted for, and looking at the full ten year interval takes one from one boom in the economy to the next. This is desirable, since it may be difficult to capture the full program effect before the labor market has adjusted to the many mass layoffs caused by the recession.

The sample consists of full time working male scientists and engineers, having at least one year full time experience from high-tech or IT industries, including services, in 1986-1997⁴⁸. Workers without experience from manufacturing, and hence not part of the previous analysis, are included for two reasons. First, it has some interest to compare workers entering the expanding IT service industries with background from manufacturing high-tech industries to workers who have acquired most of their work experience within the IT-service industries⁴⁹. Second, these workers help identify the many control variables in the wage regression, such as experience and dummies for industries, altogether 72 coefficients⁵⁰. Given the relatively small number of workers with experience from non-subsidized IT firms, it is important to identify common coefficients as precisely as possible⁵¹.

At first sight, the results in Table 5A, column 1 and 2, seem to imply that workers in IT R&D firms have had significantly higher wage growth than other workers. Looking, however, at column 3 and 4, and Part B, we see a pattern very similar to the one found in Table 3 and discussed in detail above. This suggests that the

⁴⁸The sample industries are high-tech and IT, defined as NACE 29-35, 51433, 5164, 51654, 642, 7133 and 72. Cf. footnote 31 for more information.

⁴⁹As it turns out, there does not seem to be any important differences between these groups, and I have not tabulated separate coefficients for workers that only have experience from IT service industries. On average, these workers seem to receive slightly lower wages than workers with experience from high-tech manufacturing.

⁵⁰The industry dummies do not follow a particular NACE or ISIC level. Within high-tech and IT-industries I use a detailed categorization, usually at the five digit level. In less advanced sectors, with fewer observations in the sample, the dummies are usually at the two or three digit level. Cf. the subtext to Table 5 for a full list of control variables and other details regarding the regression.

⁵¹The assumption that there is a common experience profile, common industry effects and so on, is of course not obvious, but it seems to be a reasonable approximation. Furthermore, my conclusions are robust to reducing the sample size by excluding workers without experience from firms that have invested in IT R&D.

significant growth results are driven by a possible mismeasurement of compensation for workers in Norsk Data in the beginning of the period. When excluding these workers, there is only a small and non-significant wage growth effect left, i.e. workers with experience from IT R&D-firms have a slightly higher wage growth than workers with experience from other firms, and workers with experience from subsidized IT R&D-firms have a slightly higher wage growth than workers with experience from non-subsidized IT R&D-firms, without any of these differences being significantly different from zero.

Table 6 reports the results of an analysis of the effect of experience from R&D, IT R&D and subsidized IT R&D-firms in the program years on wages in the years 1996 and 1997. Consistent with tables 3 and 5, the results show that there are no significant differences related to these various types of experience. In particular, workers with experience from subsidized firms, started out with a small but significant (using the intensity specification) average wage discount, and had slightly higher, but not significantly higher, wage growth, and they have ended up with a slightly lower, although not significantly lower, wage level as reported in Table 6⁵².

Changing the specification in Table 6 by including firm specific fixed effects, and thereby asking whether workers with experience from subsidized firms have ended up in the best paid positions within their firms, give very similar results to the specification without firm specific fixed effects and is not reported. With respect to workers with experience from Norsk Data, a detailed investigation of Table 6, contrasting Part A with Part B in light of the previous discussion of subsidies and IT R&D investments in this company, suggests that these workers have wages below the average for other workers with experience from subsidized firms⁵³.

Before concluding the wage analysis, one should reflect on how the results in Table 5 and 6 relates to Table 4 which indicated that workers in IT R&D-firms, whether subsidized or not, accepted a wage discount at the start of their career and experienced higher wage growth later on. If the estimated wage growth associated with a career in IT R&D firms had continued after the program period, it obviously should have caused a significant positive coefficient on experience from IT R&D firms both in Table 5 and 6⁵⁴. When there is no such positive effect, it implies that these workers did not receive the return they expected. One possible interpretation is that their expectations did not come through because of the technology shifts in

⁵²If including the years 1994 and 1995 in addition to 1996 and 1997, the coefficient on experience from subsidized firms in column 4 becomes marginally significant.

⁵³If running a similar regression for skilled workers with secondary technical education, however, I find a significant positive wage premium for workers with experience from Norsk Data. This may suggest that scientists and engineers accumulate more firm specific human capital, and is more exposed to technological risk than workers with secondary technical education.

⁵⁴In Table 6 this is so because the average worker with experience from IT R&D-firms, even if continuing to invest in on-the-job training by staying in such a firm, should have caught up with and passed workers without such experience by 1996/97.

the IT-industry in the late 1980s.

Tables 3 through 6, can be summarized in one sentence: *Scientists and engineers with experience from subsidized IT R&D-firms performed exactly as good, or rather as bad, as workers from non-subsidized firms.* Workers in all IT R&D firms seem to have ‘co-financed’ their employers’ R&D investments by accepting wages below their alternative wage, presumably believing that work experience from these firms would provide general human capital. The expected wage growth, however, did not materialize after the program period, leaving them no return on their investment. With respect to workers in subsidized firms, they do not seem to have gained anything from participating in the subsidized projects. Consequently, *my analysis does not support the idea that the IT R&D programs created significant benefits for workers with experience from subsidized firms.* On the positive side, however, workers in subsidized firms did not perform particularly bad, either, even though many of them became displaced in the late 1980s as shown in Figure 2⁵⁵.

6 The performance of spin-off firms

A complementary approach to looking at the performance of individual workers, is to focus on the performance of spin-off firms defined by groups of workers that have stayed together. When several workers from the same firm continue to work together, it is reasonable to assume that they are exploiting know-how built up in their previous work environment, and that there are positive complementarities between them that make them stay together. It is also possible that firm profits is a better performance measure than wages, particularly if the spin-off firms to some extent are worker-owned. Low tax rate on capital income relative to labor income may induce employee-owners to substitute wages for return on stocks⁵⁶, and employee-owners may also sacrifice wages in order to finance firm growth⁵⁷.

6.1 Sample and definition of spin-offs

Tables 7 and 8 present the results of my analysis of spin-off firms. Roughly speaking, i.e. leaving out some of the finer details to be laid out below, I define *a spin-off firm*

⁵⁵Note that I control for displacement in the wage regressions in Table 5 and 6, but the variable is not significantly different from zero. Distinguishing, however, between workers with experience from subsidized firms who have stayed with the same firm, and separators, I find a modest negative effect for separators (not reported). In the stock specification this negative effect is significant.

⁵⁶Note, however, that the Norwegian tax system have detailed rules in order to avoid this type of tax evasion.

⁵⁷One may also think that employee stock options plans would reduce the relevance of taxable labor income as an earnings measure, and show up in firm profits. This kind of options, however, has been very unusual in Norway due to an unfavorable tax regime, cf. footnote 44.

as a firm that was not originally subsidized, but where at least 25 percent of the employees have experience from a firm that was subsidized.

The sample period is 1994-1997, i.e. the years when the IT industry recovered according to Figure 3. The sample consists of all non-financial joint-stock companies with more than one employee and at least one scientist or engineer, in industries with at least one 'program firm', i.e. a firm that to a large extent draw on human capital with experience from subsidized IT R&D firms. Formally, I define program firms as firms that have, at some point, had at least a 25 percent share of employees with experience from subsidized firms, and at least one scientist or engineer with experience from a subsidized firm. Any definition of this type will necessarily be a bit arbitrary, but the idea is to identify firms that draw significantly on knowledge that was built up under the program.

The definition of program firms does not distinguish between continuing subsidized firms that has retained experienced workers, and new firms, spin-offs, employing workers with experience from subsidized firms. This is because I want to start out by tracing all firms drawing on 'program know-how'. Utilizing information about plants, however, I can identify those of the program firms that represent a continuation of originally subsidized firms⁵⁸. I label these 'continuing or reorganized subsidized firms'. This group of firms is defined as program firms that contain one or more plant that in 1986-1990 belonged to a subsidized firm. Program firms that do not fall into this category are defined as spin-off firms. According to the above definitions, there are altogether 109 program firms in the sample, 76 of these are spin-off firms and 33 are continuing or reorganized subsidized firms.

6.2 Descriptive statistics and results

Program firms are somewhat larger, more capital intensive, more R&D intensive, and more intensive in use of scientists and engineers, than non-program firms, cf. the data appendix. They are also somewhat younger and less often in a rural location. Spin-off firms are significantly younger and smaller than continuing or reorganized subsidized firms, as one would expect. Spin-offs are also less R&D-intensive, but more human capital intensive. This reflect that a larger fraction of the spin-off firms belong to service industries. 37 percent of the spin-off firms can be identified as spin-offs from Norsk Data.

The first performance measure I consider is simply sales growth. The results are reported in Table 7. Spin-off firms perform slightly better than other firms along this

⁵⁸Firm identification numbers represent legal units, and will change if one firm or plant is bought by another firm, etc. Plant identification numbers, on the other hand, will change only if the production is physically moved or substantially altered with respect to industry classification. Not all registers that are matched to produce my data set, however, use the same plant and firm identification number system. For this reason the match between plants and firms, and the tracking of units over time, is slightly imperfect.

dimension, but the difference is not significant. Moving on to profitability, Table 8 presents return on sales, return on assets and return on equity. It shows that program firms are significantly *less* profitable than other firms. On average they have 1.2 percent lower return on sales, 3.2 percent lower return on assets and 15.5 percent lower return on equity.

Looking separately at spin-offs and continuing or reorganized subsidized firms, we see that the significant negative results are exclusively associated with the spin-off firms. It is difficult to explain these coefficients, but one possibility is that the spin-off firms mostly consist of troubled remnants of previously subsidized units, and that they are kept running because their core know-how has low alternative value⁵⁹. Analyzing wages in spin-off firms (not reported), I find some support for this hypothesis. Scientists and engineers with experience from subsidized firms that work in spin-off firms, have a small wage discount. Workers with experience from subsidized firms that work in continuing or reorganized subsidized firms, on the other hand, have a significant wage premium⁶⁰. This may suggest that the most valuable know-how built up under the program is to be found in the surviving plants and not in the spin-off firms. In any case, *my analysis does not give support to the idea that important returns from the IT-program ended up outside the originally subsidized firms.*

6.3 Robustness

In all the firm performance analyses presented above, I have controlled for firm age, firm size, intensity in use of scientists and engineers, current R&D-investments, business cycle effects, and industry differences. The main results are robust to leaving out these control variables, but without controls, also continuing or reorganized subsidized firms have a profitability below average.

Since the exact definition of program and spin-off firms is based on a somewhat arbitrary cutoff value for the share of employees that has experience from firms that received subsidies, it is particularly important to test the robustness of the results with respect to these definitions. I have tried both a more inclusive definition, looking at firms with a 10 percent share of employees with experience from subsidized firms, and a more exclusive definition looking at firms with a 50 percent share of employees with experience from subsidized firms. In both cases, the main results in Tables 8 and 8 hold true. Defining spin-offs based on the share of engineers with experience from subsidized firms, rather than the share of employees with experience from subsidized firms reduces the significance of the negative coefficients. Finally, I have looked specifically at spin-offs from Norsk Data. If anything, these firms have

⁵⁹E.g. sales or service departments, or production teams that move to a new location and try to continue on their own.

⁶⁰Cf. footnote 55, for a related non-reported analysis pointing in the same direction.

a weaker performance than other spin-off firms. With respect to a possible time trend in performance, cf. the strong industry growth present in Figure 3, I find that the profitability of the spin-off firms is falling over time.

Given that the returns to innovation is known to have a very skewed distribution, one may also question whether the regression analyses reported above correctly represent *aggregate* profits for the different categories of firms. A few large and profitable spin-off firms could possibly more than outweigh the low profits in the many small firms dominating the sample. One simple way to explore this issue is to pool all spin-off firms, all continuing or reorganized subsidized firms, and all non-subsidized and non-spin-off firms, in order to compute the joint performance of the various groups. The result of this exercise is graphed in Figure 4. When assessing the joint performance this way, spin-off firms as a group have a higher return on sales than non-spin-off firms, but they perform worse with respect to sales growth, return on assets and return on equity.

A final question one may ask with respect to robustness, is whether the results are specifically related to the subsidized IT R&D firms, or whether any spin-off from firms that invested in IT R&D in the late 1980s have performed similarly bad. I have looked at this question by defining spin-offs from all R&D firms and all IT R&D firms in the same manner as I have defined spin-offs from subsidized IT R&D firms. This analysis (not reported) show that the negative results are most strongly associated with spin-offs from subsidized firms. There are, however, only six spin-offs from non-subsidized IT R&D firms in the sample. In a related analysis (also not reported) I have regressed firm profitability on a continuous measure of different types of R&D experience among the firms' scientists and engineers. In this analysis, R&D-, IT R&D- and subsidized IT R&D experience is measured in the same way as in the wage regressions presented in Tables 5 and 6. The results do not confirm the negative effect of subsidies found in the spin-off analysis, but nor do firms whose scientists and engineers have particularly much experience from subsidized firms perform significantly better.

6.4 Remarks on profitability as performance measure

An objection to the spin-off analysis might be that current sales and profitability are not relevant performance measures in the IT industry, and that the spin-off firms may become successes in the long run. Admittedly, numerous companies in the "New Economy" have been unprofitable, and still highly valued in the stock market due to large investments in intangible capital. These arguments are not entirely convincing, however, as the stock market values such firms far less now than some years ago. Also, private owners buying a company where previous owners have lost their money, may make the company look successful and produce positive profits, without there being a positive *social* return to the historical R&D investments that

produced the technology. Comparing total investments to expected future profits is difficult and requires case studies.

A particularly interesting case in the Norwegian IT-industry is Dolphin Interconnect Solutions. This company has been considered the most successful spin-off from Norsk Data, cf. section 2, but did not make positive profit in any of the sample years. The founding engineers started to develop the 'Dolphin SCI technology' in 1988 while still working for Norsk Data, and 1999 was the first year in history that the company generated positive profits⁶¹. Rough calculations suggest that total investments in Dolphin amounts to about NOK 500 million⁶². In 2000 a major part of Dolphin was sold to Sun Microsystems and the price, NOK 171 million, was considered very favorable. Per employee, the price was NOK 8 million, something which is more than 10 times the cost of an engineering man-year. However, if the part of the company sold to Sun represents more than one third of the total value of the company, the rate of return to Dolphin as an investments project has been negative. A market based evaluation, therefore, is not likely to make Dolphin come out as a large success.

7 Conclusion

This paper illustrates how matched employer-employee data can be used to assess whether human capital built up in subsidized firms is general or specific. The case considered is a series of Norwegian IT-programs from the mid and late 1980s. I find no evidence suggesting that experience from subsidized firms has been rewarded with a wage premium. Scientists and engineers with experience from subsidized firms receive on average the same wage as otherwise similar workers without such experience. This suggests that the return to the knowledge investments made by the government and the workers themselves, was zero. One possible explanation is that the technology shift in the late 1980s rendered much of the intellectual human capital built up under the programs obsolete.

Analyzing the performance of spin-off firms reinforces this dismal conclusion. Spin-offs from subsidized firms are less profitable than other firms, suggesting that the identified spin-offs to a large extent consist of troubled remnants of previously subsidized units. What keeps workers in these firms together may be a low alternative value of their know-how, rather than positive complementarities associated with successful innovations. In any case, my analysis does not give support to the idea that important returns from the IT-programs ended up outside the originally

⁶¹Cf. <http://www.dolphinics.com>.

⁶²This number is calculated on the basis of articles written about Dolphin in the major newspapers Aftenposten, Dagens Næringsliv and Bergens Tidene in the years 1991-2001. The number is adjusted for inflation. Using an additional 7 percent discount factor, the total investment amounts to NOK 800 milll. About 20 percent of the investments has been financed by public subsidies.

subsidized firms.

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Data appendix

Information about individual workers comes from a number of governmental administrative records, which are prepared by Statistics Norway for research use. Barth and Dale-Olsen (1999), appendix 2, give some details on the various registers included in the data base. I have taken great care to improve the data quality by checking for consistency across years and across related variables for the same individual. Missing values are imputed where possible. The available registers cover the years 1986 to 1997. Earnings is measured as taxable labor income. I have referred to this as the workers' wage. The value of stock options received in the employment relationship is included in the workers' taxable labor income after 1991. The use of stock options, however, was negligible. Experience is measured as potential work experience, i.e. age minus schooling minus seven.

Workers with earnings less than 150 000 1995 NOK are considered part time workers, even if coded as full time employed, and are excluded from the wage regressions. Likewise, workers who have not worked for a full calendar year are excluded, and also workers with missing educational information. Starting out with all male workers that have had some sort of affiliation with high-tech or IT industries in one of the years 1986 to 1997, and that were employed in at least one of the years 1986 to 1991, these trimming procedures reduce the total sample of worker-year observations with about 14 percent, somewhat less, 9 percent, for graduate workers.

Plant level information about employers comes from the annual manufacturing census of Statistics Norway⁶³. Information about R&D at the line of business level within firms is collected from R&D surveys and other surveys of immaterial investments and innovation. Prior to 1991 the R&D surveys were conducted by the Royal Norwegian Council for Scientific and Industrial Research. In 1991 and later years, the surveys have been conducted by Statistics Norway⁶⁴. I merge the R&D data to plants based on the plants' firm number and three-digit industrial classification code. This amounts to assuming that there are perfect R&D spillovers between plants belonging to the same line of business within multi-plant firms.

In the machinery and equipment industries utilized in this study, the R&D surveys have close to full coverage for firms with more than 20 employees. For years and firms not covered by the R&D surveys, three other data sets has been utilized. A survey of immaterial investments was conducted by Statistics Norway in 1988, covering the years 1986-88, and in 1990 covering the years 1988-90. Furthermore, an innovation survey was conducted by statistics Norway in 1993 for the year 1992. These sources, however, do not contain information about the share of R&D that is

⁶³The census is documented in the series *Manufacturing statistics*, Official Statistics of Norway, Statistics Norway, Oslo. The microdata are documented in a mimeo from 1991 by Halvorsen, Jensen and Foyn in Statistics Norway.

⁶⁴Microdata with the necessary variables is available in 1984 and biannually 1985-97.

IT-related, and also have limited information about subsidies. The data appendix in Møen (2001) gives references to reports documenting the surveys, and describe in detail the procedures used to combine the various sources when constructing the R&D database. When possible, R&D-intensity and the share of IT-related R&D is imputed by linear interpolation, and by extrapolating the first observed value backwards in time and the last observed value forward in time, firm by firm. Firms' R&D investments are known to be stable over time, and the subsidy and share of IT R&D variables are only available from the biannual surveys. Imputing missing information when possible, therefore, is a desirable procedure. R&D subsidies is a less stable variable than the other two, however, and I have therefore extrapolated this variable only one year forward.

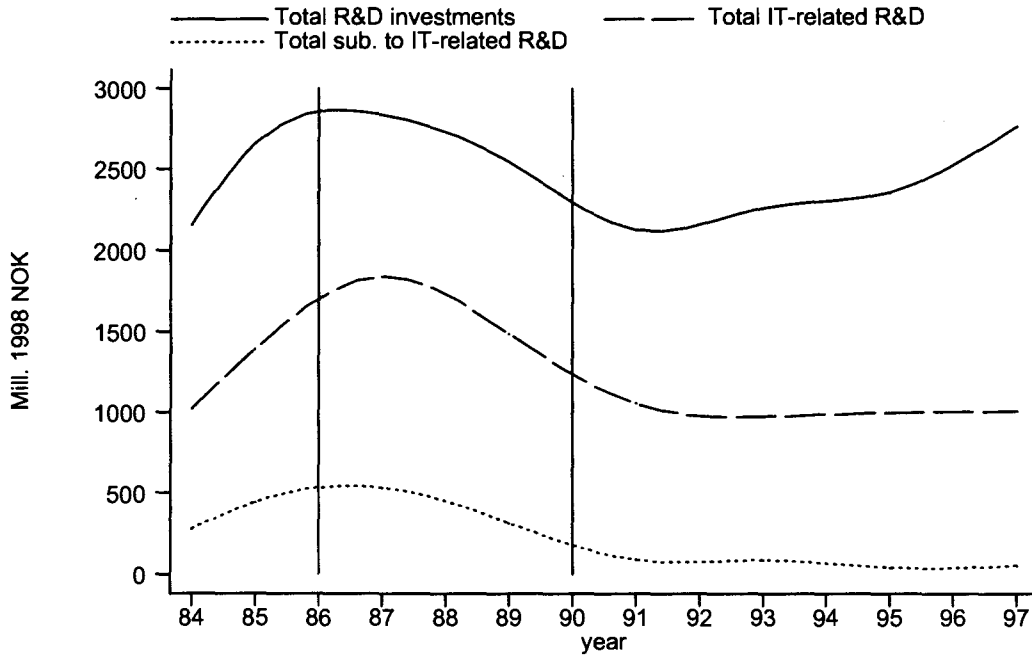
Having performed the imputations described above, about 18 percent of the worker-year observations still lack information about R&D-intensity, about 22 percent still lack information about IT R&D-intensity and about 25 percent still lack information about subsidies⁶⁵. About 76 percent of the non-missing worker-year observations of R&D investments are from surveys, 5 percent are imputed by interpolation and 18 percent are imputed by extrapolation. About 62 percent of the imputed R&D intensities are zero. With respect to subsidized IT R&D investments, about 59 percent of the non-missing worker-year subsidy variables are from surveys, and the rest are imputed. About 73 percent of the imputed subsidized IT R&D intensities are zero. In the regressions, I account for missing R&D information by using dummies.

The analysis of spin-off firms is based on the statistics of accounts for non-financial joint-stock companies prepared by Creditinform and Statistics Norway⁶⁶. The accounts statistics are from the enterprises' financial statements submitted annually to the Register of Company Accounts in Brønnøysund and cover in principle the entire population of non-financial joint-stock companies. An important advantage of this data base is that it has information about firms outside the manufacturing industry. Data are available from 1993. Firms with missing information about return on sales, assets or equity have been excluded. This reduces the sample with 8 percent. The influence of outliers is reduced by replacing values for return on sales, assets and equity below the 5th percentile with the 5th percentile, and values above the 95th percentile with the 95th percentile.

⁶⁵For scientists and engineers the number is smaller, cf. Table A1.

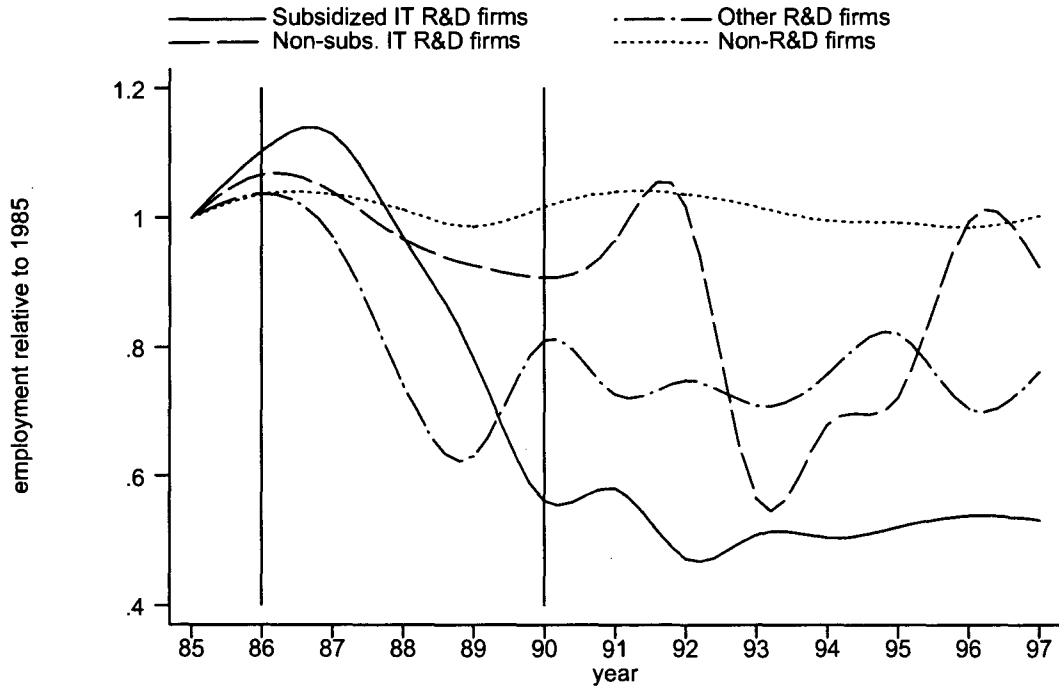
⁶⁶Cf. the annual statistics of accounts for non-financial joint-stock companies, Statistics Norway, for documentation.

Figure 1: R&D investments, IT-related R&D and subsidies to IT-related R&D in high-tech industries in 1984-1997



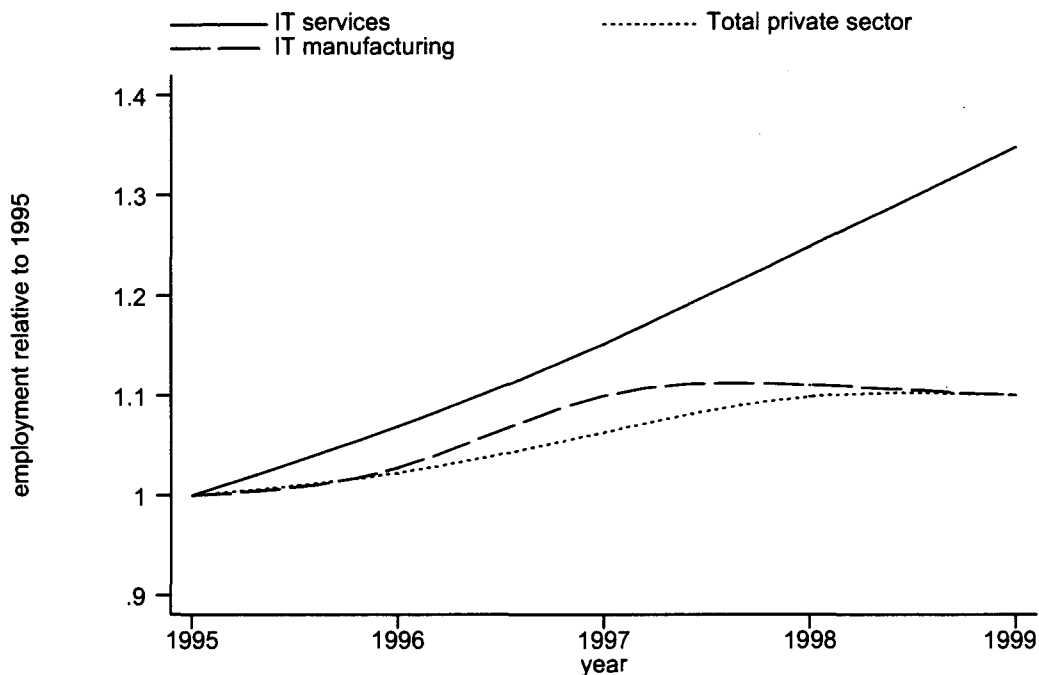
Source: Microdata from R&D surveys conducted by NTNF (The Royal Norwegian Council for Scientific and Industrial Research) and Statistics Norway. Annual data points are connected using a cubic spline. High-tech industries are defined as ISIC 382-385.

Figure 2: Employment growth 1985-1997 in subsidized IT R&D-firms vs. other categories of firms in the high-tech industry



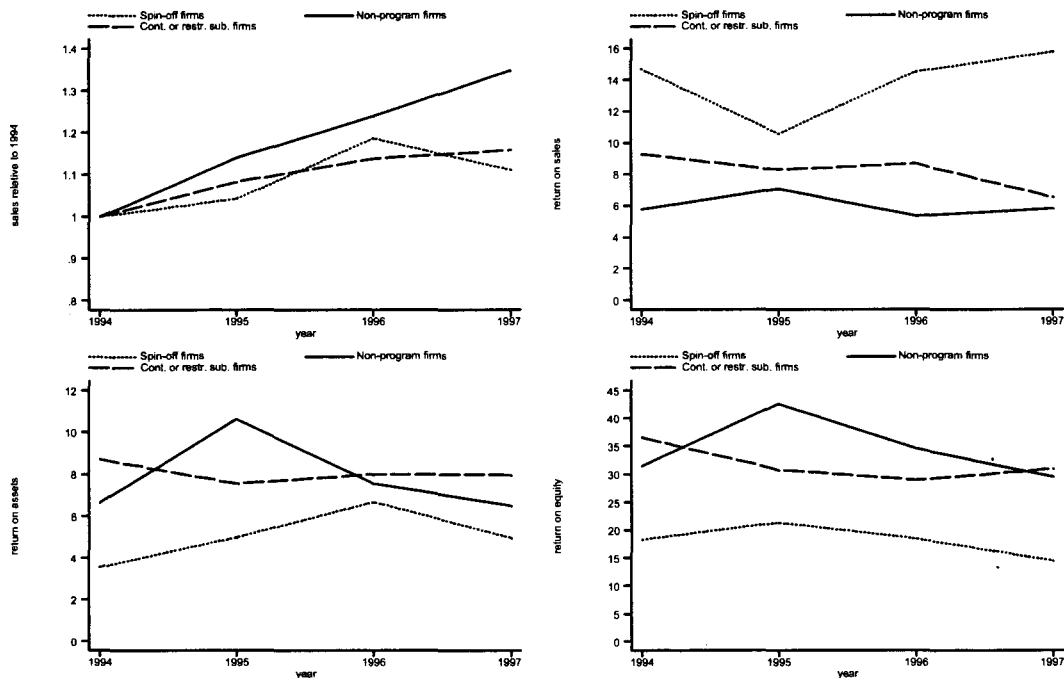
Subsidized IT R&D-firms are firms with an intensity of subsidized IT-related R&D above 0.005 and intensity of IT-related R&D above 0.1 in at least one of the years 1986-1990. Non-subsidized IT R&D-firms are less subsidized firms with an intensity of IT-related R&D above 0.1 in at least one of the years 1986-1990. Other R&D firms are other firms with R&D intensity above 0.1 in at least one of the years 1986-1990. In 1985 there were about 11 100 workers in subsidized IT R&D firms, 1 800 workers in non-subsidized IT R&D firms, 5 800 workers in other R&D firms and 58 600 workers in non-R&D firms. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. Firms with unknown R&D-intensity are excluded. High-tech industries are defined as ISIC 382-385. Firms that change industry classification are kept in the sample. Annual data points are connected using a cubic spline.

Figure 3: Employment growth in IT vs. all private industries in 1995-1999



Source: Statistics Denmark (2000) updated with numbers from Statistics Norway (www.ssb.no). IT-manufacturing is defined as production of computers and office machinery, production of insulated wires and cables, production of radio, TV and communication equipment, production of instruments except medical and surgical equipment (NACE 30, 313, 32, 332 and 333). The IT service sector comprises wholesaling, telecommunications and consultancy (NACE 51433, 5164, 51654, 642, 7133 and 72). The various IT sectors are defined as recommended by OECD, except for wholesaling which is slightly more targeted towards IT. See Statistics Denmark (2000) for details. Total private sector comprises NACE 15-37, 45, 50-74, 92 and 93. Annual data points are connected using a cubic spline.

Figure 4: Joint growth and profitability of spin-off firms vs. non-spin-off firms in 1994 to 1997



Source: Statistics Norway, Statistics of accounts for non-financial joint-stock companies. Both spin-off firms and continuing or reorganized subsidized firm are defined as having had at some point, at least a 25 percent share of employees with experience from subsidized IT R&D-firms, and at least one scientist or engineer with experience from subsidized IT R&D-firms. Together these two groups of firms constitute the 'program firms'. Spin-off firms are program firms that do not contain a plant that has been part of an originally subsidized firm. Continuing or reorganized subsidized firms are program firms that do contain a plant that has been part of an originally subsidized firm. The sample consists of all firms with more than one employee and at least one scientist or engineer, in industries with at least one program firm.

Table 1. Industry of occupation in 1997 for scientists and engineers with experience from high-tech industries in 1986-1990

	Workers from subsidized IT R&D firms	Workers from non- subsidized IT R&D firms	Workers from other R&D firms	Workers from non-R&D firms
High-tech manufacturing industries	40%	53%	49%	44%
Other manufacturing industries	2%	4%	3%	7%
IT services industries	30%	14%	10%	6%
Other services industries	12%	14%	15%	23%
Public sector	5%	5%	6%	4%
Other industries or unknown	2%	1%	8%	8%
Not in the sample	9%	9%	9%	7%
Number of scientists and engineers	1095	195	465	1664

The sample consists of male scientists and engineers born after 1935 with full time experience from a high-tech firm at least one of the years 1986-1990. High tech manufacturing industries are defined as NACE 29-35 (ISIC382-385). IT service industries are defined as NACE 51433, 5164, 51654, 642, 7133 and 72. R&D firms are firms with R&D-intensity above 0.1. IT R&D-firms are R&D firms with intensity of IT-related R&D above 0.1. Subsidized IT R&D-firms are IT R&D-firms with intensity of subsidized IT-related R&D above 0.005. Non-R&D firms are firms that have R&D intensity below 0.1. Workers are classified in the leftmost column applicable. Workers who are not observed in 1997 are classified according to their industry of occupation in 1996, if possible. Otherwise they are classified as not in the sample. R&D-intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. Workers that only have experience from firms with unknown R&D-intensity are excluded.

Table 2. Non-wage labor market outcomes for scientists and engineers with experience from high-tech industries in 1986-1990

	Workers from subsidized IT R&D firms	Workers from non- subsidized IT R&D firms	Workers from other R&D firms	Workers from non-R&D firms
Share of displaced workers that were re-employed in a different municipality [‡]	11%	11%	14%	14%
Participated in active labor market programs 1988-1997	13%	11%	11%	11%
Average employment rate 1988-1997	88%	87%	89%	89%
Re-educated or further educated by 1997	2.1%	2.1%	1.7%	1.7%
Self-employed in at least one year after 1990	.01%	.01%	.02%	.01%
Number of scientists and engineers	1095	195	465	1664

The sample consists of male scientists and engineers born after 1935 with full time experience from a high-tech firm at least one of the years 1986-1990. High tech manufacturing industries are defined as NACE 29-35 (ISIC382-385). R&D firms are firms with R&D-intensity above 0.1. IT R&D-firms are R&D firms with intensity of IT-related R&D above 0.1. Subsidized IT R&D-firms are IT R&D-firms with intensity of subsidized IT-related R&D above 0.005. Non-R&D firms are firms that have R&D intensity below 0.1. Workers are classified in the leftmost column applicable. R&D-intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. Workers that only have experience from firms with unknown R&D-intensity are excluded.

[‡] A displaced worker is defined as a worker with at least two year tenure who left a plant that downsized at least 25 percent in that year or over that year and next year.

Table 3. The effect of R&D, IT and IT-subsidies on the *wage level* for scientists and engineers in high-tech industries in 1986-1990

	(1) Dummy	(2) Intensity	(3) Dummy	(4) Intensity
<i>A: All observations</i>				
R&D	.007 (.009)	.048 (.043)	.005 (.009)	.025 (.045)
IT R&D	-.043*** (.008)	-.245** (.061)	.010 (.015)	-.270*** (.065)
Subsidized IT R&D			-.040*** (.014)	.229* (.121)
Number of observations	11 386	11 386	11 386	11 386
R-squared	.50	.50	.51	.51
<i>B: Without workers with experience from Norsk Data</i>				
R&D	-.008 (.009)	.022 (.044)	-.009 (.009)	.051 (.046)
IT R&D	-.015* (.008)	-.108* (.063)	.0002 (.015)	-.013 (.067)
Subsidized IT R&D			-.019 (.015)	-.488*** (.125)
R-squared	.50	.50	.50	.50
Number of observations	10 513	10 513	10 513	10 513

The dependent variable is ln (real annual earnings). The sample consists of male scientists and engineers born after 1935 working full time in a (manufacturing) high-tech industry. High-tech industries are defined as ISIC 382-385 (NACE 29-35). The baseline comparison group is workers with experience from non-R&D firms. Control variables included in the regression, but not reported are a quartic in experience, a quadratic in tenure, dummies for 15 different academic degrees, a quadratic in plant number of employees, dummies for 3 different regions, year dummies, 6 industry dummies and 3 dummies denoting whether the R&D, IT or subsidy variable is missing. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within individuals, are given in parentheses. In the dummy specifications, R&D firms are defined as firms with R&D intensity above 0.1. IT R&D-firms are defined as R&D-firms with an intensity of IT-related R&D above 0.1. Subsidized IT R&D-firms are defined as IT-firms with an intensity of subsidized IT-related R&D above 0.005. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms.

***. Significant at the 1% level

** Significant at the 5% level

* Significant at the 10% level

Table 4. The effect of R&D, IT and IT-subsidies on the wage profile for scientists and engineers in high-tech industries in 1986-1990

	(1) Dummy	(2) Intensity	(3) Dummy	(4) Intensity
<i>A: All observations</i>				
R&D	.015 (.016)	.081 (.074)	.013 (.015)	.016 (.075)
R&D * experience	-.001 (.001)	-.004 (.005)	-.001 (.001)	.0001 (.005)
IT R&D	-.109*** (.015)	-.600*** (.104)	-.088*** (.023)	-.696*** (.108)
IT R&D * experience	.006*** (.001)	.031*** (.008)	.007*** (.002)	.037*** (.009)
Subsidized IT R&D			-.027 (.022)	.837*** (.205)
Subsidized IT R&D * experience			-.001 (.002)	-.051*** (.017)
R-squared	.51	.51	.51	.51
Number of observations	11 386	11 386	11 386	11 386
<i>B: Without workers with experience from Norsk Data</i>				
R&D	-.004 (.015)	.057 (.075)	-.005 (.015)	.049 (.075)
R&D * experience	-.0004 (.001)	-.004 (.005)	-.0004 (.001)	-.001 (.005)
IT R&D	-.064*** (.015)	-.426*** (.109)	-.070*** (.023)	-.426*** (.113)
IT R&D * experience	.004*** (.001)	.028*** (.008)	.006*** (.002)	.035*** (.009)
Subsidized IT R&D			.009 (.022)	.138 (.211)
Subsidized IT R&D * experience			-.003 (.002)	-.050*** (.017)
R-squared	.51	.51	.51	.51
Number of observations	10 513	10 513	10 513	10 513

The dependent variable is ln (real annual earnings). The sample consists of male scientists and engineers born after 1935 working full time in a high-tech industry. High-tech industries are defined as ISIC 382-385 (NACE 29-35). The baseline comparison group is workers with experience from non-R&D firms. Control variables included in the regression, but not reported are a quartic in experience, a quadratic in tenure, a dummy for job relationships whose starting date is censored at April 30th 1978 together with its interactions with the two tenure variables, dummies for 15 different academic degrees, a quadratic in plant number of employees, dummies for 3 different regions, year dummies, year dummies interacted with experience, 6 industry dummies, 3 dummies denoting whether the R&D, IT or subsidy variable is missing and these dummies interacted with experience. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within individuals, are given in parentheses. In the dummy specifications, R&D firms are defined as firms with R&D intensity above 0.1. IT R&D-firms are defined as R&D-firms with an intensity of IT-related R&D above 0.1. Subsidized IT R&D-firms are defined as IT-firms with an intensity of subsidized IT-related R&D above 0.005. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms.

- *** Significant at the 1% level
- ** Significant at the 5% level
- * Significant at the 10% level

Table 5. The effect of R&D, IT and IT-subsidies on *wage growth 1986-1997* for scientists and engineers in high-tech and IT industries

	(1) Dummy	(2) Stock	(3) Dummy	(4) Stock
<i>A: All observations</i>				
R&D-experience	-.017 (.018)	-.005 (.031)	-.018 (.018)	.003 (.030)
IT R&D-experience	.042** (.018)	.069* (.038)	.003 (.028)	.093** (.042)
Subsidized IT R&D experience			.047* (.025)	-.155* (.072)
R-squared	.23	.23	.23	.23
Number of observations	7 130	7 130	7 130	7 130
<i>B: Without workers with experience from Norsk Data</i>				
R&D-experience	-.010 (.018)	.015 (.031)	-.011 (.018)	.010 (.030)
IT R&D-experience	.016 (.018)	-.003 (.039)	.011 (.028)	-.008 (.034)
Subsidized IT R&D experience			.007 (.025)	.045 (.077)
R-squared	.23	.23	.23	.23
Number of observations	6 762	6 762	6 762	6 762

The dependent variable is the first difference of \ln (real annual earnings) between year t and year $t-10$ in the period 1986 to 1997. The sample consists of male scientists and engineers born after 1935, having some full time experience in at least one of the years 1986-1990 and having full time experience in a high-tech or IT industry in at least one of the years 1986-1997. High-tech and IT industries are defined as NACE 29-35, 51433, 5164, 51654, 642, 7133 and 72. The latter six are IT service industries. The baseline comparison group is workers with experience from non-R&D manufacturing high-tech firms. Control variables included in the regression, but not reported are a quartic in experience a quadratic in tenure, a dummy for job relationships whose starting date is censored at April 30th 1978 together with its interactions with the two tenure variables, year dummies and dummies for 15 different academic degrees, a dummy for having experience from IT service, but not from high-tech manufacturing in 1986-1990, a dummy for not having experience from high-tech manufacturing, nor from IT service in 1986-1990, a dummy for being displaced in one of the years 1986 to 1993, 28 dummies for industry of occupation at time t , 28 dummies for industry of occupation at time $t-10$, two dummies denoting whether R&D or IT R&D is missing for those with experience from manufacturing firms and a similar dummy for subsidized IT R&D in column 4. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within individuals, are given in parentheses. In columns 1, and 3, R&D experience is measured as having experience from a firm with R&D intensity above 0.1. Likewise, IT R&D experience is measured as having experience from a firm with intensity of IT R&D above 0.1, and subsidized IT R&D experience is measured as having experience from a firm with intensity of subsidized IT R&D above 0.005. In columns 2, and 4, R&D experience is measured as the sum of the employers' R&D intensities over the years 1986-91. Likewise, IT R&D experience is measured as the sum of the employers' intensities in IT-related R&D and subsidized IT R&D experience is measured as the sum of the employers' intensities in subsidized IT-related R&D. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. R&D information is only available for manufacturing firms.

- *** Significant at the 1% level
- ** Significant at the 5% level
- * Significant at the 10% level

Table 6. The effect of R&D, IT and IT-subsidies in 1986-1990 on the wage level for scientists and engineers in 1996 and 1997 in high-tech and IT industries

	(1) Dummy	(2) Stock	(3) Dummy	(4) Stock
<i>A: All observations</i>				
R&D-experience	.012 (.017)	.035 (.027)	.012 (.017)	.037 (.036)
IT R&D-experience	-.007 (.017)	-.021 (.035)	.004 (.026)	-.014 (.038)
Subsidized IT R&D experience			-.012 (.024)	-.041 (.082)
R-squared	.21	.21	.21	.21
Number of observations	10 109	10 109	10 109	10 109
<i>B: Without workers with experience from Norsk Data</i>				
R&D-experience	.011 (.017)	.031 (.027)	.011 (.017)	.033 (.027)
IT R&D-experience	-.003 (.017)	-.009 (.036)	.005 (.026)	.004 (.043)
Subsidized IT R&D experience			-.009 (.025)	-.059 (.093)
R-squared	.22	.22	.22	.22
Number of observations	9 632	9 632	9 632	9 632

The dependent variable is \ln (real annual earnings). The sample consists of male scientists and engineers born after 1935, having some full time experience in at least one of the years 1986-1990 and having full time experience in a high-tech or IT industry in at least one of the years 1986-1997. High-tech and IT industries are defined as NACE 29-35, 51433, 5164, 51654, 642, 7133 and 72. The latter six are IT service industries. The baseline comparison group is workers with experience from non-R&D (manufacturing) high-tech firms. Control variables included in the regressions, but not reported are a quartic in experience, a quadratic in tenure, a dummy for job relationships whose starting date is censored at April 30th 1978 together with its interactions with the two tenure variables, year dummies and dummies for 15 different academic degrees, a quadratic in plant number of employees, a dummy for being displaced in one of the years 1986 to 1993, dummies for 3 different regions, a dummy for having experience from IT service, but not from high-tech manufacturing in 1986-1990, a dummy for not having experience from high-tech manufacturing, nor from IT service in 1986-1990, 28 industry dummies, two dummies denoting whether R&D or IT R&D is missing for those with experience from manufacturing firms and a similar dummy for subsidized IT R&D in column 4. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within individuals, are given in parentheses. In columns 1, and 3, R&D experience is measured as having experience from a firm with R&D intensity above 0.1. Likewise, IT R&D experience is measured as having experience from a firm with intensity of IT R&D above 0.1, and subsidized IT R&D experience is measured as having experience from a firm with intensity of subsidized IT R&D above 0.005. In columns 2, and 4, R&D experience is measured as the sum of the employers' R&D intensities over the years 1986-91. Likewise, IT R&D experience is measured as the sum of the employers' intensities in IT-related R&D and subsidized IT R&D experience is measured as the sum of the employers' intensities in subsidized IT-related R&D. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. R&D information is only available for manufacturing firms.

- *** Significant at the 1% level
- ** Significant at the 5% level
- * Significant at the 10% level

Table 7: Growth in 1994-1997 in firms that employ knowledge developed in the subsidized IT R&D firms

	(1)	(2)
Dummy for program firm	.064 (.044)	
Dummy for continuing or reorganized subsidized firm		.075 (.086)
Dummy for spin-off firm		.060 (.045)
R-squared	.93	.93
Number of observations	3 641	3 641

The dependent variable is $\ln(\text{Sales})$. The sample consists of annual observations all firms with more than one employee and at least one scientist or engineer, in industries with at least one program firm. A program firm is defined as having had, at some point, at least a 25 percent share of employees with experience from subsidized IT R&D-firms, and at least one scientist or engineer with experience from subsidized IT R&D-firms. A spin-off firm is defined as a program firm that does not contain a plant that has been part of an originally subsidized firm. A continuing or reorganized subsidized firm is defined as a program firm that does contain a plant that has been part of an originally subsidized firm. Control variables included in the regression, but not reported are $\ln(\text{Sales}_{t-1})$, a quartic in firm age, a quartic in firm no. of employees, a quartic in the share of employees that are scientists and engineers, a dummy for positive R&D-investments, a dummy for R&D-intensity above 0.05, a dummy for R&D-intensity above 0.2, a dummy for no information about R&D investments, year dummies and 38 NACE industry dummies. Firm age is deliberately censored at 30 and firm no. of employees is censored at 1000. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within firms, are given in parentheses. The influence of outliers is reduced by replacing values for return on sales, assets and equity below the 5th percentile with the 5th percentile, and values above the 95th percentile with the 95th percentile.

- *** Significant at the 1% level
- ** Significant at the 5% level
- * Significant at the 10% level

Table 8: Profitability in 1994-1998 in firms that employ knowledge developed in the subsidized IT R&D firms

<i>A: Return on sales</i>	(1)	(2)
Dummy for program firm	-1.22 (1.00)	
Dummy for continuing or reorganized subsidized firm		1.57 (1.48)
Dummy for spin-off firm		-2.56** (1.24)
R-squared	.08	.08
<i>B: Return on assets</i>		
Dummy for program firm	-3.15* (1.67)	
Dummy for continuing or reorganized subsidized firm		1.25 (2.51)
Dummy for spin-off firm		-5.26*** (2.00)
R-squared	.07	.08
<i>C: Return on equity</i>		
Dummy for program firm	-15.51** (7.57)	
Dummy for continuing or reorganized subsidized firm		2.57 (11.79)
Dummy for spin-off firm		-24.19*** (8.68)
R-squared	.06	.06
Number of observations	3 719	3 719

The sample consists of annual observations all firms with more than one employee and at least one scientist or engineer, in industries with at least one program firm. A program firm is defined as having had, at some point, at least a 25 percent share of employees with experience from subsidized IT R&D-firms, and at least one scientist or engineer with experience from subsidized IT R&D-firms. A spin-off firm is defined as a program firm that does not contain a plant that has been part of an originally subsidized firm. A continuing or reorganized subsidized firm is defined as a program firm that does contain a plant that has been part of an originally subsidized firm. Control variables included in the regression, but not reported are a quartic in firm age, a quartic in firm no. of employees, a quartic in the share of employees that are scientists and engineers, a dummy for positive R&D-investments, a dummy for R&D-intensity above 0.05, a dummy for R&D-intensity above 0.2, a dummy for no information about R&D investments, year dummies and 38 NACE industry dummies. Firm age is deliberately censored at 30 and firm no. of employees is censored at 1000. The coefficients are estimated using ordinary least squares. Standard errors, adjusted for heteroscedasticity and correlated error terms within firms, are given in parentheses. The influence of outliers is reduced by replacing values for return on sales, assets and equity below the 5th percentile with the 5th percentile, and values above the 95th percentile with the 95th percentile.

*** Significant at the 1% level

** Significant at the 5% level

* Significant at the 10% level

Table A1. Worker-year observations of scientists and engineers in high-tech industries by ISIC sub-industry and firm type in 1986-1990

		Sub. IT R&D firms	Non- sub. IT R&D firms	Other R&D firms	Non- R&D firms	Firms with un- known R&D	Firms' IT R&D- intensity weighted by no. of obs.
38210	Engines and turbines	0	0	0	351	1	.0004
38220	Agricultural machinery	0	0	1	69	4	.0011
38230	Metal and wood-working machinery	0	0	0	5	0	.0000
38241	Oil and gas well machinery and tools	0	0	0	1 748	106	.0005
32249	Other industrial machinery	0	0	0	132	21	.0004
38250	Computers and office machinery	938	386	17	15	133	.1970
38291	Household machinery	0	0	0	17	17	.0000
38292	Repair of machinery	0	0	2	35	74	.0000
38299	Other machinery	327	30	233	767	190	.0441
38310	Electric motors and eq. for el. production	10	25	316	381	160	.0253
38320	Radio, TV and communication apparatus	1 123	145	660	790	421	.1262
38330	Electrical household appliances	0	0	25	14	1	.0513
38391	Insulated cables and wires	272	0	158	54	24	.1311
38399	Other electrical apparatus and equipment	7	15	5	87	42	.0852
38411	Building of ships	0	0	0	216	135	.0002
38412	Building of boats	0	0	0	19	17	.0000
38413	Ship and boat engines and motors	0	0	0	102	12	.0004
38414	Components and fixtures for ships/boats	0	0	13	102	17	.0006
38421	Railway and tramway equipment	0	0	0	29	0	.0000
38422	Repair of railway and tramway eq.	0	0	0	60	0	.0000
38430	Motor vehicles	19	0	5	102	54	.0804
38440	Motor cycles and bicycles	0	0	0	18	0	.0050
38450	Aircraft	0	0	0	128	0	.0006
38490	Other transport equipment	0	0	0	1	0	.0000
38510	Professional and scientific instruments	81	28	101	119	96	.1311
38520	Photographic and optical goods	34	17	11	0	0	.1580
382-385	All machinery and equipment industries	2 811	646	1 546	5 361	1 525	.0810

The sample consists of male scientists and engineers born after 1935 working full time in a high-tech industry (ISIC 382-385) in 1986-1990. R&D firms are defined as firms with R&D intensity above 0.1. IT R&D-firms are defined as R&D-firms with an intensity of IT-related R&D above 0.1. Subsidized IT R&D-firms are defined as IT-firms with an intensity of subsidized IT-related R&D above 0.005. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms.

Table A2. Characteristics of scientists and engineers by firm type in high-tech industries

	Workers from subsidized IT R&D firms	Workers from non- subsidized IT R&D firms	Workers from other R&D firms	Workers from non- R&D firms
Year of birth (average)	1953	1954	1953	1953
Years of tenure (average) †	3.3	2.6	3.3	3.0
Years of education (average)	16.8	16.7	16.7	16.6
Wage in 1995 NOK (average)	350'	347'	377'	352'
Union membership (share in 1991)	16%	13%	13%	18%
Rural residence (share)	6%	6%	10%	16%
Foreign born (share)	6%	4%	6%	7%
Employers' average R&D intensity	.19	.17	.13	.03
Employers' average intensity of IT R&D	.16	.16	.03	.01
Employers' average intensity of subsidized IT R&D	.036	.001	.006	.001
Obs. with R&D info. per worker 1986-91 (average) ††	3.8	3.4	2.7	3.0
Obs. per worker 1986-1990 (average) ††	4.7	4.7	4.7	4.7
Experience from Norsk Data (share)	26%	0%	0%	0%
Number of scientists and engineers	1 095	195	465	1 664

The sample consists of male scientists and engineers born after 1935 with full time experience from a high-tech firm (ISIC 382-385) at least one of the years 1986-1990. The statistics is based on the first observation of each worker. Workers in firms with unknown R&D-intensity are excluded. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms. 'Rural residence' implies that the worker lives in a municipality where firms have some sort of preferential tax treatment.

† 8 percent of the observations have job starting date censored at April 30th 1978.

†† Only workers who finished their education before 1986 and who were still employed after 1990 are included.

Table A3. Educational composition by firm type in high-tech industries in 1986-1990

	Sub. IT R&D firms	Non-sub. IT R&D firms	Other R&D firms	Non- R&D firms	Total no. of obs.
<i>Total number of worker-year observations</i>	18 170	4 296	15 114	173 756	211 336
Scientists and engineers	15%	15%	10%	3%	10 364
College degree in technology	22%	18%	17%	7%	19 616
Secondary technical education	24%	27%	33%	46%	90 985
Higher general or administrative education	11%	9%	6%	3%	8 731
Secondary general or administrative education	18%	21%	19%	18%	38 685
Unskilled	8%	9%	14%	21%	40 193
Unknown education	2%	1%	1%	1%	2 762
	100%	100%	100%	100%	
<i>Scientists and engineers</i>	2 811	646	1 546	5 361	10 364
PhD Engineering	1%	1%	1%	2%	150
MSc Engineering Electrotechnics/Computers	45%	56%	53%	17%	3371
BSc Electrotechnical Engineering	15%	12%	13%	9%	1204
PhD Mathematics and natural science	2%	2%	1%	1%	143
MSc Mathematics	6%	4%	2%	1%	287
MSc Physics	5%	4%	2%	1%	297
MSc Engineering Machinery	6%	5%	9%	32%	2065
BSc Mechanical Engineering	1%	2%	2%	12%	710
MSc Engineering Architecture and Construction	.1%	0%	.5%	7%	375
MSc Engineering Chemistry and Geology	1%	.5%	1%	2%	174
MSc Chemistry and Geology	1%	1%	.5%	.2%	48
MSc Life Sciences	1%	0%	1%	1%	102
MSc Natural Sciences, unspecified	4%	4%	6%	5%	476
MSc Other engineering	9%	9%	7%	7%	799
BSc Other Engineering	1%	.2%	1%	3%	181
	100%	100%	100%	100%	

The sample consists of male scientists and engineers born between 1935 and 1975 with full time experience from a high-tech firm (ISIC 382-385) at least one of the years 1986-1990. Workers in firms with unknown R&D-intensity are excluded. R&D firms are defined as firms with R&D intensity above 0.1. IT R&D-firms are defined as R&D-firms with an intensity of IT-related R&D above 0.1. Subsidized IT R&D-firms are defined as IT-firms with an intensity of subsidized IT-related R&D above 0.005. R&D intensity is measured as R&D man-years per employee at the three-digit line of business level within firms.

Table A4. Plant characteristics by firm type in high-tech industries in 1986-1990

	Subsidized IT R&D firms	Non- subsidized IT R&D firms	Other R&D firms	Non- R&D firms
Average number of employees	133	80	86	73
Average experience	16	16	16	18
Average tenure [‡]	4.8	4.3	4.6	5.1
Average education	12.9	13.1	12.0	10.8
Average share of work force with higher technical or scientific education	.072	.070	.057	.009
Average hourly wage in 1995 NOK	176	183	180	165
Average capital per employee in 1995 NOK	772'	798'	1085'	748'
Average R&D man-years per employee	.28	.27	.21	.01
Average share of R&D that is IT-related	.89	.91	.18	.04
Average IT R&D man-years per employee	.24	.24	.03	.002
Average share of total R&D that is subsidized	.19	.002	.15	.06
Average subs. IT R&D man-years per employee	.045	.0004	.008	.0002
Average market share	.063	.038	.028	.030
Average union density (1991)	.42	.20	.32	.52
Plants with rural location (share)	.25	.14	.25	.31
Share of work force that is foreign born	.05	.05	.04	.04
Part of multi-plant firm (share)	.61	.47	.45	.44
Part of foreign owned firm (share)	.37	.14	.22	.08
Plants founded before 1966 (share)	.15	.25	.27	.39
Annual growth rate in 1983-1986 ^{**}	.34	.19	.18	.19
Plant closed before 1994 (share)	.46	.31	.33	.20
Number of plant-year observations	233	101	295	4 079
Number of plants	79	29	89	976
Number of firms	52	27	65	813

The statistics are based on all plant-year observations in ISIC 382-385 in 1986-1990. R&D firms are defined as firms with R&D intensity above 0.1. IT R&D-firms are defined as R&D-firms with an intensity of IT-related R&D above 0.1. Subsidized IT R&D-firms are defined as IT-firms with an intensity of subsidized IT-related R&D above 0.005. R&D man-years per employee is measured at the three-digit line of business level within firms. Firms with unknown R&D-intensity are excluded. Market share relates to national production and is measured at the five-digit line of business level for the firm that the plant belongs to. Rural location implies that the firm is located in a municipality where firms have some sort of preferential tax treatment. Multi-plant firms are only counted once in each industry-year when computing the market share statistics. A foreign owned firm is a firm that has more than 50 percent foreign ownership. The number of firms and plants refer to the number of unique firm and plant identifiers over the years 1986-1990, and are classified according to the leftmost column applicable.

[‡] 18 percent of the underlying employee observations have the job starting date censored at April 30th 1978.

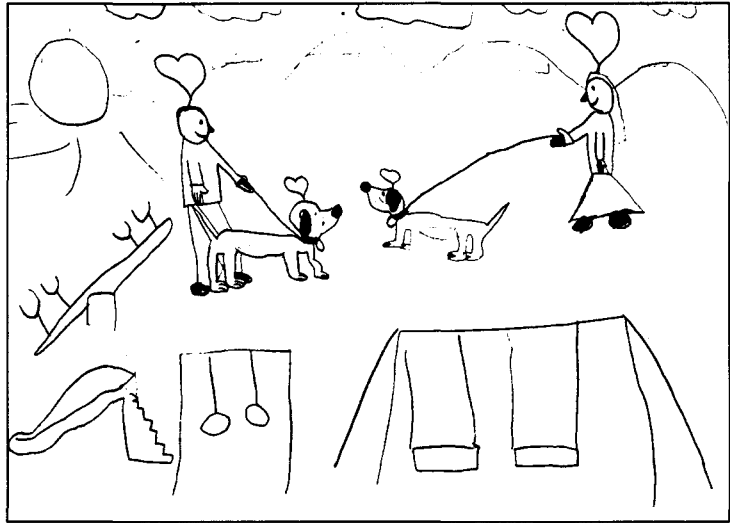
^{**} The reported growth rates are the median within each group. Growth refers to growth in nominal sales.

Table A5. Characteristics of 'program firms' and spin-offs

	Non-program firms	Program firms	Program firms that are cont. or reorganized subsidized firms	Program firms that are spin-offs
Average number of employees	116	176	253	129
Median number of employees	21	24	60	8
Average capital per employee	1 416'	3 486'	879'	5 056'
Median capital per employee	551'	657'	769'	533'
Average number of plants per firm	1.6	2.4	1.9	2.7
Average R&D man-years per employee	.04	.13	.15	.10
Average share of scientists and engineers in the work force	.16	.30	.17	.38
Average share of equity in total assets	.31	.36	.35	.37
Average ownership share of the largest foreign owner	.20	.20	.18	.20
Share of firms with rural location	.14	.03	.00	.05
Share of firms founded before 1986	.41	.31	.60	.15
Share of firms founded before 1991	.75	.65	.96	.46
Share of firms classified as belonging to a high-tech or IT-industry	.56	.78	1.00	.65
Share of firms classified as belonging to an IT-service industry	.36	.34	.15	.46
Share of firms rooted in Norsk Data	0	.24	.03	.37
Number of firm-year observations	3 643	274	103	171
Number of firms	1 437	109	33	76

The statistics are based on all firm-year observations in 1994-1998. The sample consists of all firms with more than one employee and at least one scientist or engineer, in industries with at least one program firm. A program firm is defined as having had, at some point, at least a 25 percent share of employees with experience from subsidized IT R&D-firms, and at least one scientist or engineer with experience from subsidized IT R&D-firms. A spin-off firm is defined as a program firm that does not contain a plant that has been part of an originally subsidized firm. Firms that are 'rooted' in Norsk Data are defined as having had, at some point, at least a 25 percent share of employees with experience from Norsk Data, and at least one scientist or engineer with experience from Norsk Data. Capital is measured in nominal NOK. Rural location implies that the firm is located in a municipality where firms have some sort of preferential tax treatment. High-tech and IT industries comprise NACE 29-35, 51433, 5164, 51654, 642, 7133 and 72.

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The alternative cost of writing a PhD-thesis?

A reminder from Nina Klette in the summer of 1996.

