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

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Abstract:
Economists, in particular Bresnahan and Trajtenberg (1995), 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 our study 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. We examine in some detail the largest of these IT-programs through its planning and implementation stages and emphasize how closely it is connected to recent economic analysis of GPTs. The second part of our study 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. In the final part of the paper we discuss some of the lessons about the problems with technology policy at a practical level.

Keywords: Information technology, Innovative complementarities, General purpose technologies, High tech policy

JEL classification: O30, O40, L10

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1 Introduction

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 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 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' seem 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 by the total expenditures amounting to NOK 4.4 billon ($ 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 an elaborated quantitative analysis of the impact of the IT-related technology programs on the manufacturing part of the IT-industry, and we also consider 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 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.

2 From new growth theory and coordination problems to technology policy

2.1 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 process[2]. It is the complementarity between innovation and other activities across firms 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 are far from settled, and the practice of technology policy vary substantially across countries, technological fields and various stages of the innovation process[3].

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

[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, Shleifer, and Vishny (1989), Milgrom, Qian, and Roberts (1991), and for a survey, Matsuyama (1995).

[3] See Mowery (1995).

promoted by most OECD governments.

2.2 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 application 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.

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

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 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 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

Before we take a closer look at the Norwegian technology programs targeted at information technology, it is useful to elaborate on information technology characterized as a GPT. If we return to the main characteristics, i.e. pervasiveness, inherent potential for technical improvements, and innovational complementarities, one can think about various parts of information technology as GPTs at different levels. 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. To be specific, it was the development of the worksheet that to a large extent made the PC so popular in the early 1980s, thereby expanding the market for PCs and next creating a demand for many other software developments. This illustrates the complementarity across application sectors, and it also illustrates the innovative complementarity between the development of the PC as a GPT and the development of new versions of the worksheet and other software programs.

Thinking further about the software associated with the PCs, we can recognize the worksheet as a GPT at a new level. Many sectors using the worksheet have made a number of complementary innovations in work organization. This have made new applications of the worksheet possible and thereby stimulated its subsequent development. Word processing and electronic post are other kinds of software where innovations in these basic program packages interact with innovations at an organizational level e.g. by eliminating or changing secretarial jobs.

What we argue 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 seem 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 report[5]:

> 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 emphasized[6]:

> 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

[5]'Statsbudsjettet 1986/87', St.prp. nr. 1, p. 40. Our translation.
[6]Harlem et al. (1990), p. 235. Our translation.

> applications; in manufacturing, the public 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 create 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.

To sum up, 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).

3 Coordination problems and the Norwegian IT-programs

3.1 A historical overview of the government's technology policy

There is a long tradition for an activist government policy towards the Norwegian high technology industries, dating back to the aftermath of World War II (Wicken, 1994). In the late 1940s, military needs were the sole purpose of government support to industrial R&D, and this motive remained important during all the years of the Cold War. However, beginning in the 1950s some of the R&D support also aimed at promoting automation and modernization of Norwegian manufacturing and shipping industries, and in the 1960s several initiatives were launched to promote the electronics industry, which was to a large extent considered an industry producing a general purpose technology as discussed above. Electronics was considered to be of strategic importance not only in a military perspective, but in a general economic perspective. In the 1970s there were programs to promote a national computer industry and in the 1980s the focus broadened to include general information technology.

The policy of the Norwegian government seems to have been guided by two underlying beliefs throughout the post war era. First, there was confidence in the authorities' ability to 'pick winners'. At the industry level this is reflected in the importance assigned to the electronics industry. Promoting this industry beyond what was considered necessary from a military point of view was not an obvious choice for a small and natural resource based economy as the Norwegian. At the company level the belief in the ability to pick winners was reflected in the explicit strategy of organizing the industry around a handful of 'national champions'[7]. This strategy was associated with the second underlying belief which was in the existence of innovative complementarities and the need for coordination. Key politicians and scientist firmly believed that private firms underinvested in R&D and new technology, due to short-sightedness and lack of knowledge. There was also a strong belief in scale economies and positive externalities between the educational system, research laboratories, and upstream and downstream producers, cf. Wicken (1994).

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

In Norway 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 development[8]. 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 size[9]. The largest plan in this period was the aforementioned National Program for Information Technology[10], lasting from 1987 to 1990. This program had a total budget of NOK 4.4 billion[11] and included a number of 'subprograms'.

[7]Technology policy associated with notions such as 'national champions' and 'picking winners' has not been popular during the last two decades or so in most OECD countries, cf. Mowery (1995). However, we notice that Bresnahan and Trajtenberg (1995) recognize a number of coordinating advantages with large, dominating firms such as AT&T, IBM and Microsoft, and their arguments seem to be quite consistent with the Norwegian strategy as described by Wicken (1994).

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

[9]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.

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

[11]Approximately $ 620 Mill. This is the size of the formal budget, while the 'fresh money' amounted to NOK 2.1 billion, see Harlem et al. (1990), ch. 7.2.3.

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 Technology[12], and the industrial part of the National Program for Information Technology was succeeded by the 'National Plan for Improved Utilisation of Information Technology in the Norwegian Industry 1992-95'[13]. 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.

3.3 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 sector[14]. 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)[15]:

> 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.

[12] These included: (i) 'Nyskapningsplanen 1977-82', see Grønhaug and Fredriksen (1984). (ii) 'NTNFs Handlingsprogram for Mikroelektronikk og Databehandling 1982-85', see Klette and Søgnen (1986). (iii) 'Nyskapning i næringslivet' which started in 1984. (iv) 'NTNF's sepsialprogram 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.

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

[14] See Harlem et al. (1990), chs. 4 and 7.2 .

[15] P. 64, our translation.

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 computers[16]. The largest recipient, Norsk Data, received by itself more than 12 percent of the budget allocated to firms[17].

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 Mill[18].

As can be seen from Table 1, a significant 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.

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

4.1 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.

[16]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.

[17]This percentage does not includ 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.

[18]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.

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.

4.2 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 main 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 385. It is still possible to extract the more narrowly defined IT industry, and our focus will vary between general high tech and IT according to the kind of analysis performed.

The magnitude of the R&D support given directly to manufacturing firms is plotted in Figure 1. It is immediately evident that total support has varied substantially over time and that it is dominated by ministry grants. We know that the greater part of these grants are received by a handful of firms doing defence and infrastructure related R&D for the government. Hence, the R&D support most relevant for our discussion is the subsidies administered by the research councils and industry funds. This 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 industries[19]. 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.

4.3 Microeconometric evidence on subsidized versus non-subsidized firms

Short 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.

The R&D subsidy dummies are based on the share of subsidies to total R&D over the three years prior

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

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 share[20]. 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. The data appendix gives further details.

The regressions all follow the same pattern. First, we regress the performance measure on the two subsidy dummies and time dummies alone. Then we include industry dummies as both performance and the number of firms being subsidized vary across industries. Next, we control for differences between R&D and non-R&D firms examining to what extent the perceived effect of subsidies is caused by a systematic difference between R&D performing and non-R&D performing firms. It is also 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 increase[21]. Finally, we introduce a cross term between subsidies and time, to test a hypothesis that the public agencies have learned from previous experiences, and that the subsidy schemes of the 1990s were more effectively executed than those in previous years.

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 obseravtion 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, below 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.

[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 recieve 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).

The effect of subsidies on growth. We start out by analyzing the effect of subsidies on firm growth, and the results are given in Table 2. In Table 2A the growth measure is based on man-hours, and in Table 2B 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, however, some of which are statistically significant, are consistently negative for firms receiving between 5 and 25 percent subsidies, and positive or close to zero for firms receiving more than 25 percent subsidies[22]. In 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 sales[23].

The effect of subsidies on profitability. 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 Table 3A, and there are no significant results emerging from these regressions. Looking instead at Table 3B, column (1) and (2) show that subsidized firms are indeed more profitable than non-subsidized firms, but moving on to column (3) and (4), this seems primarily to be a general characteristic of all R&D performing firms. Conditioning on firms performing R&D, the more than five percent subsidy dummy is still positive, but insignificantly different from zero.

The effect of subsidies on productivity. Turning to the effect of subsidies on productivity, the regression results are reported in Table 4. We have used both labor productivity, Table 4A, and total factor productivity, Table 4B, as dependent variable. The subsidized firms have a higher level of productivity, but not when we control for differences between R&D firms and other firms. When fixed effects are included, the coefficient on the more than five percent subsidy share dummy becomes significantly negative for both productivity measures.

The effect of subsidies on investments and private R&D expenditure. In Table 5A the effect of subsidies on the investment intensity is reported. The investment intensity is defined as investments in machinery and buildings relative to sales, and we consider this measure to proxy expected growth in

[22]This effect is given by the sum of the two coefficients. Testing robustness, we have found that the results 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 (1995).

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 Table 5A, 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 Table 5B 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 (1997), we have analyzed the contemporaneous effect of R&D subsidies on private R&D expenditure, applying a more detailed econometric specification than the one used here. Within that framework, preliminary results indicate that subsidies do have a positive effect on private R&D expenditure, at least for large firms. We have done a similar split between large and small firms here, reported in column (4), and it seems that the negative effect of subsidies is more strongly associated with small firms. The difference is not significant, however.

Have the public agencies learned over time? So far our results have been rather discouraging. Subsidized firms do not seem to perform systematically better than non-subsidized firms. However, as the government has gained experience and new insights it has continuously tried to improve its policy instruments. If these attempts have been successful, it might be that the effect of the subsidies given during the last years of the sample period have been significantly positive, even though this effect is not strong enough to dominate the coefficients based on the entire sample. To test this hypothesis, we have regressed each performance measure on time dummies, industry dummies, a dummy for R&D and a dummy for receiving more than a five percent subsidy share in interaction with a dummy for the year of observation being 1993, 1994 or 1995. This allows a separate coefficient on the subsidy dummy if the subsidy was received in the 1990s[24]. Looking at the last column in Tables 2-5, we find that no such learning effect seems to be present.

[24]Recall that the subsidy dummy is based on total subsidies over the three year periode prior to the year of observation.

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 argued that the effect of the subsidies given in the late 1980s has not been visible until lately[25]. 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. The results are reported in Table 6 for the high tech industries and in Table 7 for the more narrowly defined IT industry. Once again we have used several different performance measures, and we have deliberately chosen measures that are easy to interpret and that do not require use of deflators. Furthermore, the method should be robust to measurement errors. In part A of the tables, we have aggregated across all firms in each group, whereas part B of the tables report the median within each group. It is useful to consider both the outcome of the total industry and for the median firm in the industry since several of the distributions we consider are highly skewed and the performance of the total industry can be dominated by a few firms. When focusing on median values, we have excluded those firms exiting the industry after 1985, so that the populations compared are constant over time.

Looking first at the high tech industry, we may note that the 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 intensive firms. However, we see that the growth in private R&D investments as well as in R&D intensity has 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

[25] See e.g. the front page in Computer World no. 38, 1997.

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.

Turning to part B of Table 6, giving the median values of the firms not exiting, the evidence becomes less conclusive. With respect to growth in profitability the subsidized firms perform worse than the non-subsidized ones if we measure profitability as return to assets, whereas they performed slightly better if it is measured by the profit margin. With respect to growth in employees and sales, the result from part A is turned completely around as the subsidized firms have experienced the strongest growth. Looking at the broad picture emerging from Table 6, however, the impression is that subsidized high tech firms have not performed better than non-subsidized firms, – if anything their overall performance is slightly weaker.

Moving on to the narrower defined IT industry, the results are reported in Table 7. Starting out with sales, part A and B of the table agree that the subsidized firms have performed far better than the non-subsidized ones. This difference obviously influences aggregate R&D intensity in favor of the non-subsidized firms. If we therefore disregard this measure, it also seems that the subsidized firms have outperformed the non-subsidized ones with respect to R&D investments. Turning to productivity, the subsidized firms had the strongest growth both in labor productivity and in capital intensity when looking at the aggregate measures. According to the median values, however, the non-subsidized firms had the strongest growth with respect to both variables. This makes it difficult to draw any clear-cut conclusion about which group had the better total factor productivity development. The data are also inconclusive with respect to employment growth and profitability, and the exit rate was about the same for the two groups. In summary, 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.

4.4 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 8, 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 significantly[26]. 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 a low R&D intensity. 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 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 described in section 3.3. Looking at IT in isolation we find that the Norwegian industry received less support 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 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 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 8[27]. In this perspective, one should not take the OECD numbers presented in Table 8 at face value and conclude that Norway had a subsidy share in R&D which in 1987 is twice as large as in other OECD countries[28].

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

[27]See Bloom, Griffith, and Van Reenen (1997) for an analysis of R&D tax subsidies in a number of OECD countries.

[28]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).

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 Figures 2 through 7. Figure 2 displays the relationship between R&D intensity and production. 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 significant 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 market. Figure 3 and 4 supplement Figure 2. Since 1992, the IT-industry has experienced new growth, but as is evident from Table 8B, it has not grown relative to other Norwegian manufacturing industries.

Looking at Figure 5, it seems that the labor productivity in the Norwegian IT industry is not very different from other small countries. If the technology program of the late1980s had been successful, however, we would have expected an increase in productivity in the early 1990s. No such increase is evident in the data. Due to well-known difficulties associated with price deflators for IT products, this does not mean that there was no productivity growth, but to the extent that these measurement problems are similar accross countries, it is evident that e.g. Sweden and Finland experienced stronger growth than Norway. Finally, looking at exports, we see from Figure 6, giving exports as share of production, that Norway had a low export share compared to other small countries in the beginning of the time period analyzed, whereas it increased to a comparable level towards the end of the period. From Figure 7, we see that the increased share is not only due to reduced sales in the home market. The Norwegian IT industry experienced real export growth during the recession. Compared to the other countries, however, the export growth was not particularly strong.

4.5 Summary of economic results

Most countries support IT and related high tech industries. In Norway, the R&D 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 wrong[29]. Nonetheless, we believe a reasonable interpretation 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 in section 2.

An issue which we would like to pursue in future research is the relevance of focusing on *average* performance as we implicitly do in many of the regressions in our study. One could argue that R&D is a particularly risky activity and that one perhaps should expect nine unsuccessful projects out of ten, but the single successful project might be so profitable that it justifies the initial investment in the ten projects. To some extent we have accounted for this possibility as several of our results are based on the outcome of the whole IT industry. If the successful firms were sufficently successful to dominate the unsuccessful ones, they should show up in these industry-wide results. However, the industry catagories we use are perhaps too crude to justify this claim. In that case, one way to proceed might be to examine additional statistics describing the distribution of project outcomes more thoroughly than we have done in the present study[30].

5 Coordination problems and technology policy in practice

5.1 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.

[29]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).

[30]E.g. statistics describing the upper tail of the distribution.

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 program[31]. 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. 5[33].

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 it[34]: "The main conclusion is that [the research programs including the research activities 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

[31] See Hervik and Guvåg (1989).

[32] P. 233, our translation.

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

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

Utilisation 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 very 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.

5.2 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

[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.

principles. However, understanding the basic principles of coordination problems does not take one very far in the direction of useful, practical conclusions about how to construct technology policy. Understanding the basic problems, one is lead 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 1986[36]. 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).

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

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 among the relevant institutions" within the 'National Plan for Improved Utilisation 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 generally[37], 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

[37] Cf. Ministry of Church, Education and Research (1992).

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 high[38]. 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 theory[39]. 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. (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, but this indicates even stronger the ability of the market 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 very recent case, the Norwegian electronics company MRT Micro, which has developed PC-cards to digitalize pictures, has just announced that they have signed collaboration contracts with four firms using these PC-cards[40]. 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.

[38]See Coase (1988) where he has elaborated on this argument.
[39]See, however, the recent literature on research joint ventures, e.g. Kamien, Muller, and Zang (1992).
[40]Dagens Næringsliv, 13.11.97, p.8.

Industry associations are another set of private institutions which are important in facilitating coordination of innovative activities[41]. In a theoretical study, Romer (1993) has examined new institutional arrangements to improve the coordinating function for 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.

6 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 unsuccessful[42].

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

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

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

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. A question we have not addressed directly in this study is the role of government in initiating and promoting such cooperative activities[43].

[43] Dixit and Olson (1997) have recently studied some difficulties in getting economic agents to participate in bargaining and negotations leading up to cooperative solutions.

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7 Data Appendix

Our econometric analysis uses merged data from R&D surveys and time series files of the manufacturing statistics. The manufacturing statistics of Statistics Norway is an annual census of all plants in the Norwegian manufacturing industry. From this source we use information on output and other inputs than R&D. We have only used plants with more than five employees, as there is limited information on the smaller ones. See Halvorsen, Jensen, and Foyn (1991) for documentation. For reasons given in section 4.2, we have aggregated the R&D expenditures to the three digit (ISIC) line of business level before merging these variables to the manufacturing statistics. If a firm has several plants with the same three digit ISIC classification, the R&D expenditures are distributed according to sales before further aggregation to the industry level in Table 6 and 7. Note, however, that 64 percent of the plants with a positive R&D variable are single plant firms.

R&D surveys are available for the years 1982-85, 1987, 1989, 1991, 1993 and 1995. These surveys were carried out by the Royal Norwegian Council for Scientific and Industrial Research (NTNF) until 1989 and by Statistics Norway from 1991. See Skorge, Foyn, and Frengen (1996) for definitions and industry level figures. Figure 1 uses information from the surveys only. Since the surveys had a broad coverage in the industries studied, we believe the totals given by that figure are close to the correct numbers. The merged data set used in the econometric analysis includes fewer R&D units due to matching problems.

The international comparisons of aggregate industry performance reported in Table 8 and in Figure 2-7 are based on the STAN, ANBERD and BERD databases, prepared by the OECD. At the core of our analysis is the ANBERD (Analytical Business Enterprise R&D) database, which contains information on business enterprise R&D defined in a consistent way across the main OECD countries. The BERD database includes information about business enterprise R&D financed by the government through research contracts and direct grants. The STAN (Structural Analysis) industrial database contains internationally comparable information on input, output, exports, investments and value added in fixed and nominal prices by countries and sectors.

7.1 Variable construction

Sales is measured as the value of gross production corrected for taxes and subsidies. Profit is measured as sales subtracted labor expenses, material expenses and rentals, added R&D expenses financed by own means, as given in the R&D surveys. With respect to the stock of assets or physical capital, each plant reports the fire insurance value of machinery and buildings. In addition, we have investment data. To eliminate some of the noise that is known to exist in the insurance values, we have constructed a simple filter combining the two sources of information about the movements in the capital stock. Using the perpetual inventory method, we constructed three different estimates of the stock, based of figures from year t, t-1 and t+1. Our final estimate is the mean value of these three estimates.

The R&D variables includes both intramural and extramural R&D expenditures. These expenditures, consisting mainly of labor costs, are when necessary deflated using an index based on the movement of average wage in ISIC 382, 383 and 385. For the years without R&D surveys we imputed the R&D expenses plant by plant.

7.2 Sample size and trimming procedures

Altogether there are 6448 time-year observations of plants with more than 5 employees in ISIC 382, 383 and 385 in 1983-1995. 124 observations who lack sales, man-hours or capital, have been removed entirely from the sample. Observations who lack less vital variables have only been removed from the particular analyses for which they miss necessary information. For this reason, the sample size varies slightly across the various analyses. There is known to be some noise in the data, particularly with respect to capital, as mentioned already. For this reason we have removed outlying observations. Outliers are defined as observations whose capital intensity is more than five times higher or smaller than the year and five digit ISIC industry specific median value, or value added per man-hour or capital unit is ten times higher or smaller than the year and five digit ISIC industry specific median value. Based on this definition 283 observations, i.e. about 4.5 percent of the sample, were excluded. We have experimented with this procedure, and our main results are robust to variations in the definition of outliers.

Of the 6041 time-year observations in the main sample, 1875, i.e. about 31 percent belong to firms having performed R&D within the plant's three digit ISIC line of business, and 932 of these, i.e. 50

percent, have received an R&D subsidy. The number of plants having at some point of time prior to the year of observation a positive R&D or R&D-subsidy variable, is larger. Among the subsidized firms the median subsidy share is about 14 percent and the mean subsidy share is about 20 percent.

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	221	745
Applications	329	369	398	474	1 570
Total	907	1 025	1 197	1 252	4 381

Source: Harlem et al. (1990).

Table 2. The effect of R&D subsidies on growth

	(1)	(2)	(3)	(4)	(5)
A: Dep. var.: Growth in man-hours					
Dummy for R&D subsidy share > 0.05	-0.030*	-0.035**	-0.007	-0.019	-0.001
	(0.016)	(0.017)	(0.018)	(0.020)	(0.017)
Dummy for R&D subsidy share > 0.25	0.042	0.043	0.044	0.018	
	(0.030)	(0.030)	(0.030)	(0.037)	
Dum. for R&D subs. share > 0.05 in the 1990s					0.050
					(0.037)
Dummy for reporting R&D			-0.041***	-0.023	-0.039***
			(0.011)	(0.020)	(0.011)
Industry dummies	no	yes	yes	no	yes
Fixed effects	no	no	no	yes	no
No. of observations	5622	5622	5622	5622	5622
Root mean square error	0.40	0.40	0.40	0.37	0.40
R-squared	0.02	0.03	0.03	0.29	0.03
B: Dep. var.: Growth in sales					
Dummy for R&D subsidy share > 0.05	-0.013	-0.033	-0.021	-0.063*	0.020
	(0.026)	(0.027)	(0.030)	(0.034)	(0.035)
Dummy for R&D subsidy share > 0.25	0.076	0.082	0.083	0.094	
	(0.060)	(0.060)	(0.060)	(0.070)	
Dum. for R&D subs. share > 0.05 in the 1990s					-0.022
					(0.059)
Dummy for reporting R&D			-0.019	0.011	-0.019
			(0.020)	(0.034)	(0.020)
Industry dummies	no	yes	yes	no	yes
Fixed effects	no	no	no	yes	no
No. of observations	5622	5622	5622	5622	5622
Root mean square error	0.62	0.61	0.61	0.60	0.61
R-squared	0.01	0.02	0.02	0.19	0.02

OLS estimates based on yearly data from ISIC 382, 383 and 385 in 1982-1995. The sample is moderately trimmed, cf. the data appendix. Robust standard errors in parenthesis. Time dummies are included in all regressions. Industry dummies are at the five digit SIC level. 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 the three years prior to the year of observation.

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

Table 3. The effect of R&D subsidies on profitability

	(1)	(2)	(3)	(4)	(5)
A: Dep. var.: Return on assets					
Dummy for R&D subsidy share > 0.05	-0.061 (0.11)	-0.025 (0.075)	0.049 (0.051)	-0.075 (0.12)	-0.013 (0.047)
Dummy for R&D subsidy share > 0.25	0.047 (0.092)	0.047 (0.094)	0.049 (0.094)	0.017 (0.13)	
Dum. for R&D subs. share > 0.05 in the 1990s					0.34* (0.17)
Dummy for reporting R&D			-0.11 (0.12)	0.035 (0.17)	-0.10 (0.11)
Industry dummies	no	yes	yes	no	yes
Fixed effects	no	no	no	yes	no
No. of observations	6020	6020	6020	6020	6020
Root mean square error	7.11	7.11	7.11	7.25	7.11
R-squared	0.002	0.004	0.004	0.11	0.004
B: Dep. var.: Return on sales					
Dummy for R&D subsidy share > 0.05	0.074* (0.038)	0.050 (0.032)	0.033 (0.035)	0.011 (0.031)	0.025 (0.026)
Dummy for R&D subsidy share > 0.25	-0.047 (0.040)	-0.045 (0.041)	-0.045 (0.041)	-0.063 (0.067)	
Dum. for R&D subs. share > 0.05 in the 1990s					-0.045 (0.033)
Dummy for reporting R&D			0.024*** (0.007)	0.023** (0.009)	0.023*** (0.008)
Industry dummies	no	yes	yes	no	yes
Fixed effects	no	no	no	yes	no
No. of observations	6041	6041	6041	6041	6041
Root mean square error	0.28	0.28	0.28	0.27	0.28
R-squared	0.01	0.03	0.03	0.21	0.03

OLS estimates based on yearly data from ISIC 382, 383 and 385 in 1982-1995. The sample is moderately trimmed, cf. the data appendix. Robust standard errors in parenthesis. Time dummies are included in all regressions. Industry dummies are at the five digit SIC level. 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 the three years prior to the year of observation.

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

Table 4. The effect of R&D subsidies on productivity

	(1)	(2)	(3)	(4)	(5)
A: Dep. var.: Labor productivity					
Dummy for R&D subsidy share > 0.05	0.064***	0.031	-0.027	-0.063***	-0.008
	(0.021)	(0.020)	(0.022)	(0.022)	(0.021)
Dummy for R&D subsidy share > 0.25	0.018	0.019	0.017	0.005	
	(0.034)	(0.031)	(0.031)	(0.030)	
Dum. for R&D subs. share > 0.05 in the 1990s					-0.049
					(0.039)
Dummy for reporting R&D			0.083***	0.029*	0.083***
			(0.012)	(0.016)	(0.013)
Industry dummies	no	yes	yes	no	yes
Fixed effects	no	no	no	yes	no
No. of observations	6041	6041	6041	6041	6041
Root mean square error	44.8	42.5	42.5	30.7	42.5
R-squared	0.02	0.12	0.12	0.61	0.12
B: Dep. var.: Total factor productivity					
Dummy for R&D subsidy share > 0.05	0.058***	0.045***	0.001	-0.023**	0.004
	(0.009)	(0.0087)	(0.010)	(0.009)	(0.009)
Dummy for R&D subsidy share > 0.25	-0.0054	0.001	-0.0003	0.013	
	(0.014)	(0.013)	(0.013)	(0.012)	
Dum. for R&D subs. share > 0.05 in the 1990s					-0.011
					(0.016)
Dummy for reporting R&D			0.061***	0.030***	0.061***
			(0.006)	(0.008)	(0.006)
Industry dummies	no	yes	yes	no	yes
Fixed effects	no	no	no	yes	no
No. of observations	5874	5874	5874	5874	5874
Root mean square error	0.18	0.18	0.17	0.12	0.17
R-squared	0.01	0.11	0.13	0.62	0.13

OLS estimates based on yearly data from ISIC 382, 383 and 385 in 1982-1995. The sample is moderately trimmed, cf. the data appendix. Robust standard errors in parenthesis. Time dummies are included in all regressions. Industry dummies are at the five digit SIC level. 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 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).

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

Table 5. The effect of R&D subsidies on investments and private R&D expenditure

	(1)	(2)	(3)	(4)	(5)
A: Dep. var.: Investment intensity					
Dummy for R&D subsidy share > 0.05	0.0036 (0.0032)	0.0004 (0.0034)	0.0027 (0.0036)	0.0013 (0.0049)	0.0031 (0.0041)
Dummy for R&D subsidy share > 0.25	0.0010 (0.0061)	0.0024 (0.0061)	0.0025 (0.0061)	-0.0037 (0.0071)	
Dum. for R&D subs. share > 0.05 in the 1990s					0.0028 (0.0067)
Dummy for reporting R&D			-0.0032 (0.0027)	-0.0051 (0.0043)	-0.0032 (0.0027)
Industry dummies	no	yes	yes	no	yes
Fixed effects	no	no	no	yes	no
No. of observations	6041	6041	6041	6041	6041
Root mean square error	0.09	0.09	0.09	0.09	0.09
R-squared	0.001	0.01	0.01	0.22	0.01
B: Dep. var.: Intensity of priv. financed R&D					
Dummy for R&D subsidy share > 0.05	0.040 (0.034)	0.029 (0.030)	0.021 (0.030)	-0.035 (0.055)	0.027 (0.023)
Dummy for R&D subsidy share > 0.25	-0.030 (0.034)	-0.026 (0.036)	-0.049 (0.069)		
Dum. for R&D subs. share > 0.05 and large firm				0.052 (0.078)	
Dum. for R&D subs. share > 0.05 in the 1990s					-0.035 (0.031)
Industry dummies	no	yes	yes	yes	yes
Fixed effects	no	no	yes	yes	no
No. of observations	1958	1958	1958	1958	1958
Root mean square error	0.35	0.35	0.37	0.37	0.35
R-squared	0.01	0.02	0.11	0.11	0.02

OLS estimates based on yearly data from ISIC 382, 383 and 385 in 1982-1995. The sample is moderately trimmed, cf. the data appendix. Robust standard errors in parenthesis. Time dummies are included in all regressions. Industry dummies are at the five digit SIC level. 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 the three years prior to the year of observation. 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. Large firms are defined as larger than the median measured in man-hours.

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

Table 6. The long term effects of the R&D subsidies to the high tech industries

A: 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%

B: The development of median values in R&D firms established in ISIC 382, 383 or 385 not later than 1985 and still existing in 1995

	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	0.48	0.99	106%	1.1	1.8	58%
R&D intensity	0.48%	1.62%	239%	3.0%	2.8%	-7%
Employment	74	64	-14%	84	79	-6%
Sales	38	55	45%	44	80	82%
Labor productivity	129	211	64%	125	204	63%
Capital intensity	0.33	0.44	33%	0.32	0.52	66%
Return on assets	13.3%	18.1%	35%	15.4%	11.0%	-28%
Return on sales	9.8%	8.5%	-13%	11.3%	10.3%	-9%

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 productivty 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.

Table 7. The long term effects of the R&D subsidies to the IT industry

A: *The aggregate development for R&D firms established in ISIC 3825 or 3832 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	612	596	-3%	302	336	12%
-average	30.6	49.7	62%	11.2	22.4	100%
R&D intensity	8.7	21.2	143%	13.6	10.5	-23%
Employment	5041	1848	-63%	4782	2331	-51%
-average	252	154	-39%	177	155	-12%
Sales	4294	2831	-34%	1878	3428	83%
-average	215	236	10%	70	229	229%
Labor productivity	195	319	64%	116	291	151%
Capital intensity	0.41	0.26	-35%	0.34	0.46	36%
Return on assets	48.4%	199.5%	313%	10.2%	62.4%	512%
Return on sales	23.0%	34.2%	49%	8.7%	19.4%	122%
No. of plants	20	12	-40%	27	15	-44%

B: *The development of median values in R&D firms established in ISIC 3825 or 3832 not later than 1985 and still existing in 1995*

	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	2.1	1.5	-30%	11.1	13.2	19%
R&D intensity	9.1	7.7	-15%	9.7	9.6	-1%
Employment	60	54	-9%	123	94	-24%
Sales	38	40	3%	62	100	62%
Labor productivity	117	260	123%	142	220	55%
Capital intensity	0.23	0.42	82%	0.27	0.34	23%
Return on assets	23.1%	39.2%	70%	34.0%	23.5%	-31%
Return on sales	13.8%	17.9%	30%	12.8%	14.1%	10%

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 productivty 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.

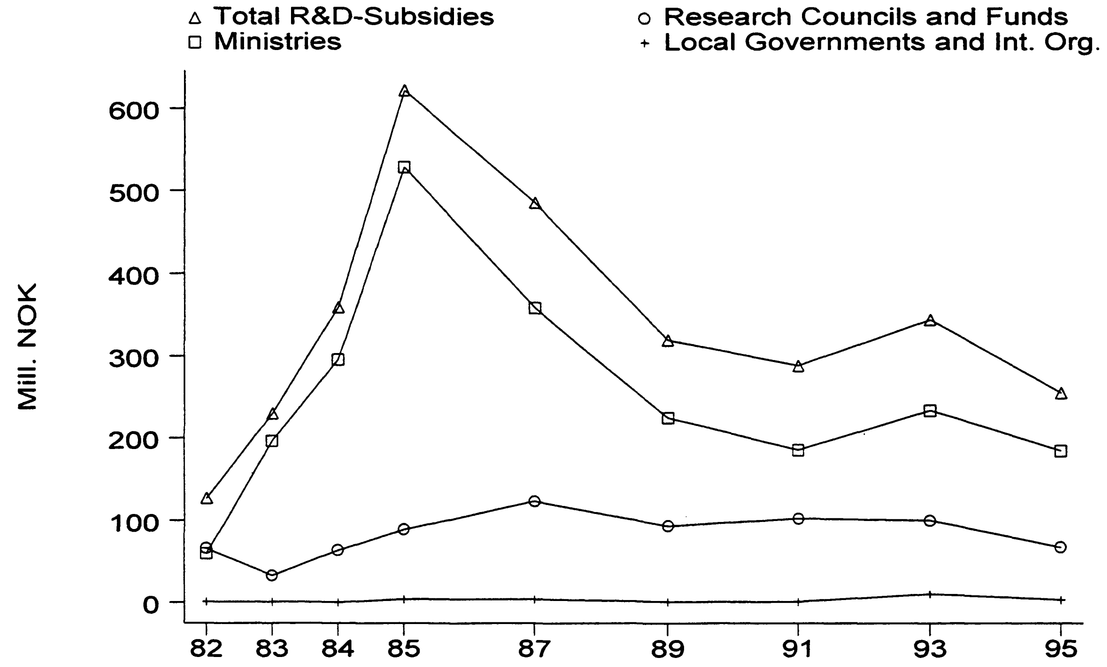
Table 8. The importance of high technology and IT relative to total manufacturing

	1983		1987		1991		1995	
	Norway	OECD	Norway	OECD	Norway	OECD	Norway	OECD
A: ISIC 382, 383 and 385								
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%	-	-
B: ISIC 3825 and 3832 (IT)								
Employment	4%	7%	4%	7%	4%	7%	3%	-
Value added	4%	6%	4%	6%	3%	6%	3%	-
Total R&D including R&D institutes	24%	23%	29%	25%	27%	25%	-	-
Total intramural R&D	31%	22%	32%	24%	32%	25%	-	-
Total subsidy to intramural R&D	37%	33%	48%	17%	26%	20%	-	-
Subs. as share of tot. intramural R&D	11%	14%	18%	8%	8%	7%	-	-

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.

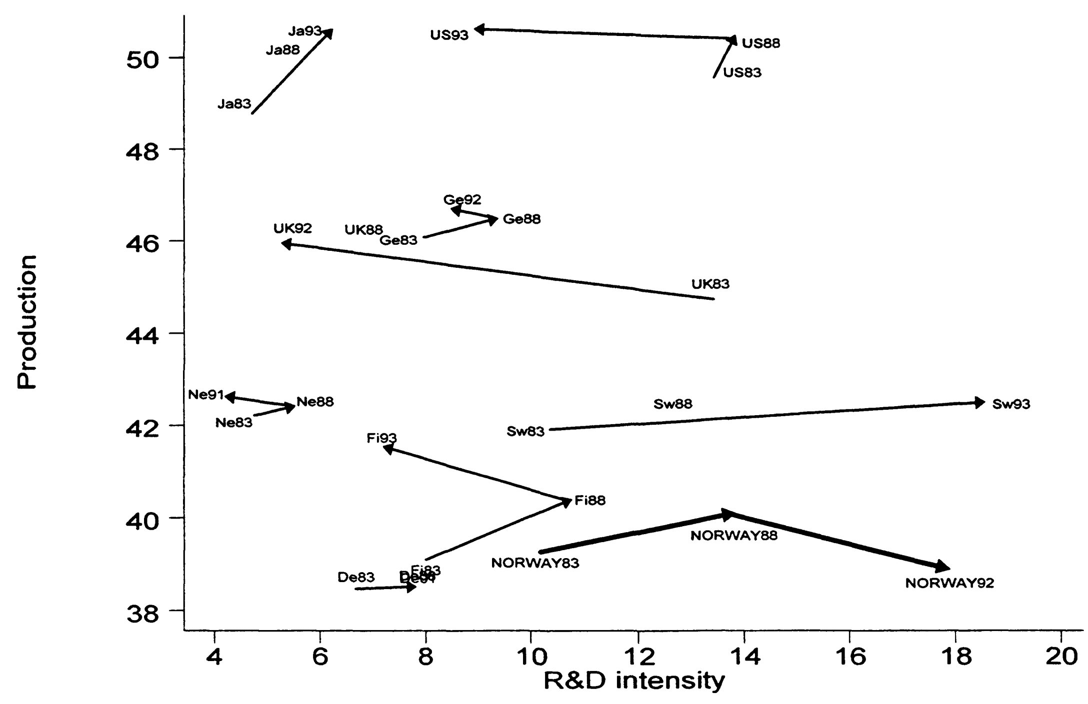
Source: OECD, DSTI(STAN, ANBERD and BERD).

Figure 1. The magnitude of the R&D subsidies to the Norwegian high tech industries (ISIC 382, 383 and 385).



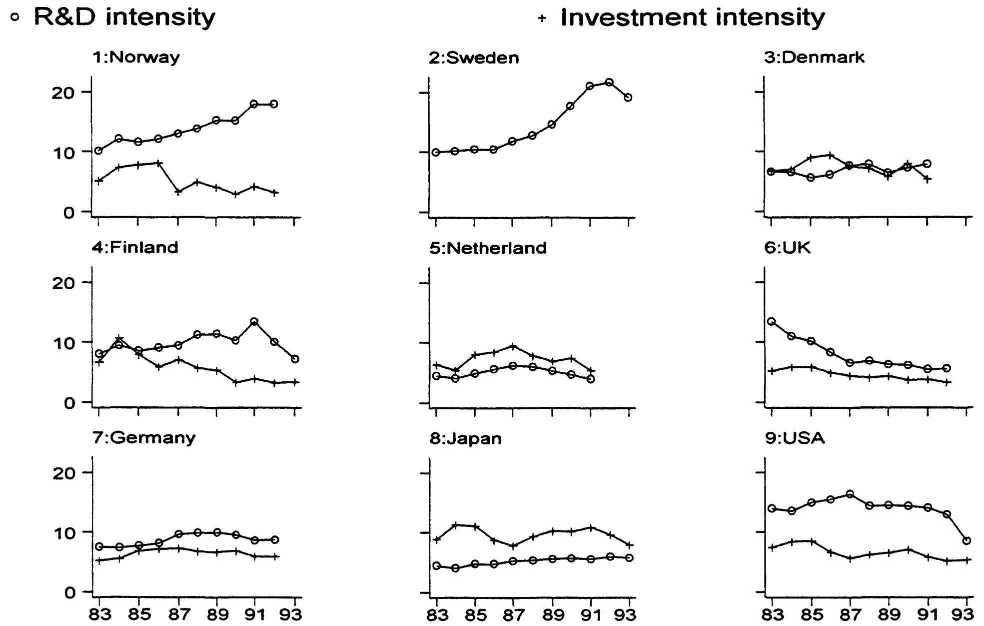
Source: R&D surveys conducted by the Royal Norwegian Council for Scientific and Industrial Research (NTNF) and Statistics Norway.

Figure 2. R&D intensity and production in the IT industry (ISIC 3825 and 3832). Norway compared to other OECD countries.



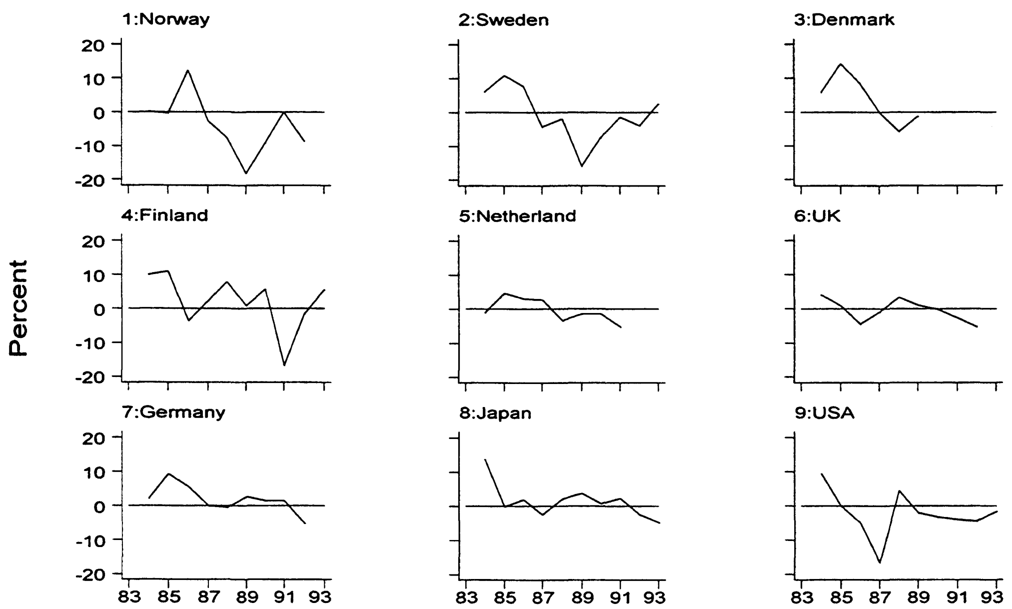
Production is measured as the log of gross output in 1985 dollars. R&D intensity is R&D investments in percent of gross output.
Source: OECD, DSTI(STAN and ANBERD).

Figure 3. R&D intensity and investment intensity in the IT industry (ISIC 3825 and 3832). Norway compared to other OECD countries



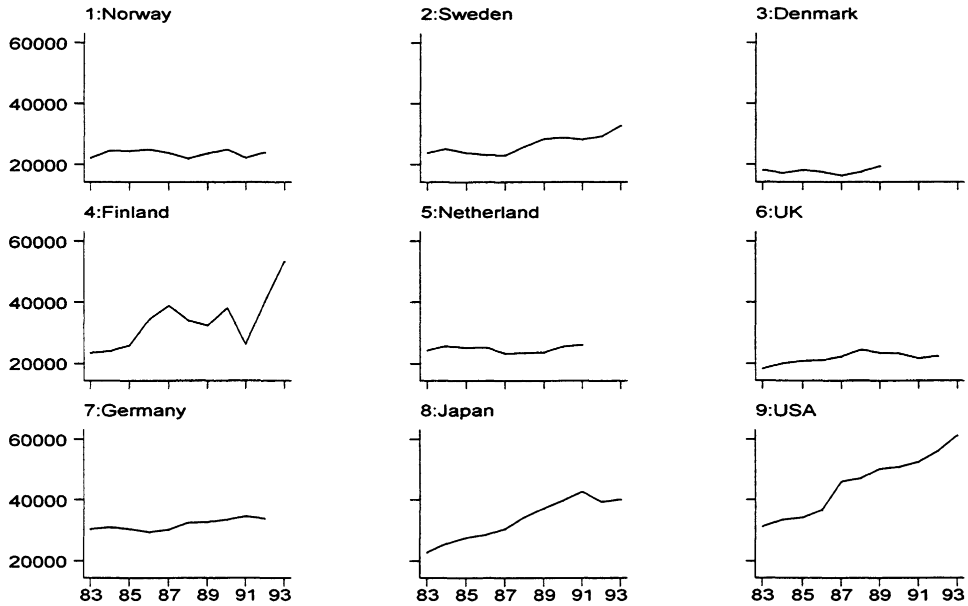
R&D intensity is R&D investments in percent of gross output. Investment intensity is fixed gross capital formation in perc. of gross output.
Source: OECD, DSTI(STAN and ANBERD).

Figure 4. Employment growth in the electronics industry (ISIC 3825 and 3832). Norway compared to other OECD countries



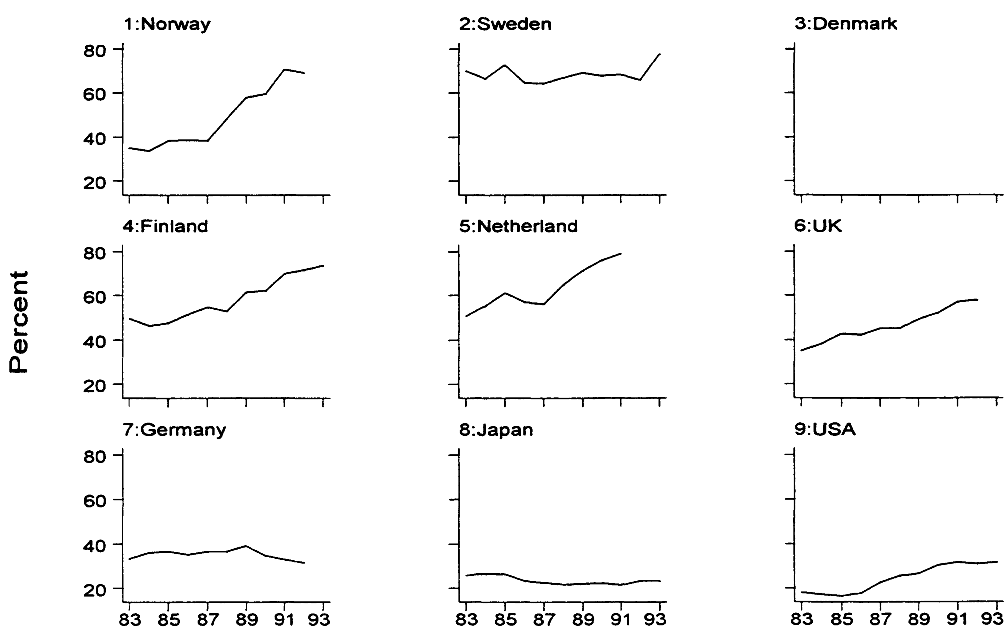
Source: OECD, DSTI(STAN and ANBERD).

Figure 5. Labor productivity in the IT industry (ISIC 3825 and 3832). Norway compared to other OECD countries



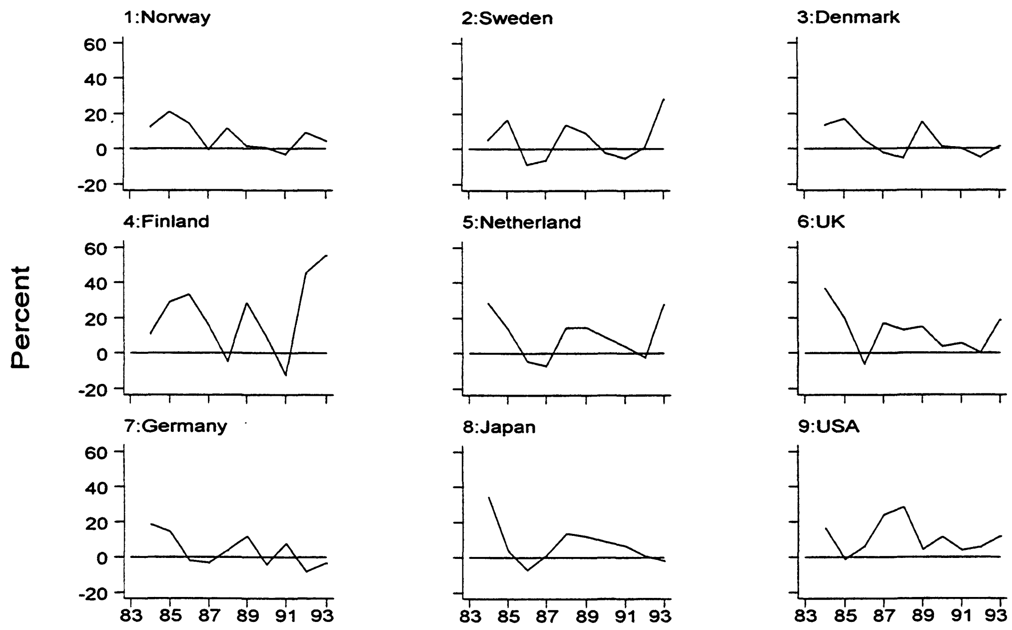
Labour productivity is measured as value added in 1985 dollars per employee.
Source: OECD, DSTI(STAN and ANBERD).

Figure 6. Exports as share of production in the IT industry (ISIC 3825 and 3832). Norway compared to other OECD countries.



Source: OECD, DSTI(STAN and ANBERD).

Figure 7. Real export growth in the IT industry (ISIC 3825 and 3832). Norway compared to other OECD countries.



Source: OECD, DSTI(STAN and ANBERD).

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