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

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

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by the total expenditures amounting to NOK 4.4 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 a quantitative analysis of the impact of the IT-related technology programs on the manufacturing part of the IT-industry including closely related high tech manufacturing sectors. In the first part of this analysis we compare the performance of targeted firms to other firms in the same industries. Next, we consider the development of the IT-industry and the related high tech manufacturing sectors relative to the performance of the manufacturing sector at large, and finally we compare the performance of these sectors in Norway to their performance in other OECD economies.

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

From new growth theory and coordination problems to technology policy

Innovation, economic growth and technology policy

Externalities associated with R&D, learning and innovation have been emphasized in recent developments in growth theory, and it has been widely recognized that these externalities create coordination problems and possibly scope for welfare improving government interventions. Theoretical work on economic development and growth has emphasized that the development of new industries in the presence of such externalities tend to create multiple equilibria where one equilibrium corresponds to the new industry never reaching a 'critical mass' or never 'taking off'[1], while other equilibria correspond to the industry 'taking off' and starting on a cumulative growth process[2]. It is the complementarity in activities across independent firms, e.g. in innovation activities, that give rise to multiple equilibria with high and low levels of growth.

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

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

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

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

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

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

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

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

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

Technology policy and IT as a general purpose technology

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

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

Introducing the National Program for Information Technology for the period 1987-90, the government wrote in its budget 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 applications; in manufacturing, the public

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

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

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

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

Coordination problems and the Norwegian IT-programs

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

In Norway in the 1980s, there were some widely held worries about the state of the domestic information technology industries, and the emphasis was on the following three sets of problems: (i) Fragmentation of public funds for R&D, innovation and utilization of IT-technology, (ii) too many small and independent firms, and (iii) little long term planning and originality in product development[7]. 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[8]. The largest plan in this period was the aforementioned National Program for Information Technology[9], lasting from 1987 to 1990. This program had total expenditures of NOK 4.4 billion[10] and included a number of 'subprograms' (see below).

Before 1987, the Royal Norwegian Council for Scientific and Industrial Research (NTNF) had implemented several funding schemes which were predecessors to the National Program for Information Technology[11] , and

7. See Hervik and Guvåg (1989), p. 7 and Harlem et al.(1990), ch.3 .
8. The R&D subsidy programs have been administered by various research councils and governmental funds. With respect to the high tech industries the Royal Norwegian Council for Scientific and Industrial Research and the Fund for Industry were the most prominent agencies. In the early 1990s the various research councils were merged into the Norwegian Research Council, and most governmental industry funds were merged into the Norwegian Industry and Regional Development Fund. Besides these agencies, R&D grants have also been awarded directly through ministries.
9. 'Den nasjonale handlingsplan for informasjonsteknologi'. See Harlem et al. (1990) and Buland (1996) for detailed documentation.
10. Approximately $ 620 Mill. NOK 2.1 billion of the expenditures were 'fresh money', see Harlem et al.(1990), ch. 7.2.4.
11. These included: (i) '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 spesialprogram for mikroelektronikk' which started in 1985 . All these activities were related and the last two programs were continued within the National Program for Information Technology from 1987. The research councils also sponsored a number of individual research projects related to IT. See 'Stortings prp. nr. 133, 1977/78' for details.

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

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

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

The National Program for Information Technology was a broad plan to coordinate activities aimed at promoting the production and applications of information technology. The plan covered basic research, education, production of integrated circuits and computers, and applications of information technology throughout the economy including the public sector[13]. Even though the original plan had a very broad scope, the actual implementation of the program focused heavily on manufacturing of electronics and other IT-products. According to Harlem et al. (1990)[14]:

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

The project funds were very unevenly distributed across firms, with the ten largest recipients receiving 35 percent of the funds. These firms were producing electronic products, telecommunication equipment, instruments and computers[15]. The largest recipient, Norsk Data, received by itself more than 12 percent of the budget allocated to firms[16].

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[17].

As can be seen from Table 1, a significant

12. "IT-plan for næringslivet 1992–95", see Olsen et al. (1997) for details.
13. See Harlem et al. (1990), chs. 4 and 7.2 .
14. P. 64, our translation.
15. The ten largest recipients were Norsk Data, Autodisplay, EB Nera, Nordic VLSI, EB, LCD Vision, Seatex, Micron, Simrad Subsea and Alcatel/STK. The order reflects the size of the funding.
16. This percentage does not 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.
17. See NIFU (1991), Table T6 and N2. Publicly funded technological R&D in universities and governmental labs in total amounted to NOK 1245 Mill, while the public funding for scientific research in universities was NOK 1297 Mill. Publicly funded R&D in private firms was NOK 465 Mill. in 1989.

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

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

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

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

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

Expectations about the effects of the IT-policy

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

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

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

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

We define the IT or information technology industry as consisting of the manufacture of office machinery and communication equipment, i.e. ISIC 3825 and 3832. This is the kind of production most intensely promoted by the governmental programs described above, and consequently the sectors where we should expect to see the main effects. However, related sectors also received significant support, and many companies have both production and research activities covering a broader class of products. Due to this and due to the associated classification problems and possible spillovers between closely related production activities within companies, we have in our econometric work decided to use R&D data aggregated to the three digit line of business level. Our sample, therefore, covers more general high tech industries than IT, namely the manufacture of machinery, electrical equipment and technical instruments, i.e. ISIC 382, 383 and 385[18]. The R&D support most relevant for our discussion is the subsidies administered by the research councils and industry funds, and this R&D support has on average been about 80 million NOK a year, having a maximum of 123 million NOK in 1987. Since then the support has decreased by 46 percent in nominal terms or by 58 percent if the figures are deflated by the consumer price index. In 1995 the support was about 67 million kroner which was about 1250 kroner per employee in the high tech 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.

Microeconometric evidence on subsidized versus non-subsidized firms

Short and medium run effects of public R&D support

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

18. In a previous version of this paper Klette and Møen (1998), we also presented an analysis based on a sample for the more narrowly defined IT industry consisting of ISIC 3825 and 3832.
19. Looking at the IT-industry in isolation, the support per employee from the Research Council and the Industry Fund was three times larger.

The R&D subsidy dummies are based on the share of subsidies to total R&D over the three years prior to the year of observation. We do not expect a small subsidy to have much effect on performance, and therefore we do not distinguish between zero and less than a five percent subsidy share. On the other hand, a large subsidy might affect a firm differently than a medium subsidy, and to test this hypothesis we have one dummy indicating more than a 5 percent subsidy share and an additional dummy indicating more than a 25 percent subsidy 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. A previous version of this paper (Klette and Møen, 1998a) gives further details on sample and variable construction.

We have started out regressing each performance measure on the two subsidy dummies, time and industry dummies. It is possible that significant coefficients on the subsidy dummies are due to reversed causality, i.e. that successful, or possibly unsuccessful, firms have a better chance of receiving subsidies. This can, at least partly, be controlled for by introducing plant specific fixed effects, which is equivalent to measuring all variables as deviations from the firm specific means. Unfortunately, this comes at a cost, as the downward bias on the estimated coefficients due to measurement errors, is likely to increase[21].

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

We start out by analyzing the effect of subsidies on firm growth, and the results are given in the first two columns in Table 2. Table 2.A reports results from ordinary OLS regressions, while Table 2.B reports results from regressions that incorporate plant fixed effects. In column 1, the growth measure is based on man-hours, and in column 2 the growth measure is based on sales. No matter which measure is used, there do not appear to be important differences between subsidized and non-subsidized firms. The point estimates are negative but statistically insignificant for firms receiving between 5 and 25 percent subsidies, and positive or close to zero (but statistically insignificant) for firms receiving more than 25 percent subsidies[22]. In

20. Firms with a subsidy share exceeding 25 percent are quite similar to other firms with respect to size, capital intensity and profit margins. However, they 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)
22. This effect is given by the sum of the two coefficients. Testing robustness, we have found that the results

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

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

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

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

passing, we notice that the results in Table 2 also show that R&D firms have on average grown more slowly than non-R&D firms, both in terms of man-hours and sales[23].

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

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

The effect of subsidies on the investment intensity is reported in column 7 in Table 2. The investment intensity is defined as investments in machinery and buildings relative to sales, and we consider this measure as a proxy for expected growth in sales. Furthermore, we believe that expected growth in sales is positively correlated with the success of the firm's R&D projects, particularly after industry differences have been controlled for. Looking at column 7, we find that there are no systematic differences between subsidized and non-subsidized firms in this respect.

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

Longer run effects

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

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

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

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

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

The subsidy share is the part of the firm's deflated R&D investments in 1985-1993 which was financed by public grants.R&D investments are deflated by a wage index and given in millions of 1995 NOK. Sales are given in nominal millions NOK. Labor 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.

argued that the effect of the subsidies given in the late 1980s has not been visible until lately[24]. Against this, one might argue that the growth experienced during the last years, is more likely to be an ordinary business cycle effect than an effect of previous technology programs, as there has been strong growth in all sectors of the Norwegian economy. In order to investigate this issue closer, we have compared the growth of subsidized and non-subsidized firms that existed in 1985, over the entire decade 1985 to 1995. We have defined subsidized firms as firms who had more than five percent of their R&D expenses over the years 1985 to 1993 financed by the government and we have aggregated across all firms in each group[25]. The results are reported in Table 3. Once again we have used several different performance measures, and we have deliberately chosen measures that are easy to interpret.

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

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

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

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

Industrial growth

The aim of the technology programs have been to promote the entire Norwegian IT industry, and in addition to R&D subsidies, relevant education and academic research have also been supported. One way to evaluate the totality of these efforts is to compare the experience of the Norwegian high tech industries to total Norwegian manufacturing and to the IT industries in other OECD countries. We have performed international comparisons using data from the OECD STAN, ANBERD and BERD databases.

Starting out looking at Table 4, we can see that in Norway the share of IT and general high tech in total manufacturing is smaller than the OECD average. Furthermore, from 1983 to 1995, these shares do not change 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 low R&D intensities.

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

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

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

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

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

benefits the IT industry. Furthermore, in several OECD countries significant amounts of public R&D support are given in terms of tax reliefs, and such tax allowances are not reflected in the numbers reported in Table 4[27]. In this perspective, one should not take the OECD numbers presented in Table 4 at face value and conclude that Norway had a subsidy share in R&D which in 1987 was twice as large as in other OECD countries.

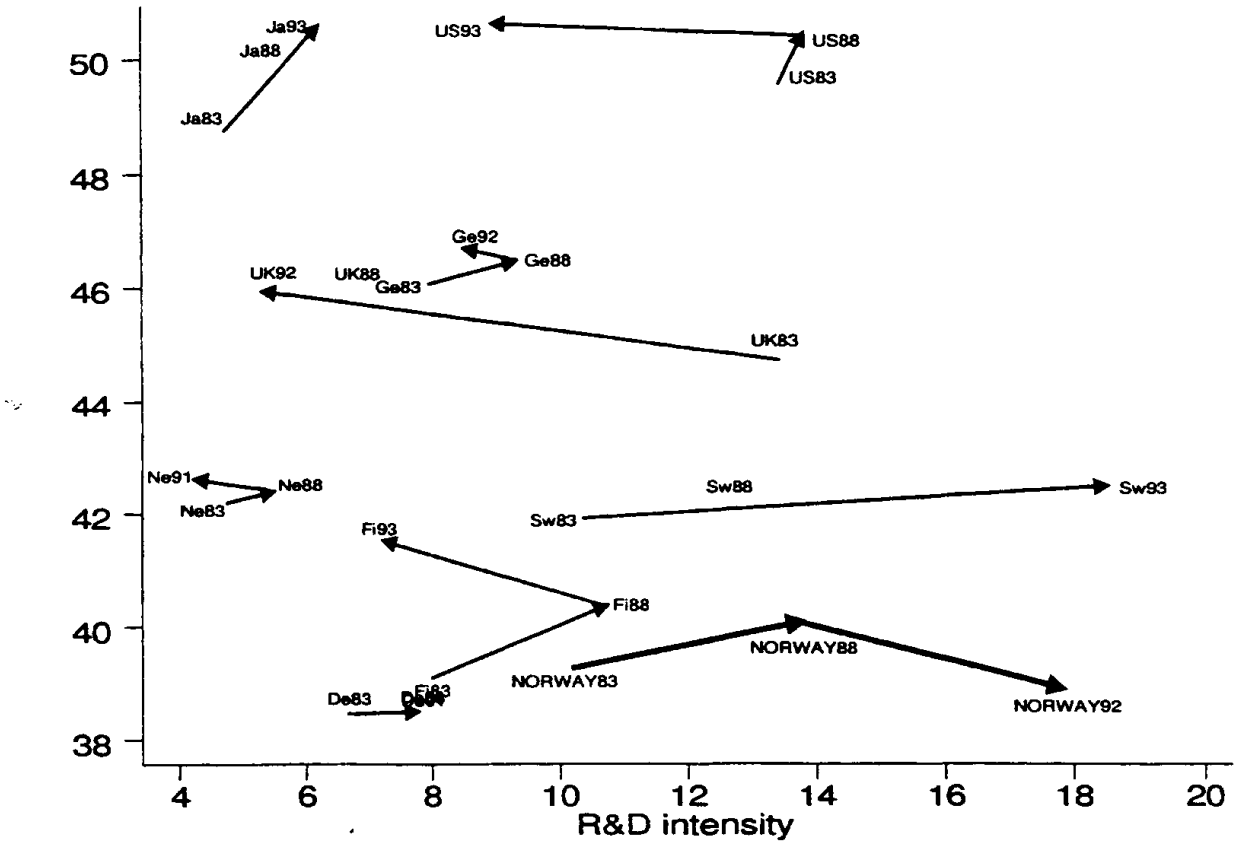
Despite this reservation about the OECD numbers, we believe it is interesting to compare the performance of the Norwegian IT industry to the IT industry in other OECD countries as we do in Figure 1 which displays the relationship between R&D intensity and production[28]. Not surprisingly, it is evident that Norway has a very small share of the world market. At the same time, the R&D intensity in the Norwegian IT industry is very high, and only Sweden had a comparable increase in the R&D intensity. Despite the increased R&D intensity, in the years 1988 to 1992 Norway was the only country with a fall in production. This fall in production is obviously related to the severe recession experienced in Norway during these years, but if the Norwegian IT industry had been internationally competitive, the condition on the domestic market should not have been too severe an obstacle in a period of growth in the international market[29].

Summary of economic results

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

27. See Bloom et al. (1997) for an analysis of R&D tax subsidies in a number of OECD countries.
28. In Klette and Møen (1998a), we also examine the differences across OECD contries in terms of R&D, employment growth, labor productivity and export performance for the IT-industry. Notice that Figure 1 is based on the IT-industry narrowly defined.
29. Further discussion of the magnitude of the IT program in Norway compared to other OECD countries can be found in Buland (1996, ch. 2) and Harlem et al. (1990, ch. 2).

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



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

subsidies were particularly large in the second half of the 1980s, both in a national and probably also in an international perspective. In this section we have investigated the effect of these subsidies, using several different approaches and data sources. First, comparing subsidized and non-subsidized firms within the high tech industries, there is little evidence in favor of the subsidized firms being more successful. Second, looking at these industries relative to aggregate Norwegian manufacturing, their importance have not increased. Third, comparing the development of the Norwegian IT industry to the IT industry of other OECD countries, the Norwegian industry does not perform particularly well. Obviously, if someone claims that the subsidized firms and the entire Norwegian IT industry would have performed a lot worse without the support, we cannot prove him or her wrong[30]. Nonetheless, we believe a reasonable inter-

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

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

Coordination problems and technology policy in practice

The IT-programs – coordination failures at the policy level

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

Our empirical analysis of the economic performance in the firms and sectors targeted by the IT-programs revealed few results suggesting that they have benefitted significantly from the financial stimulation and the coordination effort of the programs. These findings lead to the conclusion stated above that the Norwegian governmental effort to stimulate and coordinate the development of IT-products and applications have not been very successful. We are, however, not the first evaluation study to recognize the failure of the coordination activities in the IT-programs; this aspect has been emphasized in all previous evaluation reports. A report evaluating the part of the National Program for Information Technology organized by the Industry Fund, concluded that they found few concrete results with respect to the creation of 'strategic alliances' or 'coordinated groups' which was an explicit and major objective of this part of the 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

31. See Hervik and Guvåg (1989).
32. P. 233, our translation. We recognize that the focus on coordination failures in this and other evaluation reports often refers to problems in coordinating *institutional arrangments* rather than the projects directly. However, it seems likely that poor coordination at an institutional level will show up as poor coordination also at a project level and our empirical findings confirm this expectation by showing that the coordination at the project level was not very successful.
33. See also Buland (1996), especially chs. 9 and 10.
34. Cf. Ministry of Church, Education and Research (1992), p. 92–94.

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

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

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

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

Two pessimistic and one optimistic view of coordination problems

Coordination beyond stylized models

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

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

useful, practical conclusions about how to construct technology policy. Understanding the basic problems, one is 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).

Institutional inertia as a barrier to coordination

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

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

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

among the relevant institutions" within the 'National Plan for Improved Utilization of Information Technology in the Norwegian Industry 1992–95'. Institutional resistance and inertia was also a basic problem in the implementation of the National Program for Information Technology and an important reason why the heading committee of the program was reorganized twice during the four years it lasted. The previously mentioned report to the Parliament discussing research programs more 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 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.

37. Ch. Ministry of Church, Education and Research (1992).
38. See Coase (1988) where he has elaborated on this argument.
39. See, however, the recent literature on research joint ventures, e.g. Kamien et al. (1992).

(1996), about 60 percent of the Norwegian electronics firms report that they participate in technological cooperation schemes. Partner firms often have a partly integrated ownership structure, which is one important market arrangement to internalize this type of externalities. A different example of coordination through private institutions is given by Steine (1992), who argues that an important contribution to the early success of Norsk Data was its close contact with demanding customers. Norsk Data organized a formal user group in order to coordinate the development of their minicomputers and software with organizational and other innovations developed by its customers. Similar user groups and other coordinating relationships are well known throughout the computer industry. Formal contracts coordinating the development of new technologies in the primary innovating firm and 'partner' firms using the new technology are regularly announced in the business press. To take a recent case, the Norwegian electronics company MRT Micro, which has developed PC-cards to digitalize pictures, has announced that they have signed collaboration contracts with four firms using these PC-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. 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 of such organizations. However, it must be left for future research to examine the empirical performance of such organizations in coordinating R&D activities and privately funded research joint ventures more generally. Our point here is only to illustrate the widespread coordination of complementary innovative activities across independent firms through contracts and other private institutions.

Conclusions

The motivation for the IT programs in Norway in the 1980s and 1990s seem to a large extent to accord well with the coordination problems identified in the new growth theory and especially the recent theory on 'General Purpose Technologies' introduced by Bresnahan and Trajtenberg (1995). Having studied the Norwegian IT industry, we have no reason to doubt that innovative complementarities associated with such technologies can be pervasive phenomena, and that these complementarities create a number of coordination problems. A major question we have addressed in this study is to what extent the considerable public funds spent on coordinating and promoting the R&D activities in the Norwegian IT industry have been successful in overcoming such coordination problems and stimulated the performance of this industry and closely related industries. Our findings suggest that the results have been very modest and that the IT programs were largely unsuccessful[42].

40. Dagens Næringsliv, 13.11.97, p.8.
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, pp. 271-2), summarizing a number of studies on the history of Norwegian technology policy from World War II onwards, draw a similar conclusion.

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

The coordination problems created by complementary innovative activities across different firms seem in many cases to be at least partly resolved by private institutions such as industry associations, privately funded research joint ventures and other cooperative research agreements. In future research it could be interesting to examine more directly the role of such cooperative activities[43].

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