From growth theory to technology policy - coordination problems in theory and practice

by

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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 signi...cance for economic growth. An interesting part of this research identi...es coordination problems in the introduction of GPTs, and the potentially large bene...ts in coordinating research and product development. Thinking about information technology as a GPT, with the associated coordination problems, seems to ...t well with the motivation behind governmental support schemes to IT and related high-tech industries in Norway. The ...rst 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 pro...ts in the IT and IT-related industries. In the ...nal part of the paper we discuss some of the lessons about the problems with technology policy at a practical level.

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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 e¤ort 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 e¤ort. 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 ...rst 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 ...rst part of this analysis we compare the performance of targeted ...rms to other ...rms 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 ...nally 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 justi...ed 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 o¤'[1], while other equilibria correspond to the industry 'taking o¤' and starting on a cumulative growth process[2]. It is the complementarity in activities across independent …rms, 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 e¤ects 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 …elds 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.

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, di¤use 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

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[1]See the appendix in Da Rin and Hellman (1997) for a formal discussion of the notion of critical mass and take o¤ 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).

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

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 pro...table. A better GPT will in turn widen its usefulness in the application sectors and thereby make further complementary innovations in the application sectors pro...table. 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 bene...t 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 di¤erent application sectors. This creates further pecuniary externalities, and a need for coordinating innovations both between the GPT and each application sector and between di¤erent 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. Speci...c innovations in the application sectors can only be implemented pro...tably 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 signi...cant 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. Di₵culties in forecasting and coordinating the technological developments in the GPT or in the various application sectors can lower the rate of technical advance, di¤usion 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. di¤erent 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 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 ...eld for manufacturing growth, and furthermore its general signi...cance
> for increasing productivity and growth in other industries and services.

This argument was elaborated on in the report from the o¢cial 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 di¤erent 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

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

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.

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 ...rms, 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 a total budget of NOK 4.4 billion[10] and included a number of 'subprograms' (see below).

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

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[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 Scienti...c 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. 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.

for Information Technology[11], and 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 ...rms [which were mainly ...rms 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 ...rms, with the ten largest recipients receiving 35 percent of the funds. These ...rms were producing electronic products, telecommunication equipment, instruments and computers[15]. The largest recipient, Norsk Data, received

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[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 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.

[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 re‡ects the size of the funding.

by itself more than 12 percent of the budget allocated to ...rms[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 scienti...c 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 signi...cant 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 e¤ects of the IT-policy

Based on the theoretical arguments related to GPTs, one would expect the IT programs and the coordination e¤ort to stimulate economic performance in the targeted ...rms 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

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[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 scienti...c research in universities was NOK 1297 Mill. Publicly funded R&D in private ...rms was NOK 465 Mill. in 1989.

with observed outcomes in a number of ways. Our ...rst approach is based on comparing the performance of the ...rms receiving R&D support to other ...rms operating in the same industries, and the prediction we consider is that the supported ...rms performed better than other ...rms. The hypothesis is that the supported ...rms belong to targeted technology groups which will bene...t more from the IT programs and are more able to exploit the innovative opportunities related to IT than other ...rms in the IT industry.

One can argue that the comparison between supported and other ...rms in the same industry is too narrow a view and that the IT-programs have created bene...ts for all ...rms 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 ...nally, 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 de...ne the IT or information technology industry as consisting of the manufacture of o¢ce 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 e¤ects. However, related sectors also received signi...cant support, and many companies have both production and research activities covering a broader class of products. Due to this and due to the associated classi...cation 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 ...gures are de‡ated 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 ...nanced about 6 percent of the total R&D investments in these industries in 1987 and about 3

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[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 de...ned 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.

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 ...rms
Short and medium run e¤ects of public R&D support

It is di¢cult to ...nd one variable that de...nes the success of a ...rm. We therefore study the e¤ect of receiving public R&D support on a variety of di¤erent performance measures. Furthermore, as there is no theoretical model predicting how a particular level of subsidy will a¤ect these di¤erent measures, we use a simple dummy variable approach, following Irwin and Klenow (1996). Our basic idea is to compare subsidized and non-subsidized ...rms to clarify whether subsidized ...rms 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 ...les of the Norwegian manufacturing statistics collected by Statistics Norway, we have constructed eight performance measures containing information on four di¤erent aspects of ...rm success. Information on R&D and R&D subsidies is merged in from the R&D surveys conducted by the Royal Norwegian Council for Scienti...c 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 to the year of observation. We do not expect a small subsidy to have much e¤ect on performance, and therefore we do not distinguish between zero and less than a ...ve percent subsidy share. On the other hand, a large subsidy might a¤ect a ...rm di¤erently 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 de...nitions, 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 appendix gives further details on sample and variable construction.

We have regressed each performance measure on the two subsidy dummies and all regressions include time and industry dummies. It is possible that signi...cant coe¢cients on the subsidy dummies are due to reversed causality, i.e. that successful, or possibly unsuccessful, ...rms have a better chance of receiving subsidies. This can, at least partly, be controlled for by introducing

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[20] Firms with a subsidy share exceeding 25 percent are quite similar to other ...rms with respect to size, capital intensity and pro...t 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 ...rms account for 33 percent of total R&D in the high tech industries we consider.

plant speci...c ...xed e¤ects, which is equivalent to measuring all variables as deviations from the ...rm speci...c means. Unfortunately, this comes at a cost, as the downward bias on the estimated coe₵cients 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 ...rm 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 ...rms. This is essential since several of the largest IT-...rms, 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 ...rms and other ...rms in the discussion of our results, rather than more precise terms such as plants belonging to R&D performing ...rms.

We start out by analyzing the e¤ect of subsidies on ...rm growth, and the results are given in the ...rst 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 ...xed e¤ects. 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 di¤erences between subsidized and non-subsidized ...rms. The point estimates are negative but statistically insigni...cant for ...rms receiving between 5 and 25 percent subsidies, and positive or close to zero (but statistically insigni...cant) for ...rms receiving more than 25 percent subsidies[22]. In passing, we notice that the results in Table 2 also show that R&D ...rms have on average grown more slowly than non-R&D ...rms, both in terms of man-hours and sales[23].

The e¤ect of subsidies on pro...tability are examined in column 3 and 4 in Table 2. We measure pro...tability both as return to assets and by the pro...t 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 signi...cant coe₵cients emerging from these regressions, whether estimated with or without ...xed e¤ects. Neither does column 4 show any signi...cant di¤erence in the pro...t margins between ...rms with and without R&D subsidies. However, there seems to be a general characteristic of all R&D performing ...rms that they have higher pro...t margins than ...rms without R&D, as shown by the positive and signi...cant coe₵cient for the dummy for ...rms reporting R&D.

Turning to the e¤ect of subsidies on productivity, the regression results are reported in

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[21] Cf. Griliches and Hausman (1986).

[22] This e¤ect is given by the sum of the two coe₵cients. Testing robustness, we have found that the results presented in Table 2 are largely unchanged if we neglect the ...rms receiving large, defense related R&D contracts.

[23] This is consistent with the ...ndings reported in Klette and Førre (1998).

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 ...rms have a lower level of productivity, and the di¤erences are statistically highly signi...cant when ...xed e¤ects are included.

The e¤ect of subsidies on the investment intensity is reported in column 7 in Table 2. The investment intensity is de...ned 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 ...rm's R&D projects, particularly after industry di¤erences have been controlled for. Looking at column 7, we ...nd that there are no systematic di¤erences between subsidized and non-subsidized ...rms 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 signi...cant di¤erence between the intensity of privately ...nanced R&D in subsidized and non-subsidized ...rms. In an ongoing companion study, Klette and Møen (1998), we examine the e¤ect of R&D subsidies on private R&D expenditure in more detail, applying various econometric approaches. Preliminary results from that study con...rm that subsidies do have a little e¤ect on private R&D expenditure.

Longer run e¤ects

Studying the e¤ect of R&D within the high tech industries, it is customary to assume a one year lag between the R&D investments and the ...rst e¤ect on production. This is justi...ed 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 de...ned 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 e¤ect 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 e¤ect than an e¤ect 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 ...rms that existed in 1985, over the entire decade 1985 to 1995. We have de...ned subsidized ...rms as ...rms who had more than ...ve percent of their R&D expenses over the years 1985 to 1993 ...nanced by the government and we have aggregated

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

across all ...rms in each group[25]. The results are reported in Table 3. Once again we have used several di¤erent performance measures, and we have deliberately chosen measures that are easy to interpret.

Looking at Table 3, we may ...rst note that subsidized ...rms have a higher R&D intensity than non-subsidized ...rms. This indicates that the chance of getting R&D subsidies has been greater for the R&D intensive ...rms. 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 ...rms, 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 ...rms have performed better than the subsidized ones. Looking at labor productivity, we ...nd that both the level and the growth rate were of about the same magnitude for the two groups. However, as the subsidized ...rms 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 ...rms with respect to total factor productivity. Turning to pro...tability which might be considered the most important measure,

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[25] In an earlier version of this paper, Klette and Møen (1998), we also considered the performance of the median ...rm in each group, and we examined di¤erences in performance within the more narrowly de...ned IT-industry. Considering the IT industry narrowly de...ned, there is some evidence that the subsidized ...rms have performed better than the non-subsidized ones, but the evidence is not very strong.

the non-subsidized ...rms were the most pro...table both in the beginning and in the end of the period, and the subsidized ...rms had by 1995 not even caught up with the 1985 level of the non-subsidized ...rms. On the other hand, the subsidized ...rms did have a stronger growth in pro...tability than the non-subsidized ones. Finally, looking at the exit rate given in the last row, we see that there is no signi...cant di¤erence 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 e¤orts 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 signi...cantly[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

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

their R&D ...nanced by subsidies than the corresponding OECD average. The di¤erence is most signi...cant 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 (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 signi...cantly 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 bene...ts the IT industry. Furthermore, in several OECD countries signi...cant amounts of public R&D support are given in terms of tax reliefs, and such tax allowances are not re‡ected 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 is twice as large as in other OECD countries.

Despite this reservation about the OECD numbers, we believe it is interesting to compare

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

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 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 e¤ect of these subsidies, using several di¤erent approaches and data sources. First, comparing subsidized and non-subsidized ...rms within the high tech industries, there is little evidence in favor of the subsidized ...rms 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 ...rms 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 interpretation of our results is that the public ...nancial 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.

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[28] In Klette and Møen (1998), we also examine the di¤erences 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 de...ned.

[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).

[30] In that case, however, it would still be di¢cult 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).

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 e¤orts 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 ...rms and sectors targeted by the IT-programs revealed few results suggesting that they have bene...tted signi...cantly from the ...nancial stimulation and the coordination e¤ort of the programs. These ...ndings lead to the conclusion stated above that the Norwegian governmental e¤ort to stimulate and coordinate the development of IT-products and applications have not been very successful. We are, how-ever, not the ...rst 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 di¢culties 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

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[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. How-ever, it seems likely that poor coordination at an institutional level will show up as poor coordination also at a project level and our empirical ...ndings con...rm 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.

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, o¤shore and other activities, in addition to information technology which was by far the largest among them.

Given these clearly recognized problems with the coordination e¤orts 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 coordinat-
> ing 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 super...cial 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 identi...ed or examined concrete examples of opportunities for bene...cial coordination that were missed. One interpretation of this omission is that a careful discussion of such speci...c opportunities would require a lot of detailed information and therefore would be too di¢cult or time consuming – even with the bene...ts of hindsight. The amount of information required to identify coordination opportunities is the issue that we want to consider next.

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[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 di¤erent research councils.

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 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 ...rms 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 ...rms' 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 di¢culties that face policy makers; in real coordination problems, the nature of 'the game', the pay-o¤ 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 in‡uences. These problems might be particularly relevant in a rapidly developing technological ...eld 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 ...rm 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 pro...table computer ...rm in the world in 1986[36]. However, the situation was entirely di¤erent 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 de...cits at the end of the decade and heading fast towards bankruptcy. It was ...nally dissolved and partly sold to the German ...rm 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).

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[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 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 scienti...c ...elds 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 di¢cult 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 ...rms in the same industry or ...rms 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 e¤ects if transaction costs are not high[38]. His point is that – in the presence of

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[37]Cf. Ministry of Church, Education and Research (1992).
[38]See Coase (1988) where he has elaborated on this argument.

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, 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 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.

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.

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

[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).

Our point here is only to illustrate the widespread coordination of complementary innovative activities across independent ...rms 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 identi...ed 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 ...ndings 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-o¤ structure look like and how rapidly is it likely to change? Or in less formal terms; exactly which ...rms and what activities should be coordinated and in what way? These serious questions are very hard to answer in a rapidly developing ...eld 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 di¤erent ...rms 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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[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.

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

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Data Appendix

Our econometric analysis uses merged data from R&D surveys and time series ...les 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 ...ve employees, as there is limited information on the smaller ones. See Halvorsen et al. (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 ...rm has several plants with the same three digit ISIC classi...cation, 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 ...rms.

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 Scienti...c and Industrial Research (NTNF) until 1989 and by Statistics Norway from 1991. See Skorge et al. (1996) for de...nitions and industry level ...gures. 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 ...gure 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 de...ned in a consistent way across the main OECD countries. The BERD database includes information about business enterprise R&D ...nanced 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 ...xed and nominal prices by countries and sectors.

Variable construction

Sales is measured as the value of gross production corrected for taxes and subsidies. Pro...t is measured as sales subtracted labor expenses, material expenses and rentals, added R&D expenses ...nanced by own means, as given in the R&D surveys. With respect to the stock of assets or physical capital, each plant reports the ...re 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 ...lter combining the two sources of information about the movements in the capital stock. Using the perpetual inventory method, we constructed three di¤erent estimates of the stock, based of ...gures from year t, t-1 and t+1. Our ...nal 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 de‡ated 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.

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 de...ned as observations whose capital intensity is more than ...ve times higher or smaller than the year and ...ve digit ISIC industry speci...c median value, or value added per man-hour or capital unit is ten times higher or smaller than the year and ...ve digit ISIC industry speci...c median value. Based on this de...nition 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 de...nition of outliers.

Of the 6041 time-year observations in the main sample, 1875, i.e. about 31 percent belong to ...rms 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 ...rms the median subsidy share is about 14 percent and the mean subsidy share is about 20 percent.