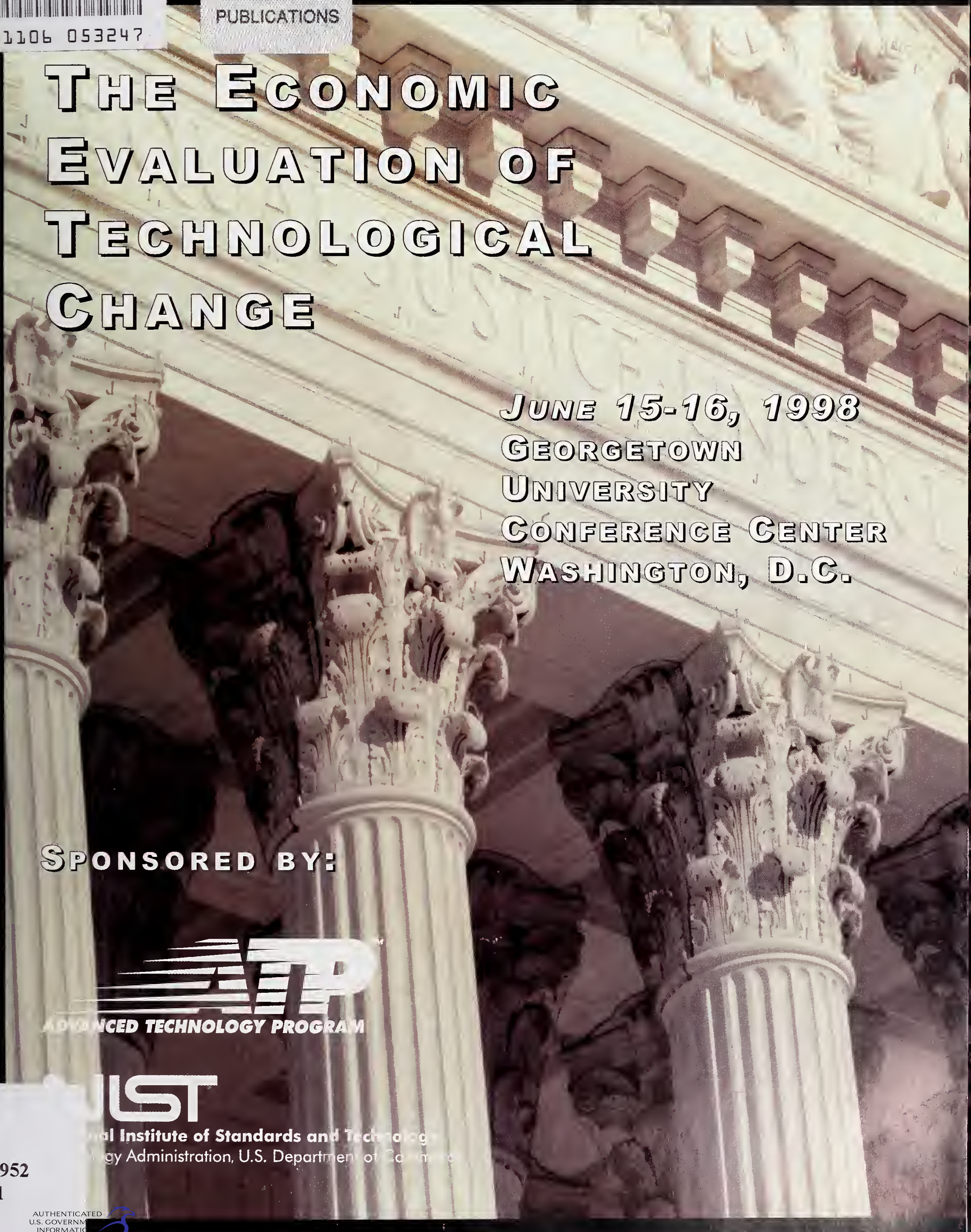

The Economic Evaluation of Technological Change

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***Papers and Proceedings* of the**
Advanced Technology Program's International Conference on the
Economic Evaluation of Technological Change

Editor's Introduction

This publication contains the *Papers and Proceedings* of the International Conference on the "Economic Evaluation of Technological Change." This collection of *Papers* relates to the evaluation of the Advanced Technology Program (ATP) and selected foreign public investment programs in technology research and development (R&D). The ATP is the nation's civilian technology program charged with improving the competitiveness of U.S. businesses by providing funding for promising high-risk technology R&D projects that are deemed to be too risky to be supported by the private sector. The common element of all Papers and presentations is an emphasis on the empirical assessment of the effects of government investment in science and technology on advanced industrial economies.

Presented papers cover a wide range of topics focusing specifically on the assessment of the effects of government technology investment programs on advanced industrial economies, and identification of outstanding issues in evaluation. The conference succeeded in bringing together from across the U.S. and the rest of the industrialized world government R&D policy-makers, analysts, R&D managers, and academic and other researchers who study technology evaluation issues. The conference advanced the state of the art of evaluating the impact of government investments of the type funded by the U.S. Department of Commerce's Advanced Technology Program in a number of ways, and furthered the dialogue on government's support for industrial R&D to achieve national and regional economic goals. As anticipated, the presentations facilitated comparisons of the evaluation methods and practices of different countries, including the role of government in the support of industrial R&D to achieve national and regional economic goals. Papers presented discussed programs in the European Union (EU), Israel, Switzerland, Norway, and Germany.

While the programs share common ground, their individual areas of focus are quite distinct. For example, the EU's Fifth Framework Program for Research and Technological Development (RTD) incorporates research themes which are grouped by socio-economic objectives rather than by technology topics as was the case for focused programs in the ATP. Switzerland's program for funding industrial R&D is focused upon fostering collaborations between academic institutions and the private sector, enabling Swiss companies to participate in international R&D programs, providing training for small- and mid-size businesses, and supporting specific industry sectors. The ATP also encourages collaboration, but technology transfer from universities to industry is not the central thrust of the program. Norway's emphasis is on involving users of technology in directing the research projects, while the ATP's focus is upon the innovator. Germany's Science and Technology program underscores the "environment shaping conditions" (market institutions that influence innovation) of its programs while the ATP's institution-building role is more direct.

Advanced Technology Program

The Advanced Technology Program (ATP) is a cost-sharing program designed to partner the federal government with the private sector to further both the development and dissemination of "high-risk"[1] technologies which offer the potential for significant, broad-based economic benefits for the nation. ATP awards are made to individual companies as well as to research joint ventures for the purpose of encouraging industry to accelerate the creation and commercialization of enabling technologies that are expected to yield large economic benefits extending significantly beyond the direct benefits to award recipients.

Rosalie Ruegg, Director of the Economic Assessment Office of ATP, in her opening remarks, describes ATP as "...a relatively recent component among United States strategies to foster innovation in the civilian sector. It is unique in having as its main long-term goal that of economic growth. In contrast, the U.S. mission agencies, such as the Department of Defense and the Department of Energy, often also call out the importance of the economic effects of research they fund, but their first priority is, respectively, defense and energy."

Ruegg identifies ATP's focus as being centered on technologies that offer the potential for substantial increases in productivity and competitiveness of firms, provide consumers with new, better, and lower-cost products and services, and increase high-wage employment in the United States. To accomplish its mission, ATP relies on the presence of expected private returns to induce companies to be willing to plan, propose, and cost-share research with the ATP, and, if the research is successful in overcoming the technical hurdles, to pursue commercial development of the new technology with private capital. The ATP applies the same criteria to the many proposals it receives from companies. It selects for public funding those projects whose potential social rate of return is expected to far exceed the private rate of return on investment. Furthermore, ATP funds only those projects which the private sector is either not going to undertake at all by itself or is not going to undertake at a scale, speed, and scope necessary to realize the large social benefit potential.

ATP Evaluation

The ATP initiated an evaluation program at its outset, as a management tool to enable the program to meet its mission better and operate more efficiently, and to meet the many external requirements and requests for ATP program results as well.

Requests for evaluation outcomes arrive from many directions, from individual members of Congress and their staff, from Congressional subcommittees, the General Accounting Office, the Executive Office of the President, the Office of Management and Budget, the Office of the Inspector General, the press, think tanks, industry groups, and others.

In addition, ATP, like other federal programs, is subject to the evaluation requirements of the 1993 Government Performance and Results Act (GPRA). The GPRA resulted from a bipartisan effort to improve accountability, productivity, and effectiveness of federal programs through strategic planning, goal setting, and performance assessment. ATP/NIST is developing assessment plans and techniques, producing measures of program performance and carrying out evaluation studies in compliance with GPRA.

Since its inception in 1990, through 1998 ATP has held 39 competitions resulting in 431 awards to single companies and joint ventures, involving over 1,000 project participants. The ATP has awarded approximately $1,386 million, and industry has provided approximately $1,397 million in matching funds during this same period.

Papers and Proceedings

The Proceedings include remarks made in the opening session and by the Luncheon and Keynote Speakers, and the responses prepared by Discussants who participated in the two conference panels, as well as papers presented in the panel sessions. The Papers constitute the greater part of the volume.

It should be noted that not all of the material presented at the conference is encompassed in these pages. In the case of the conference Papers as well as the Panel Sessions, several of the discussants' comments were not made available to the editor. Only outlines of the presentations of the luncheon speakers are available.

Acknowledgements

Putting together a first-time conference that includes experts in the field from around the world requires a great deal of assistance. I am indebted to a group of highly talented individuals for their help in bringing this conference to fruition. Lee Branstetter, the conference co-chair, participated in every stage of the planning process from the development of the conference theme to the selection of papers for presentation. Janet Brumby and Cindy Smith capably handled the voluminous correspondence associated with the travel arrangements. Toni Nashwinter and her staff met the challenge of mailing the conference announcements. Kathy Kilmer and Tammie Grice of the NIST Conference Department were instrumental in guaranteeing the smooth operation of the conference. Finally, I would like to thank Rosalie Ruegg, Maryellen Kelley and Connie Chang for providing editorial assistance.

CONFERENCE OVERVIEW

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Purpose

The purpose of the conference is to present papers that deal with the assessment of the effects of government investment in enabling technologies on advanced industrial economics including an examination of the theoretical underpinnings of the need for public investment in R&D efforts as well as a review of selected national programs. The intention is to advance the state of the art of evaluating the impact of government investments of the type funded by ATP. The conference brought together from across the U.S. and the rest of the industrialized world, government R&D policy-makers, analysts, R&D managers, and academic and other researchers who study technology evaluation issues. It is anticipated that the presentations will facilitate comparisons of the evaluation methods and practices of different countries as well as facilitate learning across national borders. The conference is one of a set of activities comprising ATP's economic evaluation program. Other evaluation activities include conducting case studies, data compilation, statistical and econometric analyses, and model building.

Selection Process

Abstracts of papers addressing the following subject areas were solicited: measurement of R&D spillovers, collaborative research and development, the impact of subsidies and tax incentives on private sector research and development activities, capital market imperfections and implications for private sector funding of R&D, substitution and complementarity between private and public R&D, and issues concerning the commercialization of science. A Call for Papers was issued through a variety of sources including the Commerce Business Daily (CBD), the web page of ATP, the web page of the National Bureau of Economic Research (NBER), as well as web pages of various universities and international organizations. Priority was placed upon empirical research, although applied theoretical papers were also considered. Selection was made on the basis of abstracts of no more than 500 words in length.

Fifty abstracts were submitted from government agencies and academic institutions from around the world including France, Germany, Italy, Switzerland, Norway, Australia, Romania, and China. In addition to the issues identified in the solicitation notice, several abstracts described foreign public investment programs similar in nature to the ATP. Five abstracts were selected for full paper development and presentation at the conference. An additional five papers were selected for presentation from studies funded by the Advanced Technology Program's Economic Assessment Office (ATP/EAO).[1] Selections were made by the conference co-chairs, Dr. Richard N. Spivack of the ATP/EAO and Dr. Lee Branstetter of the University of California at Davis and the NBER. Discussants were identified to offer critical remarks following the presentation of each paper.

Panel Sessions

Two panel sessions consisting of both academics and government representatives from several countries who have had years of experience in either researching government technology programs or in administering them were tasked with addressing the following topics. The panel titled "Publicly Financed Research Consortia" was chaired by Rosalie Ruegg, Director of the ATP/EAO, and included: Dr. Luke Georghiou of PREST, UK; Dr. Francois Sand of the EUREKA Secretariat, Belgium; Dr. Giovanni Abramo of the Consiglio Nazionale delle Recerche, Italy; and, Dr. Mariko Sakakibara formerly of the Ministry of International Trade and Industry (MITI), Japan, currently on the faculty of UCLA.

The panel that addressed the topic of "Public-Private Partnerships in R&D: Lessons Learned" was chaired by Maryellen Kelley, Senior Economist at the ATP/EAO, and consisted of: Mr. Liam O'Sullivan of the European Commission, Belgium; Dr. Phillipe Laredo of the Centre de Sociologies de l'Innovation, France; Mr. Ralph Lattimore of the Productivity Commission, Australia; and, Dr. Adam Jaffe of Brandeis University

Each member of the respective panel sessions was provided with the same set of questions in advance of the conference in an attempt to focus the discussion. The questions for the first panel, "Publicly Financed Research Consortia," were as follows: 1) *What sorts of technologies, e.g., infra structural, should be targeted in research consortia?* 2) *What is the appropriate mix of participating firms in research consortia in terms of size, technological strength, etc?* 3) *To what extent should the funding government agency attempt to actively participate in the project?*

The questions for the second panel, "Public-Private Partnerships in R&D: Lessons Learned," were as follows: 1) Why are we having this conference and how can one benefit from it. 2) Which methodologies appear most promising for current usage and which ones need further development? 3) What are the multiple purposes and rationales for such partnerships from a public policy perspective and from the perspective of private industry? 4) Consider how these rationales and the foci of

[1] The subject areas presented do not include the assessment of ATP's impact, *per se*, nor do they address ATP's operating procedures. Instead, authors were asked to write about the theoretical approaches of assessing economic impact.

technology policy initiatives vary among countries: related to economic development, policy priorities, strengths/weaknesses of the private sector. Each discussant was allowed to review their initial responses in light of the ensuing panel discussion before submitting them for publication.

Keynote Speakers

Three keynote speakers recognized as leading authorities in their field offered insights on the following areas of interest: the impact of computers on worker productivity, the decision-making process of selected U.S. corporations regarding the funding of R&D, and an oral history of the evolution of the economics of technological development as an economics subfield. The speakers are: Professor Rebecca Henderson of the Massachusetts Institute of Technology and the NBER, Professor Zvi Griliches of Harvard University and the NBER, and Dr. Jack Triplett of the Brookings Institution.

Conference Theme

The over-arching conference theme is the empirical assessment of the effects of science and technology promotion policies in advanced industrial societies. The intention is to bring together policy practitioners from advanced industrial economies with academic researchers working on evaluation issues in order to present and compare the experience in policies and policy evaluation methods and practices in different countries.

The papers are grouped into four themes. The first theme; "The Case for Public Policy: Market-based Problems Affecting the Innovation Process," examines the private capital markets' role in providing sufficient funds for high-risk technology R&D as well as the ability of developers to receive sufficient compensation when their efforts result in social benefits far exceeding private benefits. The second theme; "Policy Goals and Program Design Issues," traces the effect of differences in program design and objectives on the evaluation approach. The third theme; "Evaluation of National Programs," discusses differing measures of success and failure in terms of selected outcomes measures. Lastly, the fourth theme; "Metrics of Evaluating Public R&D Programs," presents different methodologies for assessing program impact.

Theme 1: The Case for Public Policy: Market-based Problems Affecting the Innovation Process.

An economic rationale for public sector support of developing high-risk technologies is that there exists an inadequate supply of private sector funds available for high-risk enabling technology projects. This deficiency could be attributable to a variety of factors including the risky and long-term nature of most R&D projects, and the substantial opportunity costs associated with long-term investments, as well as problems in appropriability, whereby "spillovers" occur and the returns from the innovation are not sufficiently captured by the innovator to warrant investment. Where the social rate of return is greater than the private rate of return to the innovating firm underinvestment tends to occur. The existence of spillovers implies that private firms will invest less than is socially desirable in R&D, with the result that some desirable research projects will not be undertaken, and others will be undertaken more slowly or on a smaller scale than is socially desirable. Problems with the flow of funding which create "financing gaps" also can result in underinvestment in projects with potentially high social benefits. This economic rationale underlies the very foundation of the ATP.

The papers synopsized below address the rationale for public funding of enabling technologies by discussing topics such as the "financial gaps" that exist in the debt and equity markets, and the impact of spillovers on the appropriability of rents as an important determinant of innovative activity.

Private Capital Markets in the U.S.

Lerner and Gompers focus on the adequacy of private sector financing of young entrepreneurial firms, as well as the ability of public programs to supplement private funding. Rather than considering the whole range of financial alternatives available to small high-technology firms, they concentrate on one financial intermediary: the venture capital organization. Citing the recent literature regarding the growing concern about the adequacy of private sector mechanisms in providing financing of young entrepreneurial firms, especially technology intensive ones, they note that capital constraints appear to limit R&D expenditures, especially in smaller firms. They claim that problems in the debt and equity markets are contributing to "financial gaps" which appear to be a consequence of the information gaps that exist between entrepreneurs and investors.

The authors deduce that as a source of financing for small high-technology firms, venture capital has certain limitations. Because of the unevenness (over time) of the flows into venture funds and the concentration of investments by venture capitalists in a narrow array of technologies, there continues to be a gap between the willingness and capability of these private sector sources to fund the broad array of industrial R&D activities that are socially beneficial.

Concluding that a "financial gap" continues to exist despite the growth in venture capital funds, Lerner and Gompers endorse the need for policies and programs such as the ATP to fill these gaps.

Appropriability Conditions and R&D Investment

The impact of spillovers on the appropriability of economic rents from R&D is seen by **Cohen and Walsh** as an important determinant of innovative activity and performance as well as a key concept motivating policy interventions in support of industrial R&D. Appropriability is characterized as the degree to which different appropriability mechanisms (e.g., secrecy, patents) or strategies increase the returns to the firm from its R&D investments. While there is now strong evidence supporting the argument that R&D spillovers have important effects on innovative performance and productivity growth, empirical analyses of the direct effects of appropriability on the conduct of R&D has proven elusive.

In an effort to address this short-coming, the authors test an empirical model relating R&D information flows, appropriability and R&D intensity to one another. Drawing on the results of their 1994 survey of R&D directors of large U.S. companies Cohen and Walsh find that the more effective the appropriability mechanisms in protecting the profits attributable to invention, the greater are the incentives to conduct R&D.

The authors present a methodology equipped with measures of appropriability that may be used to rank industries with respect to their appropriability conditions. The authors conclude that these measures can provide a basis for identifying industries where appropriability is weakest, and, hence, where the need for ATP is greatest.

Theme 2: Policy Goals and Program Design Issues.

The evolution of government science and technology programs entails a natural shift in focus brought about by changing political and economic environments. The following papers focus upon the significance of these changes in program design in shaping the approach to program evaluation. ATP, while still in its formative years, has focused on "spillovers" from technology diffusion as an important mechanism by which innovation contributes to economic growth. By contrast, Germany's science and technology policies have only very recently begun emphasizing the importance of spillovers.

Advanced Technology Program

In a program such as ATP, spillovers may hold the key to most of the economic benefits generated as a result of the program but in the economic literature few methodologies exist to measure their impact. In his dinner speech **Griliches**, discussing his earlier work in the field of the economics of science and technology R&D, observed that "...it was obvious that what was missing was some accounting for spillovers of R&D results and other sources of new knowledge across firms, industries, and countries. The overall conclusion was that spillovers seem to be there and are important." While assessing private and social benefits, the ATP has focused its evaluation efforts on assessing the extent and nature of the spillovers from public-private partnering in R&D activities.

German Science and Technology Policy

Over the past two decades the German Science & Technology (S&T) programs have evolved from a general scientific and basic research orientation into a focused policy instrument for industrial innovation. The current rationale for the programs rests upon issues of market failure and the role of the government in "shaping conditions" conducive to technology R&D with minimal state intervention. Adopting the term "diffusion-oriented" the German S&T programs incorporate the notion that the invention and initial commercial exploitation of new products and processes matter less than the rapid and widespread diffusion of that technology.

Dreher and Kuhlmann present an overview of the German S&T programs including a history of program evaluation and an overview of the many evaluation instruments with an assessment of how they could be utilized by future users. The experience of nearly two decades of program evaluation have established an evaluation studies research community in Germany in the fields of economics and social sciences covering a relatively broad range of methodological approaches and evaluation instruments. As the German S&T policy has evolved from a scientific and basic research orientation towards use as an instrument for industrial innovation, there has been a growing interest in evaluation metrics.

Advocates of public sector support for the private development of high risk technologies base their support on theories of market failure. On the other hand, opponents discount such theories of market failure and focus on perceived discrepancies between the decision making rationales of passive bureaucrats and those of active entrepreneurs. Such discrepancies, they argue, lead bureaucrats to a less than optimal selection process for both projects and technologies. As a consequence, administrators of government programs are presumed to lack the information necessary for proper decision making and therefore lack sufficient information necessary for proper decision making. The result is a German S&T policy best described as 'diffusion-oriented' rather than 'mission-oriented' with an orientation towards an environment shaping policy in which there appears to be the lack of a comprehensive theoretical model of technological change which includes action by the state as an active determinant, other then simply 'shaping conditions'.

The German S&T "diffusion-oriented" policy fits well within the overall objective of having the state act as the guarantor of a high level of basic research and a sound technology base for industry while not being regarded as a 'director' of industry. **Arvanitis, et al**, observed a similar premise in their investigation of the Swiss technology programs.

ATP may also be classified as "diffusion-oriented" rather than "mission-oriented," but further similarities with the German and Swiss programs beyond this classification scheme are quite limited especially when the discussion turns to the "environment shaping conditions" of these programs.

Spillovers from Innovation

Fogarty, Sinha, and Jaffe present an analysis of technical interrelations using patent data that they suggest may provide a useful framework for developing ATP strategies. Specifically, they suggest that clusters of interrelated technologies may indicate industries with large spillover potentials. The authors conclude that ATP's funded projects may produce more influential spillovers if selection is based upon knowledge of the network of ties between R&D organizations. Technologies that involve such links are taken by Fogarty et al. to indicate the influence of enabling technologies. Finally, the methodology could be useful in providing a possible approach to measuring the "spillover gap."

Fogarty, Sinha, and Jaffe's paper addresses a deficiency in existing methodologies that utilize patent information to measure spillovers in which weights are assigned to patents simply by the quantity of citations. In these models it is often assumed that 'all patent citations are equal' (assigned a value of 1). The authors improve upon this analysis by applying a fuzzy 'systems' methodology which allows them to develop indicative membership measures between 0 and 1 representing the strength of the interaction between any pairwise combination of R&D labs, specific to organization, technology, and region. They believe that this approach renders new, deeper insights into innovation as well as allowing important tests of R&D spillover hypotheses with relevance to ATP and similar government support programs.

Using the R&D lab as the basic unit of measurement their fuzzy system methodology represents R&D networks as a function of the influences of R&D labs among one another's patenting activity. By a 'system' they refer to the existence of a hierarchy of technologies, R&D organizations, and regions connected by a communication network. System effects occur when a change in any component diffuses throughout the network. They reason that the notion of an innovation system is intuitively appealing and is consistent with existing evidence on R&D spillovers.

From their analysis, Fogarty, Sinha, and Jaffe suggest that there is an underlying 'spillover network' structure. Further research is needed to identify the spillover mechanisms and the factors affecting progress along various diffusion pathways.

Theme 3: Evaluation of National Programs.

Several papers were presented in which selected foreign programs' evaluation practices were discussed, highlighting the similarities as well as differences between the various national programs. Some of the variance in programs may be ascribed to the differences in the cultural and political environments existing in the countries, while other discrepancies may be attributable to a mix of technology specific factors. For the most part, conference participants shared the view that market structures lead to sub-optimal results in selected areas in which governments are attempting to increase innovative activity.

Public investment programs in technology R&D can be found in many countries of varying sizes and economic maturity around the world. These government programs emphasize the importance of innovation to economic prosperity by providing financial assistance to firms and other entities and fostering collaboration as a mechanism for solving larger, more complex research problems. From a policy standpoint, several programs which started out with a scientific and basic research orientation have migrated into policy for industrial innovation. **O'Sullivan,** commenting on the European Union programs, observed that R&D policy was once viewed mainly as an instrument of microeconomic policy, but is now viewed as an economic policy tool which also has macroeconomic significance. **Dreher and Kuhlmann** concur with this view for the case of German Science and Technology programs.

The evaluation of the European Union's Framework Programs[2] consists of continuous monitoring of project activities, annual reporting, and five-year assessments, carried out midway through program implementation. The criteria include relevance of objectives, efficiency of operation and effectiveness in terms of objectives achievement, "European added value" and dissemination/exploitation of results. Applying these methodologies to the new challenges brought about by the introduction of the Fifth Framework Program has required evaluation metrics of regional economic and social benefits. Evaluation studies are now expected to deliver assessments of multiple goals, including evidence of the degree to which technical

[2] The EU Framework Programs for Research and Technological Development was created in 1984 and are structured to set strategic goals for community research over five-year time horizons.

objectives (defined as industrial competitiveness) are achieved and broad social objectives are met (e.g., creation of employment, distributional issues, etc.). These assessment criteria are relatively new. Progress in meeting objectives under the core goal of improving the competitiveness of European industry is still an important evaluation criterion as well.

This is in stark contrast to the evaluation requirements of ATP, whose overall goal is the diffusion of technologies and the creation of broad-based economic benefits through commercialization activities of the funded firms and through various spillover pathways. The Fifth Framework Programmes' objectives are expressed in terms of socio-economic problem solving. **Laredo** noted that a keyword in this conference for justifying public intervention in innovation was in his opinion "spillovers". He noted that nearly all of the U.S. presentations at the conference emphasized the importance of spillovers in assessing the benefits from the ATP, whereas references to spillovers were completely absent from the presentations concerning other countries.

Sand, drawing upon his experiences from the EUREKA[3] program, discussed the importance of the "partnering" or "risk sharing" aspects of the European public support programs whereby public funds are provided to permit the participants to take a risk that they would not have taken alone. **Georghiou** notes that there is also a rationale for targeting specific technical areas in certain circumstances. These include those areas where co-ordination of the R&D activities can improve the pace at which innovations are commercialized. ATP's "focused" programs[4], in which industry groups identify a cluster of technologies, or a set of problems that may be attacked with a number of different (but related) approaches, may be seen as an example of Georghiou's point. In a focused program, multiple projects are funded in the same area.

Estimating Social Welfare Benefits: Israeli Industrial Programs

Griliches and Regev discuss the various support institutions and programs that were created over the past 20 years by the Israeli government in a concerted, large scale effort to develop and promote science-based, high-tech industrial sectors. For Israel, the scarcity of natural resources, the small size of the economy and the presence of a highly educated workforce, led policy makers to emphasize economic policies where innovation and technical change could lead to a high growth path.

Previous research by Griliches and Lichtenberg[5] on U.S. defense-related R&D expenditures showed a negative effect of public R&D investment on industry productivity. Public funding of industry R&D undertaken by firms for purposes other than in response to the needs of defense agencies or some other government mission is relatively new in the United States. Hence, previous research showing an absence of social benefits from public investment in industry R&D is not informative about the effects of public R&D spending in a program such as ATP. **Griliches** and **Regev** explore the impact of a program in Israel that has provided funding to firms for their own R&D activities for more the 20 years. In this paper, the authors examine the effects of an Israeli government-supported R&D program on the productivity of those firms.

They estimate the effects of the Israeli government's R&D program on Israeli firms' productivity (measured as the firm's output per person year) in econometric models using four different estimation procedures. In all regressions, the effect of government funded R&D is always positive and statistically significant in almost all of the estimated models. **Griliches** and **Regev** consider these estimates to be higher than what they expected. They attribute the results to two possible features of public funding programs. The first explanation is that there is a selection effect underlying these results, meaning that the firms who apply to the government and are awarded funds have better R&D projects than those who don't apply and don't win. The second explanation is that these effects reflect heterogeneity among firms in their capabilities and that the government office responsible for selection is able to discern these differences. Both explanations support the conclusion that there is a substantial program effect on Israeli firm performance. These estimates may be refined in future work to include measures of the "permanent" attributes of firms related to their R&D capabilities and other variables.

Griliches and Regev conclude "that the mechanisms that allocate R&D dollars seem to be doing their work properly in most cases, and the more they manage to 'pick winners' the better." Development of methodologies that will assist in the selection process to improve the ability of programs to correctly

[3] Based in Brussels, the EUREKA Initiative was launched in 1985, providing a framework for international collaboration in the area of advanced technologies among firms, research institutes and universities with the aim of strengthening the productivity and competitiveness of Europe's industries.

[4] Beginning with the 1999 Competition, ATP replaced focused program competitions it had since 1994 and the General Competition with an Open Competition consisting of five "technology boards" to assess project proposals.

[5] Griliches, Zvi and Frank Lichtenberg, "R&D and Productivity at the Industry Level: Is There Still a Relationship?" In Z. Griliches (ed.), R&D, Patents and Productivity. Chicago: University of Chicago Press, pp. 465-496. 1984.

diagnose a firm's and a technology's potential may, therefore, increase the continued success of such programs.

Estimating Social Welfare Benefits: Norwegian Industrial Programs

Klette and Moen reach a conclusion contrary to that of Griliches and Regev regarding the effectiveness of R&D public support programs. They examine the Norwegian government's initiative implemented in the 1980's for the Information Technology (IT) industry and test a hypothesis that public policy interventions occur when generic or general purpose technologies (GPT's) are involved. (GPT's are defined as having wide applicability and possessing the potential for significant economic growth). They present a quantitative analysis of the IT-related technology programs in which they compare the performance of targeted firms to non-targeted firms in the same industries and then consider the development of the IT-industry and the related high-tech manufacturing sectors relative to the performance of the manufacturing sector at large. Finally, they compare the performance of these sectors in Norway to their performance in other OECD economies.

Citing the current status of economic models, including most theoretical growth models, that tend to "treat all forms of technical change in the same, diffuse manner," the authors contend that there has been little economic analysis suggesting that research and innovation associated with 'generic' technologies such as information technology require particular attention. Based on the theoretical arguments related to GPT's, and presented throughout their paper, they conclude that one would expect the IT programs and the coordination efforts which accompany them to stimulate economic performance in the targeted firms and therefore are justified in receiving government subsidies. But their research provides little evidence that industry has benefited significantly from the financial stimulation and the coordination effort of the support programs. These findings lead to the conclusion that the Norwegian government's efforts to stimulate and coordinate the development of IT-products and applications have not met with much success.

The authors' explanation for their findings can be summed up in the conception of the industrial innovation process where coordination problems and "market failure" issues are pervasive. Policy makers and bureaucrats may lack the necessary information and know-how to design programs that improve upon the existing market conditions. In contrast, ATP's approach views public policy as offering market corrections through the collaborative efforts of a "public/private partnership."

Development and Diffusion of Technology: Swiss Technology Programs

Arvanitis, Hollenstein and Lenz evaluate the Swiss government's program to promote a more rapid and broad diffusion of Advanced Manufacturing Technologies (AMT) by examining the degree to which the program achieved a level of success greater than what would have been attained by firms acting alone. Their investigation of the issue of 'additionality' is particularly interesting in light of the fact that Swiss technology policy places a relatively low emphasis upon direct measures for fostering innovation in the economy, preferring instead to create a favorable "environment" for the introduction of new products and production techniques. This "framework-oriented" policy is supplemented, though, by the use of particular initiatives to support rapid diffusion of selected basic technologies which are considered to be relevant for a broad spectrum of industrial activities.

Their results demonstrate a positive impact from the policy in the case of small firms and/or those firms adopting AMT for the first time or characterized by a low intensity of AMT use. There was no demonstrated influence on the adoption strategy of large firms. Regarding the issue of additionality, in the case of small firms they conclude that it is quite probable that subsidized R&D projects in the field of AMT, in general, might just allow firms to substitute government funds for their own. Evidence surrounding the impact of publicly supported technology R&D, in regards to the issue of additionality, often remains inconclusive. **Mariko,** citing her work on the Japanese economy, observed that the provision of government subsidies could contribute to the enhancement of technological opportunities firms face. Subsidies can reduce the effective cost of conducting R&D which, in turn, could encourage firms to undertake more R&D. But on the contrary, she also notes that though government-sponsored R&D consortia will allow firms to conduct research projects which firms would have done on a much smaller scale without government subsidies, government subsidies could be used as a substitute for a firm's spending on R&D. This makes it quite difficult to gauge the overall impact.

Theme 4: Metrics of Evaluating Public R&D Programs.

The following papers focus on the methodological aspects of evaluation using a variety of measures of outcomes and impacts, e. g., patent analysis, product quality and performance analysis, and an examination of the issue of "additionality."

As Ruegg pointed out in her opening remarks, evaluation has been practised by the ATP since the inception of the program in order to respond to both external and internal requests and needs regarding program performance. Externally, ATP has faced demands for performance measures which have been driven by policy issues. Specific requests for evaluation results have come from individual members of Congress and their staff, from Congressional subcommittees, the General Accounting Office, the Executive Office of the President, the Office of Management and Budget, the Office of Inspector General, the Press, think tanks, industry, and others. ATP has also received inquiries that are focused more on evaluation tools and methodologies than on specific evaluation results, from counterpart programs in other countries, from other Federal agencies, State and regional government agencies, universities, businesses, and consultants.

In response to these increased demands for performance results, along with the passage of the Government Performance and Results Act (1993), the Economic Assessment Office (EAO) of ATP was created in 1994 and tasked with measuring the impacts of ATP's funding of high-risk, enabling technologies, as well as investigating underlying relationships between technological change and economic phenomena.

The EAO also funds the development of new methodologies. Two of the papers discussed at the conference on the theme of metrics provide examples of new approaches to evaluation metrics (**Mowery and Austin and MaCauley**) were commissioned by the EAO.

Patent Analysis

Patent citations have often been used to trace technology diffusion. **Narin and Olivastro** believe citations from patents to papers provide direct evidence of spillovers from basic research to industrial technology and in their paper attempt to measure the spillover effects of publicly supported research onto industrial technology by analyzing more than 750,000 non-patent references listed as "other references cited" on the front pages of the U.S. patents. It is inferred that these citations are direct evidence of a massive spillover from basic research to industrial technology. By applying this technique they also seek to test the hypothesis that publicly supported science acts as a driving force behind high technology and economic growth.

The results from the Narin and Olivastro study indicate a high probability that public science does play an essential role in supporting U.S. industry, with the intensity of the linkage between patented industrial technology and public science having increased significantly over the last decade. This result is prevalent across all the science-linked areas of industry, amongst companies large and small, and appears to be a fundamental pillar for the advance of U.S. technology. The underlying hypothesis – that public science is a driving force behind high technology – seems to be strongly supported by their data analysis. Furthermore, they show that the science influencing industry is mainstream focusing upon issues of importance to the discipline. In other words the research is quite basic, quite recent, published in highly influential journals, authored at major universities and laboratories, and is supported by public and charitable institutions.

While the use of patent data as a measure of spillovers is quite common throughout the literature, **Mowery,** as well as others, questions how much information of use to other inventors patents convey, especially in the absence of methods for rival inventors to access know-how. He suggests that patents alone are insufficient to spark widespread imitation. He also observes that even if one assumes that patents do convey information, the often-lengthy lead times in their publication means that sectors in which lead time is especially important should find patents particularly unhelpful sources of information. While the precise utility of patent data as a measure of spillovers continues to stir debate it remains one of the most used measures and is often the subject of varied interpretation.

Product Quality Improvements and Performance as Measures of Program Achievement

Austin and Macauley present a method for estimating consumer surplus from planned new product innovations focusing upon the improved price-performance characteristics and benefits of those innovations for existing services. These new technologies are claimed to have leapfrogged beyond current best practice and therefore their benefits are assessed with respect to a baseline of existing, state-of-the-art technologies that are themselves continually being improved. The authors present their findings in terms of the economic value to consumers of resulting quality improvements, compared to advances that would have been expected to occur in the absence of the program.

They employ a cost-index approach using changes in quality-adjusted prices of new technologies which, under certain assumptions, provides a measure of consumer surplus. The ability to perform this calculation depends upon the structure of the downstream market in which the technology is to be applied, and is appropriate to the kinds of new technologies sponsored by ATP whose demand is typically mediated by producers using the innovations in their production processes. As long as the downstream market is competitive, or is a government agency, the producer acts as an agent for consumers when it uses an upstream technology. This activity generates a classic supply and demand curve intersect rendering the area under the "derived-demand" curve, calculated by the cost-index method, as a measure of consumer surplus.

The approach suggested by Austin and Macauley avoids the need for econometric estimation and makes it possible to perform the estimation in sectors for which output quantity and quality-adjusted output price are unobservable. Since ATP funds the R&D of technical innovations that have not yet reached the market this evaluation technique allows for predicting consumer surplus on the basis of what one currently knows about these technologies.

Additionality

Georghiou addresses the issue of "additionality," a term used in reference to whether a particular public expenditure is used 'in addition to' those funds which would have been expended by a firm in its absence or used in place of those funds. He presents a brief overview of the evaluation efforts applied to two of Europe's principal programs for the support of collaborative R&D, the European Commission's Framework Programmes and the inter-governmental EUREKA Initiative. In his assessment of these programs he focuses upon the use of evaluation metrics as a policy instrument noting their limitations. In the case of measuring the impact of public funding upon the economy as a whole, he discusses the importance of "additionality" as a policy concern. The theme of additionality has, at times, emerged in the U.S. at the center of the debate surrounding ATP. There is some concern among policy makers that funds provided by the government are a substitute for investments that the private sector should undertake on their own. In Europe the issue of "additionality" is currently at the center of a dispute between different branches of the European Commission whereby one branch advocates the demonstration of the impact of public funding on a project-by-project basis while another finds it sufficient to demonstrate the results of public funding as an overall increase in spending on R&D.

Georghiou's investigation of companies involved in collaborative R&D projects shows a substantial degree of agreement among managers about the importance of the government program in stimulating additional R&D investment by the private sector. His survey results indicate that twice as many companies would not have carried out the R&D projects as compared to those who said they would have continued even if no government funding was received. He concludes that it is not obvious whether projects with high additionality will produce greater or smaller impacts. On the one hand, one would expect firms to cover their highest priority projects with their own resources and hence put forward marginal projects for funding. This reasoning is not confirmed by the evidence from his evaluations though as there are several examples of projects with both high additionality and high subsequent impact. This result could be explained by the assumption that public funding motivates firms to undertake projects with a higher risk but also a potentially higher pay-off.

"Crowding out" refers to the phenomenon that only a limited amount of R&D can be undertaken and that when government funds R&D there will be less private-sector investment in R&D. The issue of "crowding out" was of major importance to each one of the public support programs discussed at this conference.

In regards to whether public support programs stimulate additional R&D, **Lerner and Gompers** caution that public funding in areas with extensive private financing may lead to a "crowding out" phenomenon whereby public funds may replace private expenditures for research. The total amount spent on R&D and resulting innovation may consequently not increase much in these cases, thus limiting social returns.

Dreher and Kuhlmann address the issue of additionality through their discussion of two public support programs aimed at SMEs, the R&D Personnel Costs Subsidies Program of the Federal Ministry for Economic Affairs and the Promotion of Research Personnel Growth. They conclude that - although there were some free-rider effects (crowding out)- the sponsored SMEs from the manufacturing sector greatly increased their R&D efforts.

Conclusion

A common theme expressed by many of the participants during the conference concerned the nature and the scope of the challenge in developing and implementing evaluation metrics of R&D programs. **Griliches,** in his keynote address, identified some of these challenges, "...aggregate productivity numbers are only dimly and possibly misleadingly related both to the measurement of true technical change and the impact of R&D on it, especially federally supported R&D. This is due, in part, to difficulties in productivity measurement per se, and second to the particular location of most of R&D in the industrial spectrum." The measurement difficulties are attributable to the application of current productivity measures to "...the 'unmeasurable' sectors, such as services and construction," and the growth in importance of these sectors in the overall economy.

Despite these daunting challenges, the evaluation efforts discussed at the conference offered an opportunity to highlight those tools and methodologies which offer great promise and are proving to be capable of investigating more thoroughly such themes as the "financial gaps" that result from a lack of funds for high-risk technology R&D and the calculation of returns on public investment, including those that offer more "complete" measurements by incorporating "spillovers" into the net social benefits.

ATP's goal of achieving economic benefits through technology development was shared by all of the programs discussed at the conference. How each program measured success towards reaching this goal differed significantly especially for smaller countries such as Norway, Switzerland, and Israel.

Future work must view the evaluation of technology R&D as an all-inclusive event—one in which a portfolio of methodologies exist and are applied in several areas. The Economic Assessment Office of ATP is developing such a portfolio offering a balanced approach to evaluation by covering a variety of themes believed to be essential to gaining insight into the program's impact upon the U.S. economy. The portfolio contains case studies of funded projects, analytical studies of spillovers and spillover pathways, studies identifying imperfections in the financial markets which may lead to insufficient funding for technology R&D, studies of the role of ATP in forming collaborations, and theoretical papers examining such themes as "crowding out" and "additionality."

To complement this work it is necessary to collect new types of data while at the same time develop "more appropriate" metrics capable of providing better evaluation measures. It is believed that only through such a balanced approach one may expect to gain a true understanding of the economic impacts offered by such complex programs as ATP.

THE CASE FOR PUBLIC POLICY: MARKET-BASED PROBLEMS AFFECTING THE INNOVATION PROCESS

SECTION

A

Capital Formation and Investment in Venture Markets: An Assessment of Market Imperfections

by Josh Lerner and Paul A. Gompers[1]

The recent economic literature suggests several reasons for concern about the adequacy of private sector mechanisms to finance small high-technology firms. A growing body of empirical research on capital constraints (reviewed in Hubbard [1998]) documents that an inability to obtain external financing limits many forms of business investment. Particularly relevant are works by Hall [1992], Hao and Jaffe [1993], and Himmelberg and Petersen [1994]. These show that capital constraints appear to limit research-and-development expenditures, especially in smaller firms. A related body of literature documents that investments in R&D yield high private and social rates of return (e.g., Griliches [1986], Mansfield, et al. [1977]). These findings similarly suggest that a higher level of R&D spending would be desirable.

Why are Investments in Entrepreneurial Firms Problematic?

Entrepreneurial firms often develop products and ideas that require substantial capital during the formative stages of the companies' life. Many entrepreneurs do not have sufficient funds to finance projects themselves, and they must therefore seek outside financing. But because the nature of the entrepreneurial setting, the process of raising financing can often be a troubled one.

To briefly review the types of conflicts that can emerge in these settings, Jensen and Meckling [1976] demonstrate that agency conflicts between managers and investors can affect the willingness of both debt and equity providers to invest capital. If the firm raises equity from outside investors, the manager has an incentive to engage in wasteful expenditures (e.g., lavish offices) because he may benefit disproportionately from these but does not bear their entire cost. Similarly, if the firm raises debt, the manager may increase risk to undesirable levels. Because providers of capital recognize these problems, outside investors demand a higher rate of return than would be the case if the funds were internally generated.

Even if the manager is motivated to maximize shareholder value, informational asymmetries may make raising external capital more expensive or even preclude it entirely. Myers and Majluf [1984] and Greenwald, Stiglitz, and Weiss [1984] demonstrate that equity offerings of firms may be associated with a "lemons" problem. If the manager is better informed about the firm's investment opportunities and acts in the interest of current shareholders, then managers only issue new shares when the company's stock is overvalued. Indeed, numerous studies have documented that stock prices decline upon the announcement of equity issues largely because of the negative signal that it sends to the market.

These information problems have also been shown to exist in debt markets. Stiglitz and Weiss [1981] show that if banks find it difficult to discriminate among companies, raising interest rates can have perverse selection effects. In particular, high interest rates discourage all but the highest-risk borrowers, so the quality of the loan pool declines markedly. To address this problem, banks may restrict the amount of lending rather than increasing interest rates.

These problems in the debt and equity markets are a consequence of the information gaps between the entrepreneurs and investors. If the information asymmetries could be eliminated, financing constraints would disappear. Financial economists argue that venture capital organizations can address these problems. By intensively scrutinizing firms before providing capital and then monitoring them afterwards, they can alleviate some of the information gaps and reduce capital constraints.

How Do Venture Capitalists Address These Problems?

In particular, a series of academic studies (Gompers [1995, 1997], Lerner [1994, 1995], and Sahlman [1990] are empirical examples; see Barry [1994] for an overview of the extensive theoretical literature) have documented the mechanisms that venture capitalists employ to address these challenges. We will highlight six of these responses below.

The first set relates to the financing of firms. First, from whom a firm acquires capital is not always obvious. Each source-private equity investors, corporations, and the public markets-may be appropriate for a firm at different points in its life. Furthermore, as the firm changes over time, the appropriate source of financing may change. Because the firm may be very different in the future, investors and entrepreneurs need to be able to anticipate change.

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[1] Josh Lerner and Paul A. Gompers are on the faculty of the Harvard Business School and are members of the NBER.

Second, the form of financing plays a critical role in reducing potential conflicts. Financing provided by private equity investors can be simple debt or equity, or it can involve hybrid securities like convertible preferred equity or convertible debt. These financial structures can potentially screen out overconfident or under-qualified entrepreneurs. The structure and timing of financing can also reduce the impact of uncertainty on future returns.

A third element is the division of the profits between the entrepreneurs and the investors. The most obvious aspect is the pricing of the investment: for a given cash infusion, how much of the company does the private equity investor receive? Compensation contracts can be written that align the incentives of managers and investors. Incentive compensation can be in the form of cash, stock, or options. Performance can be tied to several measures and compared to various benchmarks. Carefully designed incentive schemes can avert destructive behavior.

The second set of activities of private equity investors relates to the strategic control of the firm. Monitoring is a critical role. Both parties must ensure that proper actions are taken and that appropriate progress is being made. Critical control mechanisms-e.g., active and qualified boards of directors, the right to approve important decisions, and the ability to fire and recruit key managers-need to be effectively allocated in any relationship between an entrepreneur and investors.

Venture capital investors can also encourage firms to alter the nature of their assets and thus obtain greater financial flexibility. Patents, trademarks, and copyrights are all mechanisms to protect firm assets. Understanding the advantages and limitations of various forms of intellectual property protection, and coordinating financial and intellectual property strategies are essential to ensuring a young firm's growth. Investors can also shape firms' assets by encouraging certain strategic decisions, such as the creation of a set of "locked-in" users who rely on the firm's products.

Evaluation is the final, and perhaps most critical, element of the relationship between entrepreneurs and private equity investors. The ultimate control mechanism exercised by the private equity investors is to refuse to provide more financing to a firm. In many cases, the investor can-through direct or indirect actions-even block the firm's ability to raise capital from other sources.

The importance of these mechanisms is underscored by the success of venture-backed firms. A variety of evidence suggests that venture-backed firms are more successful than their peers:

- One illustration of this difference is in the share of the companies making the transition from private to public ownership through initial public offerings (IPOs), which typically include many of the most successful firms. In recent years, fully 30% of the IPOs have been of venture-backed firms. (Detailed summary statistics are available in Gompers and Lerner [1997].) This is much greater than the share of young firms receiving venture financing.
- Venture-backed firms are also more successful after going public. Brav and Gompers [1997] show that in the five years after going public, IPOs that had previously received equity financing from venture capitalists outperform other offerings.
- Venture capital appears to contribute to technological innovation. In a panel study of twenty industries over three decades, Kortum and Lerner [1998] demonstrate a relationship between the extent of venture financing in particular industries and their rate of patents. The pattern appears to be robust to a variety of controls for reverse causality and alternative explanations.

What Are the Limitations of Venture Capital Investment?

At the same time, venture capital appears to have important limitations as a source of financing for small high-technology firms. Both the unevenness of the inflows into venture funds and the concentration of investments within a few narrow technologies may limit its effectiveness as a source of financing.

The first of these limitations relates to the supply of venture capital. During the past twenty years, commitments to the U.S. venture capital industry have grown dramatically. This growth has not been uniform: peaks in fundraising have been followed by major retrenchments. Despite the importance of and interest in the venture capital sector, the underlying causes of these dramatic movements in venture fundraising are little understood.

In a paper titled "What Drives Venture Capital Fundraising?,"[2] we analyze these patterns systematically. We find that regulatory changes have had an important impact on commitments to venture capital funds. The Department of Labor's 1978 clarification of the prudent man rule, which enabled pension funds to freely invest in venture capital, had a generally positive effect on commitments to the industry by increasing the supply of funds.

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[2] This paper and another titled "Money Chasing Deals?" were prepared in support of this study and are available upon request from the authors.

Capital gains tax rates also appear to have an important effect on fundraising at both the industry and venture organization level. Decreases in the capital gains tax rates are associated with greater venture capital commitments. Rate changes, however, affect both taxable and tax-exempt investors almost identically. Decreases in capital gains tax rates appear to increase commitments to venture capital funds not through increases in the desire for contributions to new funds by taxable investors, but rather through increases in the demand for venture capital investments when workers have greater incentives to become entrepreneurs.

A key point to emerge from this analysis is the importance of economic policies in shaping the supply of venture capital. These shifts are largely exogenous to the nature of technological opportunities. This pattern suggests that it is by no means clear that the optimal number of small high-technology firms are receiving financing from the venture sector or that there is no role for public venture capital programs. There is also the possibility, however, that the level of venture capital funding may be too high. Furthermore, if public policy can more readily affect the demand for venture capital than the supply of funding, then it unclear whether direct grant programs such as the ATP can affect fundraising levels. The optimal level of venture capital funding and the manner in which it can be affected by the ATP program remain open research questions.

A second paper examines the narrow focus of venture capital investment. Venture capital investments are tremendously concentrated, whether measured by the technological span of the firms backed, the location of the firms, or the size of the investment. One of the key implications of "Money Chasing Deals?" is the potentially detrimental impact that this concentration can have.

Panels B and C of Table 1 document this pattern, showing the distribution of early-stage venture financings by state and Standard Industrial Classification (SIC) code in 1995. The concentration of awards in California and Massachusetts, as well as in computer software and communications sectors, is apparent.

This concentration may be problematic, whether we examine its impact on social or private returns. On the one hand, several models argue that institutional investors frequently engage in "herding": making investments that are too similar to one another. These models suggest that a variety of factors-for instance, when performance is assessed on a relative, not an absolute, basis-can lead to investors obtaining poor performance by making too similar investments. (Much of the theoretical literature is reviewed in Devenow and Welch [1996]; Sahlman and Stevenson [1986] present a case study suggesting such behavior by venture capitalists.) As a result, social welfare may suffer because value-creating investments in less popular technological and geographic areas may have been ignored.

The concentration in technological investment areas may be a matter of particular concern. An extensive literature on technology races (reviewed in Reinganum [1989]) shows how a small initial technological advantage can translate into a sustained lead. If venture capital organizations neglect making small investments into a wide variety of technologies, the long-run detrimental impact on America's competitive position may be substantial.

"Money Chasing Deals?" examines the pattern of investment during the most recent period of growth (between 1987 and 1995). As venture fundraising climbed, investments remained narrowly concentrated on healthcare and information technologies. Rather than diversifying their investments, venture groups bid up the price paid for individual investments.

We employ a dataset of over 4000 venture investments between 1987 and 1995 as well as detailed information on capital inflows. Because gaps of one to two years between refinancings of venture-backed firms are typical, a price index based purely on the changes in valuations between financings for the same company would be incomplete and misleading. We consequently employ a hedonic approach, regressing the valuation of firms on their characteristics such as age, stage of development, and industry, as well as inflow of funds into the venture capital industry. We also control for public market valuations through indexes of public market prices of firms in the same industries and average book-to-market and earnings-to-price ratios.

In this way, we seek to disaggregate whether movements in valuations reflect the flow of funds into the private equity industry or alternatively the changing composition of transactions or shifts in public market values. We find a strong relation between the valuation of venture capital investments and capital inflows. While other variables also have significant explanatory power-for instance, the marginal impact of a doubling in public market values was between a 15% and 35% increase in the valuation of private equity transactions-the inflows variable is significantly positive. A doubling of inflows into venture funds led to between a 7% and 21% increase in valuation levels. The results are robust to the use of a variety of specifications and control variables. These results corroborate practitioner claims that increasing capital inflows have led to higher security prices, or colloquially, "too much money chasing too few deals." (Three representative accounts over the decades are Noone and Rubel [1970], Sahlman and Stevenson [1986], and Asset Alternatives [1996].)

We also find that firms located in geographical areas where venture capitalists tend to concentrate and in industries that are particularly sought after increase in price even more in response to venture inflows. This suggests that attractive, underfunded opportunities exist in overlooked areas and technologies.

It is also worth noting that there is another way in which venture capital investments are concentrated: the similarities in investment size. In particular, venture funds tend to make quite substantial investments, even in young firms. For instance, the mean venture investment in a start-up or early-stage business between 1961 and 1992 was $1.8 million (in 1992 dollars) (Gompers [1995]).

The substantial size of these investments is largely a consequence of the demands of institutional investors. The typical venture organization raises a fund (structured as a limited partnership) every few years. Because investments in partnerships are often time-consuming to negotiate and monitor, institutions prefer making relatively large investments in venture funds (typically $10 million or more). Furthermore, governance and regulatory considerations lead investors to limit the share of the fund that any one limited partner holds. (The structure of venture partnerships is discussed at length in Gompers and Lerner [1996, 1999].) These pressures lead venture organizations to raise substantial funds. As the venture industry has grown, the average fund size has increased, from $30 million in 1985 to $80 million in 1995 (VentureOne [1996]). Because each firm in his portfolio must be closely scrutinized, the typical venture capitalist is responsible for no more than a dozen investments. Venture organizations are consequently unwilling to invest in very young firms that only require small capital infusions. Panel A of Table 1 compares seed and early-stage investments by venture funds with the total amount raised by these funds.

Are Alternative Financing Sources Adequate?

It may be wondered why these inefficiencies in the venture capital market should be a source of general concern, much less public intervention. A natural question is why entrepreneurial firms do not rely on the several alternative capital sources that also finance entrepreneurial firms. Can small high-technology firms raise capital from other financing sources, most notably individual investors or banks?

Both of the leading alternative sources of financing for entrepreneurial firms, however, have substantial limitations. These limitations are particularly critical in small high-technology industries that are particularly interesting to policy-makers.

The informal risk capital market consists of individuals commonly referred to as "angels." These "angels" are wealthy businessmen, doctors, lawyers, and others who are willing to take an equity stake in a fledgling company in return for seed capital. Firms that require substantial amounts of money, however, may not be able to receive sufficient capital from the "angel" network because the market is dispersed with little information sharing and the amount of invested capital tends to be small. The amount that a firm can raise from individual investors is usually much less than the minimum financing round that a venture fund will consider providing. Freear and Wetzel [1990] report that median financing round raised by private high-technology firms from individual investors was about $200,000. 82% of the rounds from individuals were under $500,000.

Similarly, bank financing is unlikely to fill the gap for technology-based firms. Companies that lack substantial tangible assets and have very uncertain prospects are unlikely to receive substantial bank loans. These firms face many years of negative earnings and are unable to make interest payments on debt obligations. This characterization applies to many, if not most, technology-based young firms.

Thus, a substantial gap exists between the resources that firms can raise from individual investors and from venture capitalists. Bank loans may also not be able to address this problem. Awards from programs such as Advanced Technology Program may partially fill these gaps, as well as addressing the concerns about the geographic and industry concentration of awards discussed above.

What Are Implications for the Advanced Technology Program?

These analyses have two primary implications for the administrators of the Advanced Technology Program. In this final section, we highlight these implications for program management.

First, the administrators should be sensitive to the importance of the venture capital sector as a source of financing. In many cases, funds from the Advanced Technology Program cannot carry the technology all the way to the marketplace. At some point, additional resources will be required. Furthermore, as discussed above, venture capitalists provide a range of services in addition to their capital. These may be difficult to duplicate through other means. Thus, venture capital is an important-and in many instances, the best-financing source as high-technology firms move new products or services from conception to the market.

A second insight is the need to tailor the Advanced Technology Program's awards to reflect the dynamics of venture capital market. This awareness is likely to lead to opportunities to maximize the return from public funds. One example is the industry concentration of venture funds discussed above. It probably makes little sense to target awards in technologies that have recently attracted heavy backing from venture investors, such as human genomics or Internet tools. Public funding in areas with extensive private financing may lead to a "crowding out" phenomenon: public funds may replace private expenditures for research. The total amount spent on R&D and resulting innovation may consequently not increase much in these cases (for a discussion of this problem, see Wallsten [1997]). Rather, it seems more sensible to target the broad array of technologies not attracting much interest from the venture community.

Similarly, it may make sense to adjust the Program's strategy during periods when venture investors are experiencing difficulties raising new funds (e.g., much of the 1970s, the late 1980s, and the early 1990s). A critical mechanism in the venture capitalist's tool-kit is the staging of investments. Giving entrepreneurs only part of the money they need and tying the possibility of refinancing to reaching a particular technological milestone helps limit venture capitalists' losses by allowing the venture capitalist to cut off funding to underperforming firms. (By way of contrast, corporations, which usually lack such disciplinary mechanisms, have been known to spend hundreds of millions of dollars on new ventures before terminating them.) During sudden fundraising droughts, however, this method can lead to firms with promising technology being cut off from further funding. As our case studies indicate, Advanced Technology Program funds have, in some cases, allowed small companies with promising technologies but which were experiencing technological delays to reach a stipulated milestone and obtain additional financing. This may well be an attractive strategy to pursue during these periods.

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Table 1: Volume of Venture Capital Activity. *The table provides an overview of investment activity by U.S. venture capital organizations. Panel A indicates the total amount raised by venture capital funds and the amount of early-stage investment, all expressed in 1994 dollars. No data are available on the number of early-stage investments prior to 1981. Panels B and C display the amount of venture investments in 1995, disaggregated by the leading states and industries. The sources are VentureOne [1996] and unpublished databases of Venture Economics and VentureOne.*

Panel A: Amount of Venture Activity			
	Venture Capital	Early-Stage Investments by Venture Funds	
Year	*Raised in Year*	*$ of Financings*	*Number of Financings*
1977	91	474	
1978	442	520	
1979	503	755	
1980	1260	802	
1981	1713	806	227
1982	2061	813	343
1983	5516	1707	413
1984	4931	1689	568
1985	4240	1194	529
1986	4429	1478	716
1987	5550	1440	796
1988	3822	1272	674
1989	3858	1119	623
1990	2173	705	571
1991	1569	458	335
1992	2822	646	435
1993	3008	765	368
1994	4596	1005	499
1995	4536	1438	611

Panel B: Leading States, Venture Financing, 1995			
State	*$ of Financings*	*% of Total*	*# of Financings*
California	2274	30.6	437
Massachusetts	772	10.4	131
New Jersey	724	9.7	36
Texas	352	4.7	40
Illinois	340	4.6	29

Panel C: Leading Industries, Venture Financing, 1995			
Industry (SIC Code)	*$ of Financings*	*% of Total*	*# of Financings*
Communications & networking	1376	18.5	180
Software & information services	1239	16.7	291
Retailing & consumer products	1207	16.2	90
Medical compounds	716	9.6	113
Medical devices & equipment	607	8.2	108

R&D Spillovers, Appropriability and R&D Intensity: A Survey Based Approach

by Wesley M. Cohen and John P. Walsh[1 2]

Abstract

This paper uses recently collected data from the Carnegie Mellon Survey on Industrial R&D to build an industry-level empirical model of R&D spillovers, appropriability and R&D intensity, in order to evaluate the quality of our survey-based measures and to deepen our understanding of appropriability and spillovers and their impacts on R&D spending. We find that the more appropriable are the rents to R&D, the higher the R&D intensity of an industry. We also find that intraindustry R&D-related information flows negatively affect some appropriability mechanisms, but lead to greater R&D intensity. This last result indicates that, controlling for the effect of intraindustry information flows on appropriability, intraindustry R&D information flows complement firms' own R&D efforts. We also use these newly-developed measures of appropriability to rank industries with respect to their appropriability conditions. We find that our survey-based measures provide a basis for identifying industries where appropriability is weakest, and, hence, where one might expect R&D spending to be particularly subject to market failure.

Introduction

R&D spillovers and the appropriability of rents due to R&D are seen as key determinants of innovative activity and performance and are key concepts motivating policy interventions in support of industrial R&D. Unfortunately, direct measurement of these two notions has proven elusive. Moreover, while there is now strong evidence supporting the argument that R&D spillovers have important effects on innovative performance and productivity growth, empirical analyses of the direct effects of appropriability on the conduct of R&D have not yielded a consensus.

This paper uses recently collected data from the Carnegie Mellon Survey on Industrial R&D to build an industry-level empirical model of R&D spillovers, appropriability and R&D intensity, in order to evaluate the quality of our survey-based measures and to deepen our understanding of appropriability and spillovers and their impacts on R&D spending.

We find that the more appropriable are the rents to R&D, the higher the R&D intensity of an industry. We also find that intraindustry R&D-related information flows negatively affect some appropriability mechanisms, but lead to greater R&D intensity. This last result indicates that, controlling for the effect of intraindustry information flows on appropriability, intraindustry R&D information flows complement firms' own R&D efforts.

We also use these newly-developed measures of appropriability to rank industries with respect to their appropriability conditions. Although within- industry heterogeneity of responses limits our ability to discriminate across industries, we still find that our survey-based measures provide a basis for identifying industries where appropriability is weakest, and, hence, where one might expect R&D spending to be particularly subject to market failure.

Section 2 of the paper describes the industry-level model of appropriability and R&D that we intend to test. In Section 3, we describe the data. Section 4 presents the model and the construction of measures. In Section 5, we present the empirical results from the industry level model. In Section 6, we present rankings of industries intended to suggest where R&D market failures are most likely to occur. We conclude in Section 7.

Conceptual Approach and Model

Intraindustry R&D spillovers are the uncompensated benefits derived by firms from their rivals' R&D activities. Conceived as such, there is little distinction between R&D spillovers and appropriability, which refers to the degree to which firms can appropriate the profits from their own R&D activity. At times, however, the notion of spillovers are identified with intraindustry R&D-related information flows. While R&D information flow may be a key determinant of R&D spillovers and appropriability, it may not be the only determinant. Conflating R&D spillovers (and hence appropriability) with intraindustry information flow has led some scholars to claim that the empirical effect of appropriability on R&D spending is ambiguous (Cf. Cohen and Levin [1989]). These ambiguous findings may result from failing to examine the effect of appropriability on R&D spending while controlling for the independent and direct effect of intraindustry

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R&D information flows. With separate measures of appropriability and intraindustry R&D information flows available from the Carnegie Mellon Survey of Industrial R&D, we can control for the effect of intraindustry R&D information flows on appropriability, and then separately observe the possibly countervailing effect of these information flows on R&D.

There are two ways to think about appropriability. The most straightforward way is to think of it as simply the profits due to invention that firms within an industry are able to retain for themselves. A second way builds on institutional observations of Levin, et al. [1987] that firms protect those rents in different ways, with patents, secrecy, lead time, complementary capabilities, and so on. This observation suggests a more multidimensional view of appropriability in which it is conceived of as the rents due to invention that firms retain through the use of each of these mechanisms, recognizing that in some industries, only one such mechanism may be emphasized, and in others, combinations of these mechanisms may be used. Explicitly controlling for the particular mechanisms employed can capture the differential effects of different mechanisms on R&D information spillovers and, indirectly, on R&D incentives. For example, heavy reliance on secrecy may produce significantly less information spillover than use of patents, even if both are equally effective in conferring appropriability.

In this paper, we test an empirical model relating R&D information flows, appropriability and R&D intensity to one another, where appropriability is characterized as the degree to which different appropriability mechanisms or strategies increase the rents due to R&D. Diagram 1 characterizes the central relationships that we posit.[3] In this framework, we suggest that the more effective are appropriability mechanisms such as secrecy or patents in protecting the profits due to invention, the greater are the incentives to conduct R&D. At the same time, we suggest that there is a reciprocal relationship between the effectiveness of the different appropriability mechanisms and the extent of intraindustry information flows. To the degree that R&D-related information flows are stronger within an industry, the more difficult appropriation of rents to R&D will be, notwithstanding the particular mechanism employed. However, use of specific appropriability mechanisms may, at the same time, condition the extent of intraindustry information flows. For example, if firms rely on secrecy, we would expect information flows to be less than if they rely on patents, which disclose information. As argued above, we expect that once the negative effect of intraindustry information flows on appropriability is controlled, we are then in a position to see whether the direct effect of those flows on R&D is negative or positive. We would expect the direct effect to be positive to the degree that information from rivals complements own R&D effort and negative to the degree that it substitutes for own R&D. We also expect that the greater the R&D intensity of an industry, the greater the information flows. Moreover, to the degree that firms in an industry conduct more R&D, the more able they are to exploit those flows. Both of these arguments imply a positive effect of R&D on intraindustry R&D information flows.

Data

The proposed empirical analysis relies principally upon survey data from the 1994 Carnegie Mellon Survey (CMS) of Industrial R&D in the United States. These survey data provide measures of the extent of knowledge flows both across competitors and from outside the industry, measures of the effectiveness of appropriability mechanisms and measures of the R&D activity and performance of firms and industries, among other variables.

Building on prior empirical research showing that there are important cross-industry differences in the factors affecting technical advance (e.g. Nelson et al. [1967]; Cohen [1995]), data were collected at the business unit level rather than at the level of the enterprise as a whole. The respondents were R&D unit directors for manufacturing firms. Our sample frame was drawn largely from the *Directory of American Research and Technology* (DART). The U.S. survey effort yielded 1489 completed questionnaires, representing an unadjusted response rate of 46% and an adjusted response rate of 54%[4]. For this analysis, our sample is aggregated to 54 3-digit manufacturing industries with more than six cases. We also use archival sources to collect data on firm sales and employment and industry sales, number of firms and concentration ratios.

Table 1 provides the descriptive statistics on firm and business unit size and R&D intensity for the sample. The average firm and business unit sales revenues are $4.4 billion and $1.7 billion respectively. As the figures for the first and third quartiles indicate, the business unit and firm size distributions are quite broad, including numerous small firms. The sample mean R&D intensity, defined as business unit R&D divided by business unit sales, is 2.3%.

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[3] Diagram 1 omits the exogenous variables hypothesized to affect each of the endogenous variables.

[4] Our response rate was adjusted for respondent ineligibility inferred from our nonrespondent survey.

Table 1. Descriptive Statistics for CMS sample

Variable	N	Mean	Median	1st Quartile	3rd Quartile
Business Unit Employees (1000's)	959	4.40	0.45	0.12	2.10
Business Unit Sales ($ millions)	833	1720.00	120.00	20.00	650.00
Firm Employees (1000's)	1115	20.00	3.30	0.30	17.00
Firm Sales ($ millions)	1129	4440.00	550.00	40.00	2750.00
Business Unit R&D Intensity (%)	700	2.33	1.92	0.67	4.61

Measures And Model

In this section, we will discuss our measures of spillover, appropriability and R&D intensity and our model for estimating the relations among these variables, based on Diagram 1. Our unit of analysis for this model is the industry, and thus all measures are constructed at the industry level. We begin by discussing our measures of appropriability, and then describe our measures of spillover and R&D intensity.

Appropriability, as suggested above, is a multidimensional concept. Our survey contained twelve items asking respondents about the percentage of innovations for which a given appropriability mechanism was effective for protecting the firm's competitive advantage from those innovations (i.e., the extent to which this mechanism is important). The key mechanisms considered in our survey include secrecy, patents, other legal mechanisms (e.g., copyright or design registration), complementary manufacturing facilities and know-how, complementary sales and service, and being first to market, asked separately for product and process innovations. Using a respondent-level exploratory factor analysis of these twelve items, we find three distinct dimensions to appropriability. Employing Bartlett's factor score (Mardia, Kent and Bibby [1979]), which uses the factor loadings of each measure as weights, we construct for each respondent normalized factor scores for each of the three factors. We then use simple averages for respondents in each industry to construct the following industry-level measures of appropriability:

- CAPABILITIES/LEAD: For product and process innovations, the extent to which complementary manufacturing facilities and know-how, complementary sales and service and being first to market are effective in protecting innovations.
- LEGAL: For product and process innovations, the extent to which patents and other legal mechanism are effective in protecting innovations.
- SECRECY: For product and process innovations, the extent to which secrecy is effective in protecting innovations.

In addition to these three measures of appropriability, we also have the following measures for spillover and R&D intensity:

- INFO-RIVALS: Our measure of intraindustry R&D information flows is the percentage of respondents in an industry saying that information from rivals either suggested new R&D projects or contributed to R&D project completion in the prior three years.
- R&D-INTENSITY: We use a sales weighted average of the R&D intensities of the business units in each industry, where R&D intensity is business unit R&D divided by business unit sales.

The major focus of this paper is to develop a model of R&D intensity that distinguishes between the possibly offsetting effects of spillovers and appropriability on R&D intensity by controlling for the reciprocal effects of each on the other and measuring separately their effects on R&D intensity. The work of Spence [1984], Levin and Reiss [1984] and Cohen and Levinthal [1989] all highlight offsetting effects of R&D information spillovers on R&D spending. Although, at the industry level, such information flows diminish the appropriability of firms' profits due to R&D, they may also complement firms' R&D and thus yield offsetting effects on industry R&D spending. Because they did not benefit from data permitting separate measurement of intraindustry information flows and appropriability, prior studies have claimed that these offsetting effects account for the ambiguous effect on R&D intensity of their operationalizations of industry appropriability (e.g., Cohen and Levinthal [1989]). Following prior work, we consider industry R&D intensity to be a function of three industry-level variables, namely technological opportunity, demand, and the degree to which firms expect to appropriate returns to their innovations (cf. Cohen [1995]). We include our three appropriability mechanism effectiveness scores, namely LEGAL, CAPABILITIES/LEAD and SECRECY, along with our measure for intraindustry information flows, INFO-RIVALS and our control for market mediated information flows. Our model structure and measures should allow us to discern the countervailing effects of intraindustry information flows on R&D

intensity. To the extent that intraindustry spillovers influence R&D spending either by complementing firms' R&D efforts or by making those efforts more efficient, they are considered to reflect a dimension of technological opportunity. Thus, our variable, INFO-RIVALS should reflect one dimension of technological opportunity. In our specification, building on prior empirical work, we include variables representing other dimensions of technological opportunity as well. We follow Levin, Cohen and Mowery [1985] and Cohen, Levin and Mowery [1987] by including a survey-based variable representing the vitality of the underlying scientific and engineering knowledge base. Knowledge flows from supplying firms have also been considered a dimension of technological opportunity since they might have the effect of making firms' R&D more efficient, and so we include a measure of information flows from suppliers as well. We also control for the effect of industry demand by including a measure of each industry's average annual rate of growth.

Following Diagram 1, we use these variables to estimate a system of five equations using two stage least squares.[5] In addition to the endogenous variables in the diagram, our model includes several exogenous variables that measure extraindustry information flows (such as those from universities, suppliers and customers), ties between R&D and production units, the emphasis on product versus process innovation, the importance of university research, and demand growth (for details, see Cohen and Walsh [1998]). We also control for market-mediated channels of intraindustry information flows (to make our measure INFO-RIVALS more closely tied to nonpecuniary spillovers). There is at least one predetermined variable in each equation, so the entire model is identified. Since we are examining industry-level effects, all variables are expressed as industry averages. To control for sampling error in these estimates, and as a partial control for the heterogeneity of firms within our sample industries, we weight each case by the square root of the number of observations in that industry.

Results

Table 2 presents the results of the two-stage least squares estimates for the model shown in Diagram 1. We will discuss the results for each endogenous variable.

Intraindustry R&D Information Flows [INFO-RIVALS]

The first column of Table 2 gives the results for the predictors of spillovers (INFO-RIVALS). The results suggest that the particular appropriability mechanisms that tend to be used in industries indeed affect information flows. The clearest and most robust effect is exercised by SECRECY, which has a negative and significant effect on information spillovers.[6] A negative effect of secrecy in general is quite sensible and conforms to priors. An interesting result here is the fact that LEGAL apparently exercises little or no effect on intraindustry R&D information flows. The reason might be that patents, for example, are designed to have two effects. While they are supposed to confer appropriability, they also diffuse information. Thus, while patents may deny rivals from exploiting some information, at least in some forms, they at the same may provide information that benefit rival R&D. The absence of any clear sign for the effect of LEGAL is consistent with these offsetting effects. As expected, higher industry R&D intensity (R&D-INTENSITY) appears to contribute significantly to intraindustry information flows.

Appropriability Strategies [SECRECY, CAPABILITIES/LEAD, LEGAL]

The next three columns give the results for our measures of appropriability. Across the three appropriability mechanism equations, our measure for intraindustry information flows (INFO-RIVALS) exercises a significant, negative effect only on SECRECY. Otherwise, the qualitative effects are typically very small.[7]

R&D Intensity

The last column gives the results for our featured R&D intensity equation. We see that our intraindustry information flow variable [INFO-RIVALS] has a significant *positive* effect on R&D intensity. We also see that the variables representing the effectiveness of the three appropriability strategies [SECRECY, CAPABILITIES/LEAD and LEGAL] all have additional positive effects on R&D intensity. In the three-stage least squares equation, all three effects are significant. This result suggests that

[5] Although perhaps more appropriate for a larger sample, three stage least squares regressions are also employed for estimation, partly to exploit its efficiency properties and partly as a robustness check on the two stage least squares results. The results are largely similar, with some changes in significance levels for certain effects. Three-stage least squares results available from the authors.

[6] Given a small number of industry observations in our sample (N=54), we will use a cutoff of a .10 confidence level to qualify a coefficient estimate as "significant."

[7] If, however, we drop the number of R&D competitors from the model, with which INFO-RIVALS is somewhat collinear, the sign on INFO-RIVALS becomes consistently negative and the statistical significance of the INFO-RIVALS variable strengthens in all three appropriability mechanism equations, although rarely exceeding conventional thresholds.

Table 2. Two-Stage Least Squares Regression of Intraindustry Information Flows, Appropriability and R&D Intensity

VARIABLE	INFO_RIVALS	SECRECY	CAPABILITIES /LEAD	LEGAL	R&D INTENSITY
INFO_RIVALS		-**	+	+	+***
SECRECY	-***		-	-	+
CAPABILITIES/ LEAD	-	+		-**	+
LEGAL	+	+*	-		+**
R&D INTENSITY	+***				
R^2	50	42	37	51	53

Notes: N=54
*** p<.01
** p<.05
* p<.10

The model includes exogenous variables measuring extraindustry information flows, technological opportunity, demand growth and controls for market-based information flows. Full model and three-stage least squares results available from authors.

once one controls for the influence of intraindustry information flows on appropriability, the direct influence of intraindustry R&D information flows on R&D intensity is strong and positive. This result suggests a strong complementarity between own R&D and information spilled out from rivals' R&D. Thus, we appear to have distinguished a direct effect of intraindustry information spillovers from that of appropriability.

In contrast to prior empirical results in the literature, our results provide evidence that greater appropriability encourages industry R&D intensity. We have obtained this result, however, after controlling for the effect of intraindustry information flows on appropriability itself. That effect turns out to be negative and significant only in the case of SECRECY. We also observe a strong positive impact of intraindustry R&D information flows on industry R&D intensity. These results, and particularly those in the R&D intensity equation, conform with predictions grounded in prior theory and empirical work. Not only do they, therefore, support the way economists tend to see the role of appropriability and spillovers, they also elicit some confidence in the survey-based measures that we have employed.

Industry Level Indicators Of Appropriability And Intraindustry Information Flows

The fact that our industry-level measures of appropriability and intraindustry R&D information flows are performing in a sensible way in our model suggests that these measures may actually reflect what we think they do. If we take this proposition seriously, too seriously perhaps, these measures may allow us to discriminate across industries according to the extent of intraindustry R&D information flows and appropriability. By doing so, we should be able to identify industries where the spillovers from R&D are greatest, and R&D investment is most subject to market failure.

To probe whether our industry-level measures allow us to distinguish industries by level of R&D spillovers and appropriability, we present for the fifteen most R&D intensive industries in our sample the industry means for our measure of intraindustry R&D information flows and the factor scores representing the effectiveness of the three core appropriability strategies that we identified. In addition to presenting industry means in Figures 1 through 4, each of these figures also present ninety-five percent confidence intervals around those means, which is particularly important if we wish to use these measures to claim, for example, that secrecy or legal mechanisms are more effective in one industry than in another.

For the fifteen most R&D intensive industries in our sample, Figure 1 presents our measure of intraindustry information flows, namely the percentage of respondents reporting that information from rivals suggested new R&D projects or contributed to the completion of existing projects. The ninety-five percent confidence intervals suggest that although the percentages vary from 26% for plastic materials and synthetics to 100% for agricultural chemicals, these differences are not very discriminating. If we rely on the confidence intervals, we make, at best, coarse distinctions. For example, we can claim that the information flows in plastic materials and synthetics, industrial organic chemicals and communications equipment are lower than those in agricultural chemicals, or that those in plastic materials and synthetics are lower than those in motor vehicles and equipment, computers or semiconductors, but it is not possible to discriminate the numerous industries in the middle from those either at the top or bottom.

Figures 2 through 4 present the factor-based indexes for the effectiveness of the three appropriability strategies involving, respectively: the exploitation of complementary capabilities and lead time in Figure 2; the exploitation of secrecy in Figure 3; and the exploitation of legal mechanisms, particularly patents, in Figure 4. In each of these figures, an industry factor score index of zero signifies that the industry is average with regard to the appropriability strategy in question. As in the case of Figure 1, the overriding impression conveyed by the confidence intervals shown in Figures 2 through 4 is that it is difficult to finely discriminate across industries. We do find, however, that we can usually distinguish groups of industries with regard to the effectiveness of each appropriability strategy. For example, Figure 2 suggests that the two top industries, photographic equipment and supplies and electronic components, appear to benefit from greater effectiveness of complementary capabilities and lead time, and agricultural chemicals less so than other industries. With regard to the factor score for the effectiveness of secrecy considered in Figure 3, four industries, namely miscellaneous chemical products, semiconductors, drugs and plastic materials and synthetics appear to rank significantly higher than the other eleven industries. With regard to patents and other legal mechanisms considered in Figure 4, six industries appear to rank higher than the other nine, including agricultural chemicals, medical instruments, computers, special purpose machinery, construction machinery and equipment and drugs.

The question is how might we exploit these coarse distinctions to identify industries where R&D spending might be particularly subject to market failure. One approach might be to exclude those industries where at least one of the three sets of mechanisms appears to work particularly well. On this basis, we can eliminate the eleven industries named above, leaving communications equipment, industrial organic chemicals, motor vehicles and equipment, and measurement and control devices as industries where R&D may be particularly subject to market failure. Since our regression analyses above suggest that the link between intraindustry R&D information flows and appropriability—at least as measured in terms of the strength of appropriability strategies—is not that close, one cannot conclude that there is some close negative monotonic relationship between the two. Motivated by both theory and our other empirical finding that intraindustry information flows positively contribute to industry R&D activity, it would be useful therefore to consider those information flows in any consideration of industries to which government might provide R&D support. Consider, therefore, the four industries which our results would suggest may be most susceptible to a market failure in their R&D decisions, namely communications equipment, industrial organic chemicals, motor vehicles and equipment, and measurement and control devices. Presenting our featured measure of intraindustry information flows, Figure 1 shows that of these four industries, two—industrial organic chemicals and communication equipment—rank thirteenth and fourteenth with respect to these flows, and rank significantly below the top ranked industry, though not significantly below the large group of industries in the middle which includes the measurement and control devices and the motor vehicles and equipment industries. Thus, our measure of intraindustry information flows does not offer a strong basis for discriminating across industries for the purpose of public support of R&D, unless one is willing to accept a lower confidence level in drawing such distinctions.

Additional information can be brought to bear. For example, recall from our regression analyses above that, to reflect the intraindustry information flows associated with nonpecuniary R&D spillovers, it was useful to control for the importance of market-mediated channels of information flow across rivals. Thus, consider Figure 5, which ranks the fifteen most R&D intensive industries by our composite factor index reflecting the importance of these market-mediated channels. We observe that the importance of such channels in motor vehicles and equipment is not significantly distinguishable from their importance in the drug industry, which is the top ranked industry on this dimension. This suggests that while intraindustry information flows are considerable in motor vehicles and equipment, they may be market-mediated to an important extent and may thus not reflect nonpecuniary R&D spillovers. In contrast, the importance of market mediated information channels is quite low for the measurement and control device industry, and significantly below that of the communications equipment and motor vehicles and equipment industries. This finding might suggest that if one had to choose between these three industries as targets for government support strictly on the basis of this very crude evaluation of the likelihood of generating social gains from R&D that are not privately captured, the measurement and control device industry would be a sensible candidate.

At this point, we are reluctant to recommend public support for industrial R&D in any industry too seriously. Clearly, there are numerous substantive and methodological assumptions underpinning the analysis that need to be subject to considerable scrutiny. For example, it is a leap of faith, although one to which we have subscribed, to assume that our crude measures of the effectiveness of appropriability strategies accurately index the share of social returns to R&D that are privately garnered. Moreover, any decisions to allocate public funds in support of R&D across industries need to consider other factors that condition the absolute level of social gains from R&D, such as technological opportunity and demand conditions. In this regard, any guidance offered by our measures of appropriability reflects a presumption that all else is being held equal—but all else is not held equal, and these other factors must therefore be considered. For example, while our measures might commend the measurement and control device and industrial organic chemical industries as candidates for government support, one might argue that the technological opportunities facing the former may be much greater than those facing the latter. We suggest, though, that however tentative our conclusions may be for the moment, survey-based measures of appropriability and intraindustry information flows may be of some use in guiding our thinking about what industries might be the most fruitful beneficiaries of government R&D support from a social welfare perspective. Thus, while the utility of these measures for guiding policymakers' allocation of R&D support across industries is compromised by their coarseness and particularly by the heterogeneity of responses within industries, the measures may be of use even within these constraints.

Conclusion

We began with several objectives: to create industry-level measures of appropriability and spillovers and validate these with a model of R&D intensity, spillovers and appropriability; and to use these measures to identify industries where market failures may be more likely. We used the Carnegie Mellon Survey of Industrial R&D to provide the data with which we constructed measures for these various concepts.

Factor analysis suggests that appropriability can be partitioned into three distinct components, representing complementary capabilities and lead time advantages; secrecy; and patents and other legal mechanisms. Our industry-level model of R&D intensity, spillovers and appropriability suggests that the measures of spillover and appropriability derived from the CMS may be reasonably valid indicators of these difficult-to-operationalize concepts. The overall model fits well and most of the results reported in the model reflect prior understandings of the expected relationships. All three of the appropriability dimensions are positively related to R&D intensity, as is R&D information flows from rivals. In addition, intraindustry R&D information flow is negatively related to the effectiveness of secrecy as a strategy of appropriation. Finally, higher R&D intensity is associated with greater information flows. Thus, we see a complementarity between R&D and spillovers, with each positively related to the other, controlling for appropriability (and opportunity and demand growth).

We then use these measures to rank industries in terms of information flows and appropriability, focusing on the more R&D intensive industries. Here, we find that while industries differ, within-industry variance is substantial. We can point to certain industries as being near the top or the bottom, but we are reluctant to make distinctions among most of the industries on any given measure. We suspect small numbers at the industry level (with fewer than 10 cases in some industries), measurement error, and firm-level differences all contribute to this within-industry variance. Although within-industry heterogeneity of responses limits our ability to discriminate across industries, we still find that our survey-based measures provide a basis for identifying industries where appropriability is weakest, and, hence, where one might expect R&D spending to be particularly subject to market failure.

Overall, our results suggest that survey-based measures of appropriability and spillovers may be useful in modeling the relationships between R&D intensity, spillovers and appropriability. In addition, appropriability may be best thought of as a multidimensional concept, as firms and industries emphasize different strategies for appropriating the returns to innovation. These strategies have differential effects on information flows and, indirectly, on R&D intensity. One question that needs further research is how these various dimensions are related to a firm's or industry's total appropriability of rents due to innovation. In addition, further research might focus on how to refine our measures to increase their discriminatory power. Finally, our results suggest that R&D intensity is positively related to appropriability, when controlling for the effects of spillovers, and that spillovers have a net positive effect on R&D intensity.

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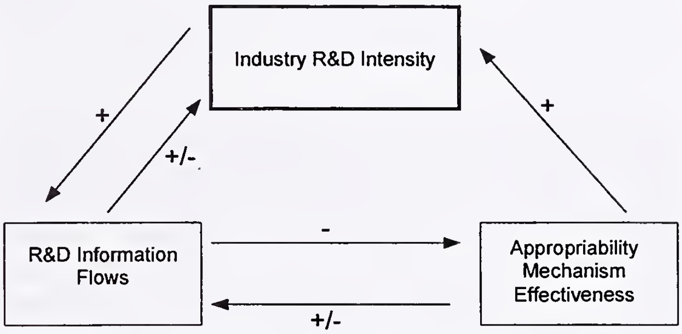

Diagram 1. Relationships across Industry R&D Intensity, Intraindustry R&D Information Flows and Appropriability Mechanism Effectiveness.

Comments On "R&D Spillovers, Appropriability, And R&D Intensity: A Survey-based Approach

by David C. Mowery[1]

This paper presents some very interesting preliminary empirical results from the Carnegie-Mellon University survey of industrial R&D managers. The bulk of the paper is devoted to an analysis of the determinants of R&D intensity, however, and the links between this analysis and program evaluation or design raise a number of many questions. I first consider the core analysis and findings of the paper and then briefly discuss its implications for program design and evaluation.

Cohen & Walsh use their survey data to disentangle the significance of Cohen & Levinthal's "2 faces of R&D"—how significant, relative to one another, are the discouragements to R&D investment resulting from limitations on firms' appropriability of the returns to their R&D, vs. the encouragement to R&D investment that may result from any complementarities between intra-industry knowledge flows (nonpecuniary spillovers) and own-firm R&D investment? As the authors note, these competing influences are difficult to disentangle, not least because the firm's choice of instruments to protect the results of its R&D may directly affect the nonpecuniary spillovers associated with that R&D. For example, patents may have very different results from secrecy, if one believes that the information disclosed in patents is useful to rival would-be inventors (assumes that knowhow is of little importance; note the abundant historical evidence that patents alone are insufficient).

The authors use a system of equations to estimate the determinants of (1) the importance of intra-industry knowledge flows; (2) the importance of secrecy, legal protection, and lead time/capabilities as mechanisms for appropriating returns; and (3) drawing on the results of the first two specifications, the determinants of R&D intensity. All of these analyses are conducted at the "line of business" level of analysis, relying on survey respondents' estimates of R&D spending and other business conditions in their unit of larger, diversified corporations. The most important results in this section are (1) the finding that spillovers do indeed promote higher levels of R&D investment; and (2) the finding that spillovers are not related in any very well-behaved fashion to the operation of mechanisms of appropriability, i.e., one can't find any robust, monotonically negative relationship between spillovers and the mechanisms of appropriability analyzed in the paper.

The authors rely exclusively on survey data for their analysis, and should incorporate some data from other, non-survey sources into this analysis and as a validity check on the original survey data. For example, some of the R&D intensity variables, and a number of the variables that attempt to measure the role of "external" sources of technical knowledge might be measured with data from other sources, including data on patents.

Among their detailed results, several are of particular interest. The authors find that legal means of appropriating returns have little/no effect on intra-industry flows. This result raises several questions: (1) how much information of use to other inventors do patents convey, especially in the absence of methods for rival inventors to access knowhow? Considerable evidence suggests that patents alone are insufficient to spark widespread imitation; they are rights to exclude, rather than documents with commercially relevant information. This raises question (2): Even assuming that patents do convey information, the often-lengthy lead times in their publication means that sectors in which lead time is especially important should find patents particularly unhelpful sources of information. This question merits further exploration.

Although the authors highlight this point for their measure of the importance of secrecy, all of their measures of the importance of different channels for capturing the returns to R&D confound some concept of the frequency with which they are used with a notion of their importance; in the case of patents, the only one of these mechanisms for which we have good data, the distribution of importance is enormously skewed within a large portfolio. And in other work, Cohen & Walsh report a decline in the effectiveness of patents for capturing returns simultaneously with an upsurge in their use.

The authors' empirical results on the use by firms of secrecy to appropriate the returns to R&D seem especially problematic. Note the inconsistency between the statement that "...public channels of information flow across competitors are stronger when similar channels between universities and industry are stronger." (p. 15) and "...as the amount of information conveyed through public channels increases, firms will again become more concerned about keeping their own findings secret, even while it may be more difficult to do so."

Another anomalous result is in the equation for R&D intensity, where "pecuniary" spillovers, defined by the authors as high ratings of importance for collaborative R&D, reverse engineering of competitors' products, and inward licensing of technology, has a negative coefficient. Since many of the activities included by the authors in this category presumably are supported by firms' in-house R&D investments, the negative coefficient seems strange. Moreover, it implies that R&D-intensive

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firms invest little in categories that they judge as important channels of inward spillovers. This result, suggesting that contract R&D, collaboration, and other types of collaboration are of lower importance in more R&D intensive industries, also seems to contradict casual empiricism.

Moving on to consider links between their results and program design or evaluation criteria, the authors next look at the extent to which their measures differentiate among individual 3-digit industries, focusing on the 15 most R&D-intensive, in an attempt to determine where one would identify the most fruitful targets for public subsidies. Interestingly, most of their measures provide little basis for distinguishing sharply among industries within these top 15. Survey results, according to the authors, thus far don't provide much guidance to the policymaker seeking economically defensible targets for R&D subsidies. Moreover, the authors' groups of industries that display similar levels of reliance on various devices for appropriating the returns to R&D display very little similarity in other dimensions, suggesting that these results must be treated with caution.

The authors also examine the distribution of ATP-funded projects across their industries, to determine whether the selection of projects is related in any meaningful way to the level of spillovers, finding that R&D intensity predicts the number of funded projects, while higher appropriability is associated with smaller numbers of funded projects. But this result is not very significant, since, the authors note that they do not include the total number of proposals. In other words, this finding may simply mean that more R&D-intensive industries with weaker mechanisms for capturing the returns from R&D write more proposals.

In conclusion, this paper presents a number of very intriguing results, and its use of survey data for collecting detailed information on inter-industry differences is a model for other exercises in such areas as "innovation surveys." But the guidance from this paper for program design and evaluation is limited. Such guidance as does emerge is most useful for broader assessments of choice among policy tools or design, rather than for the analysis of specific programs such as ATP. For example, Are R&D subsidies the most desirable instrument for "high-spillover" industries? How does the payoff from R&D subsidies to firms compare with those from R&D grants or subsidies to other "sectorally relevant" institutions, such as government labs, universities? This paper's survey results could be used to address some of these questions. But the results say little about the utility R&D subsidies for firms or groups of firms, the ATP policy design. Another challenge to the design of ATP concerns the paper's finding of significant knowledge spillovers among firms within an industry? In view of the fact that survey respondents do not view patents as an important vehicle for these knowledge spillovers, the encouragement for patenting of research by ATP and other "R&D partnership" programs (e.g., CRADAs) sponsored by the federal government may in fact limit, rather than promote, knowledge spillovers.

POLICY GOALS AND PROGRAM DESIGN ISSUES

SECTION

B

Orchestrating Technology Policies - German Lessons for Evaluations

by Dr. Carsten Dreher and Dr. Stefan Kuhlmann*

Abstract

Debates in Germany on technology policy suffer from the absence of a comprehensive theory of technological change and from not taking into account the evidence and lessons of evaluation experiences in order to allow a more differentiated picture on policy making, instruments and technologies. This paper offers a closer look on these issues. It provides (1) an overview on German S&T-policy, (2) summarizes the experiences of evaluations of German S&T-policies, and, (3) elaborates the roles of different instruments in the development and diffusion process of new technologies. The conclusion will be derived as lessons for S&T-policy evaluations from a German perspective.

Introduction

In the seventies the German Science and Technology (S&T) policy made a forward leap from a scientific and basic research orientation towards a policy for industrial innovation. Then – and partly still today – in Germany the advocates of 'Strukturpolitik' and 'Ordnungspolitik' fought a serious battle.[1]

- Advocates of state technology policy measures use an argumentation based on the theory of market failure.[2] According to this theory, market structures in a national economy may lead to sub-optimal market results due, for instance, to insufficiently market sizes or high barriers to market entry. Or, due to the influence of external effects, the market mechanism may not create pareto-optimal results. Under such circumstances the state may be justified in intervening – or may even have to intervene.
- On the other hand, 'opponents' of state technology policy generally advance two arguments,[3] firstly, that the rationales by policy decision-makers differ fundamentally from the rationales of enterprises active in the market place and, secondly, that because of their distance from the market policy-makers do not have sufficient information at hand compared with enterprises actively engaged in the market.[4]

Hence, the debates about the sense or nonsense of industrial innovation policies in the U.S. with their rigidity and sometimes emotional intensity (Branscomb, Keller 1998) sound familiar to German ears.

This debate suffers from two deficits,[5] the first being that there is no comprehensive theory of technological change which includes action by the state as an active determinant in models, rather than 'shaping conditions'. Secondly, after decades of practicing technology policy, it would seem appropriate, possibly even essential, for the debate to take into account the experience gathered so far, and to evidence a more sophisticated differentiation between technology policy instruments.

Here, a valuable contribution can be made by discussion of the results derived from the examination and evaluation of many individual state technology policy measures. Evaluation research has now accumulated a considerable wealth of experience with regard to the practice and administration of technology policy measures, and in their optimization.[6] Thus evaluation research could put more detail into policy debate, thus endowing it with practical usefulness for policy.

As contribution to this problem the paper offers a closer look on the different roles of S&T-policy instruments and their affinity to the subject of state intervention – the technologies. Considering the procedural aspects of evaluations could be helpful, too. This allows conclusions on the governance of S&T-policies in general. This paper relies on two recently published books (Dreher 1997, Kuhlmann 1998) which conclusions were combined for this conference.

For this aim the paper will (1) provide an overview on Geman S&T-policies, (2) summarize the experiences of evaluations of German S&T-policies and (3) elaborate instruments in the devel

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[1] cf. overview on the German debates GIELOW u.a. 1985, EWERS 1990, BÖGELEIN 1990, FRITSCH u.a. 1993, OBERENDER (Hrsg.) 1994, KLODT 1995.

[2] e.g. HAUFF, SCHARPF 1975; GAHLEN, STADLER 1986; MEISSNER, ZINN 1989.

[3] e.g. KIRCHGÄSSNER 1979; STAUDT 1986; FELS 1989; EWERS 1990; OBERENDER, STREIT (Hrsg.) 1991.

[4] e.g. STREIT 1984, BEIRAT 1985.

[5] cf. SOETE 1991, MEYER-KRAHMER, KUNTZE 1992 and as again highlighted by the OECD-conference on 'Policy Evaluation in Innovation and Technology: Towards Best Practice' in Paris 1997.

[6] e.g. BECHER, KUHLMANN 1995.

opment and diffusion process of new technologies. The conclu sion will be derived as lessons for S&T-policy evaluations from a German perspective.

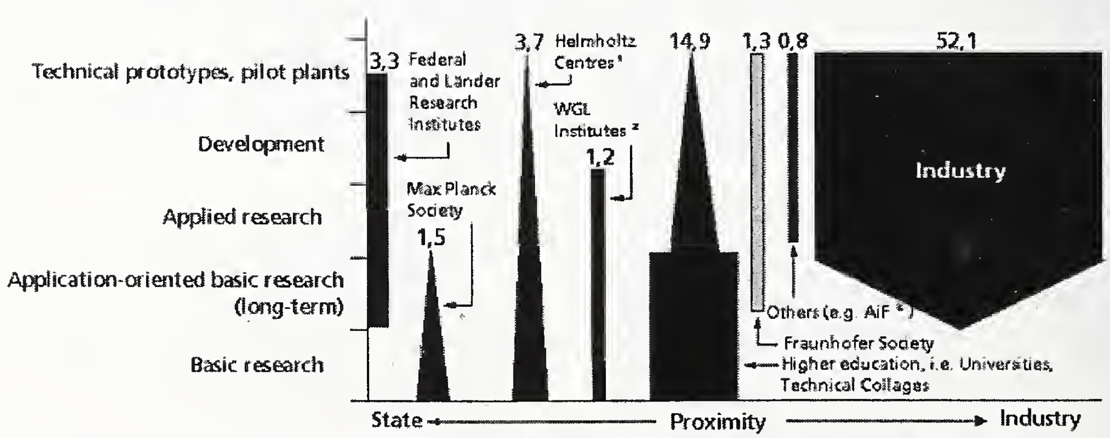
Science and Technology Policy in Germany

In an international comparison, the German science and technology system is considered to be well developed: in 1993, 475,000 persons (full-time equivalents) performed research and development (R&D). Altogether, the expenditure on research in Germany in 1995 amounted to 79 billion DM. As a percentage of the gross domestic product (1988: 2.9; 1995: 2.3) this still puts Germany among the world leaders, but in the last few years it has fallen somewhat behind Japan (1988: 2.9; 1995: 3.0) and the USA (1988: 2.8; 1995: 2.6) (see OECD, April 1995; BMBF 1998). The R&D infrastructure is regarded as highly differentiated (cf. Reger/ Kuhlmann 1995, 11pp, data from BMBF 1996, see figure 1):

- Industry accounts for the major share of R&D in Germany: in 1995, almost 70 per cent of mainly applied research and experimental development. Only relatively few large multinational enterprises, especially in the chemical and electrotechnical industries, conduct long-term, application-oriented basic research.
- The higher education institutes (i.e. universities, technical colleges; 110,000 R&D staff) have the second highest research expenditure. They concentrate on basic research and long-term application-oriented research, largely funded by the federal states and by the *Deutsche Forschungsgemeinschaft* (DFG), a highly independent funding body financially supported by the federal and the state governments. In the course of the last 10 years, additionally, there has been a marked increase in the share of the roles of different share of industrial R&D in the research budget of several universities, especially technical ones.
- A group of federal and state research establishments (11,000 R&D staff) carries out research which is more or less directly associated with the tasks of the public authorities that finance it, usually federal or state ministries (e.g. the development of norms and standards, testing procedures, certification, etc.).
- The 16 national research centers (22,500 R&D staff, now acting jointly as *Helmholtz Society*) perform particularly activities with a long-term orientation which appear to have a high degree of risk, require relatively large research teams and incur high costs. In recent years the national research centers have diversified their fields of activity considerably and are now active in a wide range of areas, especially in high energy physics, space technology, medicine, biotechnology, applied mathematics, software technology and environmental technology.
- The institutes of the *Max Planck Society* (MPG; 9,000 R&D staff) mainly perform basic research in selected fields of natural sciences and the arts. They concentrate on new research topics of potential future importance which either have not yet found an established place at higher education institutes, or – because of their interdisciplinary character or the resources they require - cannot find a place there.
- The institutes of the *Fraunhofer Society* (FhG; ca. 4,000 R&D staff) have the task of promoting the practical application of scientific knowledge through long-term application-oriented and applied research. The FhG performs mainly contract research which is financed partly by industry and partly by the public sector. The organization regards itself as the 'interface' between science and in-

Figure 1: The German Research Landscape 1995

R&D expenditure bn DM



1 Hermann von Helmholtz Association of German Research Centres (HGF), i.e. the national research centres
2 Gottfried-Wilhelm-Leibnitz Society (WGL), formerly Blue List
3 AiF, Confederation of Industrial Research Associations 'Otto von Guericke' e.V.

dustry in Germany. No other German R&D institution has grown so rapidly over the last 15 years.

- The laboratories of the Confederation of Industrial Research Associations (AiF) perform tasks in applied research and experimental development for the sector-specific needs of industrial enterprises. Their work, which is financed partly from public sources and partly by industry, particularly benefits small and medium-sized enterprises (SMEs) which are grouped into sector-specific research organizations.
- The institutes of the *Leibnitz Society* (formerly known as 'blue list') form a remaining category of institutions jointly founded by the federal and state level (ca. 10,000 R&D staff). After the unification many East German institutes were promoted this way.

One of the main reasons for the extent of institutional differentiation in the German research 'landscape' is the fact that there is no strong, central policy body responsible for science, research and technology: within the federal system of Germany, it is essentially the 16 states (*Länder*) that are responsible for science and academic research. Although in the course of time the Federal Government has, in agreement with the states, taken on many areas of responsibility, there is always a certain degree of competition between the central authorities and the states, and also between the various states. The states are running nearly all higher education institutes; they maintain (to a varying extent) non-university research institutions and - also to a varying extent - launched their own technology policy programs. This does lead to some redundancies in the capacities of the research and innovation system, but it also guarantees a decentralized, 'autonomous' structure of research capacities, even outside the large cities and agglomerations.

Against this background, it is not surprising that German S/T policy relating to industry over the last decade was described as 'diffusion-oriented' rather than 'mission-oriented' (cf. Ergas 1987, 192). A strategic industrial or technology policy with definite missions, such as is pursued in France, can hardly be implemented in a decentralized structured research system. Another reason for the stronger 'diffusion orientation' of German S/T policy is the basic attitude prevalent in public policy that the state does not wish to be regarded as a 'director' of industry, but only as the guarantor of an effective academic training system (higher education institutes), a high level of basic research and a sound technology base for industry (industrially oriented R&D programs). However this basic position, as critics continually point out, only works to a limited extent in practice (cf. e.g. Starbatty/Vetterlein 1990).

Since the 1950s, German S/T policy - as in other western European industrialized countries - has continually extended the scope of its activities; this can be illustrated using a 'shell model' (cf. Meyer-Krahmer/Kuntze 1992; Bräunling and Maas 1988). In this model, the core area of S/T support in the 1950s comprised the (basic) university research and 'special area research' carried out in federal and state research establishments.

- A first 'layer' is characterized by big technology programs from the mid 1950s onwards, showing a marked orientation towards goals similar to those of the USA, mainly in the fields of nuclear technology, aerospace and data processing, and later microelectronics (see e.g. Weyer 1994)
- A second research support 'layer' was developed from the beginning of the 1970s, in order to create and support the conditions necessary for the export of technology-intensive goods. Public funding flowed into research projects of industry and institutes for applied research to promote cross-sectoral technologies (e.g. materials), key technologies (e.g. microelectronics) and technological systems (e.g. transport systems).
- In the 1970s, the reform policies of the Social Democratic government triggered the formation of a third research support 'layer', complementing the goals of the first and second layers by research activities in the areas of environment, public health and the employment market whose aims related primarily to social policy.
- From the end of the 1970s, a fourth 'layer' emerged, using the instruments of innovation policy: their aim is the diffusion of innovative or improved technologies, also among SMEs and in less developed geographical regions. This includes the support of activities in R&D as well as the building up and strengthening of an infrastructure for the support of technology transfer from the science system into industry. This layer grew during the 1980s but has lost some importance since the early 1990s.

The shell model clearly shows that over the last 40 years these focal orientations of policy have not succeeded one another, but have accumulated! The result has been the formation of a differentiated range of S/T policy instruments, extending from institutional support measures, over financial research support programs and the creation of institutions for technology transfer, to regulative policy measures. Today, roughly speaking, half the S/T funding of the Federal Ministry for Education, Science, Research and Technology (BMBF)[7] is spent in the form of institutional support and the other half in the form of research, technology or innovation programs (i.e. project funding).

[7] in 1994 the Federal Ministry for Research and Technology (BMFT) was merged with the Ministry for Education and Science. The official acronym is now BMBF.

A remarkable turbulence shook the R&D infrastructure after the *German unification*: Between 1990 and 1994 the S/T infrastructure of the former German Democratic Republic experienced a drastic and painful process of shrinkage - e.g. the industrial R&D personnel decreased from 70,000 to 12,000 -, and the research capacities of the East were basically restructured (see Holland/Kuhlmann 1995). Today, they constitute a generally compatible part of the total German research landscape, and are beginning to participate in European collaborative research. Looking back critically, there was practically no alternative to this high-speed, pro-active, and to some extent authoritarian adaptation process in the East. Nevertheless, unique opportunities for creating a modernized S/T infrastructure in Germany as a whole were not taken; the persevering interests of the long-standing and politically well equipped West German R&D institutions dominated this process of change (Mayntz 1993 and 1994), although serious and qualitatively high standing evaluation procedures were applied.

Evaluation of S&T Programs in Germany

The functions and the use of evaluation procedures in the German S/T system are wide-ranging,[8] and the expectations and requirements of the evaluation users vary significantly

- from the provision of legitimization for the distribution of public money and the demonstration of adequate and effective use of the funding,
- via targeting and 'controlling' in the sense of improved management and 'fine tuning' of S/T policy programs,
- to an attempt to improve transparency in the rules of the game and the profusion of research funding and subsidies, and to enhance the information basis for shaping S/T policies, in the sense of a 'moderation' between diverging and competing interests of various players within the S/T system.

When taking a historical view, we can differentiate two basic development lines of evaluation – similar to other industrialized countries – in the field of S/T in Germany. They can be sketched – like the S/T policy measures described above – as a shell model:

- The 'core' consists of the *'peer review'* procedures and later additionally the measurement of research performance of single researchers or groups (using bibliometrics etc.) as *science-internal* instruments for the allocation of funds to research institutions. These instruments are widely used in the German S/T system, in particular in the realm of basic and long-term applied research.
- An 'outer layer' of this shell model consists of evaluation studies in the sense of *'impact analyses'* of S/T policy programs. This evaluation concept could be understood as *science-external*, initiated prevalently by policy-makers in order to prove the achievement of politically set scientific, technological, economic or societal targets. Impact analyses spread since the late 1970s in particular in the areas of innovation and strategic technology programs.

It is important to note that evaluation efforts of the 'impact analysis' type did not supplant the peer review approach: with the historical emergence of technology and innovation programs, the impact analysis practice was added to the existing 'system of evaluation'. Compared to other national S/T systems, though, it is remarkable that significant parts of the German S/T system, in particular the field of university research institutions (let alone university teaching) have not been evaluated at all so far! (Kuhlmann 1997) Considering the background of this conference we are focusing on S&T program evaluations in this paper.

In Germany evaluation studies in the sense of impact analyses of S/T policy programs have been increasingly carried out since the end of the 1970s (cf. Kuhlmann/Meyer-Krahmer 1995; Meyer-Krahmer/Montigny 1989), usually performed by outside independent research institutes on behalf of the policy administration system.

An *early 'landmark evaluation'* that served as a model for many other program impact studies in Germany was conducted in the field of support measures for small and medium-sized enterprises (SMEs): from the end of the 1970s to the end of the 1980s, particular attention was paid in West Germany to SMEs within the framework of innovation policy. The most important measures were the 'R&D Personnel Costs Subsidies Program (PCSP)' of the Federal Ministry for Economic Affairs and the 'Promotion of Research Personnel Growth (GP)' which was launched later by the Federal Ministry for Research and Technology. Between 1979 and 1988 almost 20,000 SMEs were sponsored under the PCSP, involving a total amount of DM 3.2 thousand million. SMEs which had taken on new R&D personnel between 1984 and 1987 were entitled to apply under the GP; about 6,000 enterprises were sponsored, most of which had also taken part in the PCSP; the program volume is estimated at DM 230 million. Both programs have been subject to a joint evaluation by the German Institute for Economic Research (DIW) and the Fraunhofer Institute for Systems and Innovation Research (ISI) (cf. Meyer-Krahmer et al. 1984; Kuntze/Hornschild 1995). In Germany, only a few programs have been evaluated in such depth and over such a long time period. The evaluation concept for the

[8] this section of the paper follows mainly Kuhlmann 1995.

PCSP was established even before the start of the program; this meant that useful basic information for the evaluation could be ascertained from the application forms of all applying companies. A monitoring evaluation was conducted during the first phase of the program between 1979 and 1984, which was divided into 2 sections covering short- and medium-term effects. The overall conclusion of the evaluation efforts was that - although there were some free-rider effects - the sponsored SMEs from the manufacturing sector greatly increased their R&D efforts since the end of the 1970s, and that the two programs have contributed to this development. Viewed against its historical background and taking into account the results of the evaluations, the decision to discontinue all personnel subsidies at the end of the 1980s did not seem justified. At least for the GP, the results of the evaluation showed that a further strengthening of the innovation potential of SMEs could be expected (Kuntze/Hornschild 1995, 52).

Since this 'landmark' effort most SME-oriented programs have been evaluated comparatively often, in particular in the fields of application-oriented industrial research and development (e.g. Becher/Wolff 1995), technology transfer (e.g. Pfirrmann/Schroeder 1995; Hafkesbrink/Horst 1995), and technology diffusion (for manufacturing technologies, e.g. Lay 1989; Lay 1993; Wengel et al. 1995) – i.e. those measures with a wide public appeal. Since the end of the 1980s also strategic programs aiming at strengthening R&D in key technology lines have been increasingly analyzed (e.g. laser technology: Reinhard 1995; Microsystems technology: Becker 1995; Eschenbach et al. 1995; Lorenzen 1990).

This experience of nearly two decades of program evaluation helped to establish a certain 'evaluation scene' in Germany, consisting of a group of experts and institutes in the fields of economics and social sciences covering a relative broad range of methodological approaches and evaluation instruments (see contributions in Becher/Kuhlmann 1995).

In 1992/93 the German Ministry for Research and Technology (BMFT) initiated a 'Metaevaluation' of this gathered experience (cf. Kuhlmann/Holland 1995). The task of the study was to suggest improvements in the methodological instruments and the management of program evaluations of the BMFT on the basis of a comparative analysis and assessment of methods and results of 50 program evaluations which the ministry has commissioned since 1985. In the following we will report on the results of this 'Metaevaluation'. The 50 evaluation studies were characterized according to a set of simple categories, and the following picture emerged hereby:

- *Type of evaluation*: three evaluation types could be differentiated: retrospective (ex post) evaluations, (monitoring) studies and prospective (ex ante) analyses. Ex post evaluations aim mainly to analyze the effects achieved in order to check the (further) need for public promotion measures. Monitoring evaluation should support the program management and make corrections in the course possible, if required. 'Strategic' ex ante analyses should assess the effects of alternative technology policy approaches and interventions prognostically; 'operational' ex ante studies examine the attainability of already set program targets and the probable effects, depending on the chosen program design. The elements of this typology mostly appeared in a mixed form: the ex post element was most frequently represented, however the monitoring type appeared almost as often, and mainly as a product of monitoring or ex post evaluations, the operational ex ante element; strategic ex ante analyses were conducted more frequently than expected.
- *Target group analyses*: almost all studies analyzed the situation or the behavior of potential or actual target groups for S/T policy measures relatively comprehensively. In most cases these analyses were based on oral and/or written questionings.
- Analysis of the *status of research and technology* in the target area of the program under evaluation, in national and in international terms: this can be of great significance for the assessment of the necessity and appropriateness of the policy interventions. In approximately half of the studies, in which such an analysis would have been sensible, examinations were carried out in relative detail; for the other half, such analyses were conducted either only to a limited extent or not at all. Technology foresight concepts (e.g. Delphi approach) are only beginning to be utilized in connection with evaluation studies.
- Analysis of *technology diffusion* achieved: in more than half the cases in which analyses of the actually realized (ex post) or the anticipated (ex ante) technology diffusion would have been useful, such examinations were conducted either only to a limited extent or not at all; in less than half of the studies comprehensive diffusion analyses were carried out.
- *Data basis*: only few studies base their analyses on a combination of standard S/T indicators (e.g. R&D, patent, trade statistics from 'official' sources) and perceptual data (e.g. results of own surveys, data on applicants). A smaller group of studies used both types of data scarcely or not at all. The majority of the studies was based exclusively, or predominantly, on the results of own inquiries (mainly perceptive data).

- *Policy recommendations*: most studies contain relatively comprehensive conclusions for S/T policy action. Less than half contain only poor recommendations or none at all (however it must be remembered that policy papers could have been submitted separately from the final report).
- *Duration of evaluation*: The major part of the studies had a duration of approximately two years. Some very short-term studies (under one year) by their very nature contain only very limited questions and can scarcely be described as thorough evaluations.
- *Publication*: the major part of the studies is virtually inaccessible to the public; the final reports are frequently available only as 'gray literature' or only as an internal document. A mere quarter of all studies have been published as books (and appear in the catalogues of libraries and booksellers).

The program evaluation practice of the BMFT was concentrated on a limited number of promotion fields in the past years. More than 80 per cent of the *financial expenditure for evaluation studies* was spent in the areas of innovation promotion, health research, technology and working conditions, information technology, materials research, and transportation research, which make up 40 per cent of the total research promotion of the BMFT. The majority of the promotion fields, measured in the spending on evaluation, show only few evaluation activities; however, since the late 1980s they have been slowly but steadily spreading to other fields. By comparison with other industrial nations, it appears that the German expenditure on program evaluation in proportion to funding budgets is in midfield (i.e. between 0.5 and 1.0 per cent).

Did all these evaluation efforts concerning S/T policy programs finally have any *influence on the practical policy-making*? In a few cases, in fact, drastic consequences were drawn: e.g. in 1989 a planned but not yet realized program was stopped: a DIW evaluation recommended to hold back a program supporting the dissemination of compound materials in SMEs which the BMFT had been considering - neither the technology development nor industry were estimated to be 'ripe' enough at that time for such a promotion. The evaluation saved many million Marks of public money from being wasted. Nevertheless, normally the impacts of evaluation studies are not so immediately apparent, but they can have a lasting effect: in many cases the results of

The promotion has focused on big FMS with 5 - 10 connected machine tools. But manufacturing conditions emphasized small systems because flexibility requirements in German manufacturing (not the same mass production as in Japan or U.S.) would have increased the costs for informatjion technologies and material flow automation extremely. These underlying

mainly on the interest and the orientation of the individual policy-makers in charge. There is no regular public forum for debates on evaluation results.

The goal of the 'Metaevaluation' was to identify typical problem zones and significant requirements for future evaluation studies, which should be taken into consideration in the discussion about the further development of evaluation practice. We identified *several crucial lessons*:

- Although already an old requirement of evaluation research, the systematic scrutiny of the *underlying assumptions* of economic or technological problems which make a state intervention necessary has repeatedly proved to be difficult. This important analysis was often only very insufficiently carried out, which is in itself an expression of unsolved methodological problems.
- Evaluation practice must always be developed in the context of the *specific conditions in the relevant promotion field* (ranging e.g. from health research to strategic technologies, and to pilot programs for technology-based start-up companies). Especially the methodological approach (e.g. the use of adequate indicator systems for evaluations on diverse program levels) must meet the specific demands of the promotion field. Highly standardized procedures are unsuitable.
- There were only few *horizontal evaluation studies* of different but related policy initiatives used in the process of research planning. The inclusion of activities of other actors in the field of research and technology promotion, and the increasing overlapping and fusion of S/T fields could have been taken into account here. Horizontal evaluation studies could be of great interest to various user groups.
- The significance of assessment processes along the lines of *peer review* must not be underestimated. The designing of the interface with evaluation studies is a conceptual problem which has not been solved satisfactorily yet.
- In several larger evaluation studies a strained (at times explosive) relationship developed between the detached (as required) evaluation activity on the one hand and a certain involvement in the management of a program on the other. Such an evaluation concept 'is in danger of deviating too far from the ideal scene of extensive independence, since its close involvement in the innovation support program and the ensuing allegiance to the program aims can prevent an objective evaluation' (Eschenbach et al. 1995, 192). Double functions must be picked up at the outset and organized transparently, in order to guarantee the *independence of the evaluators*.

- A more intensified *user orientation* of evaluation studies reduces possible conflicts due to diverging expectations of the performance and results. Ideally, different interests in an evaluation study are deliberately included in the concept and possible contradictions are thus productively utilized.
- Evaluation studies are carried out in order to support S/T policy decisions, as well as in the implementation of running programs and when designing new ones. Therefore, studies should also contain *policy recommendations* as a rule. If the results of the empirical survey seem to point to other political conclusions than the commissioner of the study expects or wishes, then it must be guaranteed that these deviating votes can still be explicitly presented and also published - otherwise the credibility of evaluation processes is basically at stake.

It would doubtless be premature at this stage to speak of an 'evaluation culture' in the field of German S/T policies: up till now only 'peer review' evaluations are widely accepted, while evaluation studies have raised some interest but not yet occupied an assured position in the policy-making system.

Using evaluation procedures as one source of creating transparency in S/T policy 'games in multiactor networks' (Scharpf 1993) would imply an analysis of the frequently contradictory rationales of S/T policy players in order to facilitate mutual critique and learning processes. This would also involve the assessment of indirect and unintended individual and interactive impacts of S/T policy measures in societal, economic and ecological spheres. However, the interest of policy-makers in such advanced evaluation concepts is limited: in Germany the authorities commissioning evaluation efforts generally tend to be administrators with departmental orientations and do not, as the system stands, have a strong interest in studies with a far-reaching perspective.

S&T-Policy Instruments and the Role of Technology

Whereas the observation of German evaluation practice recommends an assurance of basic and agreed principles and an actor oriented input into the public discussion about the impacts and future of S&T policy actions, for policymakers within the public arenas the following questions arise:

- Which different instruments are available?
- and where and when is the right time to use them?

Answers to these questions allow a useful input into the way role evaluations should play in a national S&T-system.

The process of identifying the tasks of different technology policy instruments and defining the prerequisites for their application leads to directly plausible ideas about possible areas of application.[9] Arnold, Guy 1992, Meyer-Krahmer, Kuntze 1992 and Lütz 1992 attempt a classification of technology policy instruments based on stylized paths of technology development which are not operationalized any further, either qualitatively or quantitatively[10]. A classification based on measuring the activity levels of scientific research, industrial R&D and turnover is undertaken by Grupp (Ed.) 1993, p.218.[11] Estimations of the possible economically realizable potentials through numbers of possible users or the absolute turnovers to be expected is not undertaken in this model.

However, as emphasized by Jacobs 1990, it is the problems associated with diffusion which are particularly relevant for the political 'steering' of the development and spread of technology.[12] Jacobs emphasizes that income from technological innovations can only be realized at the point of use or sale. Molina 1994 analyzes the diffusion paths of new technologies and their dependency upon agreements and constructs. In doing so, he emphasizes that technology diffusion flourishes best in a situation where account is taken of the specific nature of demand for the technology. Only in this way can the demand orientation in technology policy, advocated e.g. by Meyer-Krahmer 1996, p. 19, be realized.

Thus a description of technological development and diffusion has to define the number of possible users (adopter potentials) in absolute terms, so as to provide technology policy decision-makers with information on the size of beneficial effects when selecting instruments.[13] It is also necessary to precisely determine the state of the technology and its compatibility with (future) user structures, and to identify the attainable adopter potentials in detail. A reference model, elaborated in Dreher 1997, offers a characterization of the development and diffusion process using the above criteria. These criteria have to be reflected in the prerequisites for technology policy instruments and in their predefined tasks. Despite the numerous different mathematical formulations, theories of the diffusion of new technologies have one feature in common: diffusion curves are 'S curves'. The

[9] mainly following DREHER 1997.

[10] MEYER-KRAHMER, KUNTZE 1992, p. 106 using a product-life-cycle model and VDI/VDE (LÜTZ 1992, p. 33) referring to a not specified 'maturity degree'.

[11] cf. SCHWITALLA 1993; GRUPP 1992; SCHMOCH u.a. 1988.

[12] cf. ARNOLD, GUY 1992.

[13] on the necessity see also STONEMANN, DIEDEREN 1994, MEYER 1995.

S-curve also reappears for various adopter categories (Rogers 1983). The reference model is based on the product life cycle model of Abernathy, Utterback 1978, the diffusion phases of Rogers 1893[14] and on diffusion patterns of firms gained from empirical diffusion research, particularly Lay, Michler 1989. Four phases are distinguished, each having different characteristics with regard to the state of technology and the characteristics of adopter firms (more details in Dreher 1997, pp. 54-86, see figure 2):

in Phase I, the technology is used for the first time
in Phase II, the first imitators use the technology
in Phase III, a dominant design emerges and diffusion accelerates
in Phase IV, imitating firms cause diffusion to progress to the saturation limit.

These characteristics could be easily connected to certain instruments of technology policy. By focusing on different types of financial subsidies for a selective technology policy (for the full range of possible instruments see e.g. Meyer-Krahmer, Kuntze 1992), the following tasks of the instruments have to be considered as well as the necessary conditions which have to be fulfilled before using them (see figure 3).

Figure 2: Phases in the Development and Diffusion of a New Technology

Phase	State of technology	Technology development process	Central competitive advantage	Compatibility with adopter structures 1)	Size of adopting enterprises	Adopter category 2)	Max. proportion of adopter potential
I	many variants evolve	Uncertainty, searching	new or better functionality	Low	no distinction	Innovator	0.025 N
II	selection of variants	Stabilization	quality and reliability of offer	Medium	tend to be large firms	early adopter	0.16 N
III	formation of dominant design	Optimization	price	High	tend to be large and medium-sized	early majority adopters	0.5 N
IV	dominant design plus market niche offers	Optimization and special adaptation developments	price plus customer-specific adaptations and after-sales services	Complete compatibility, individual adaptation	medium and small firms	late majority adopters and laggards	N

Figure 3: Tasks and Prerequisites for Use of German Technology Policy Instruments (financial subsidies only)

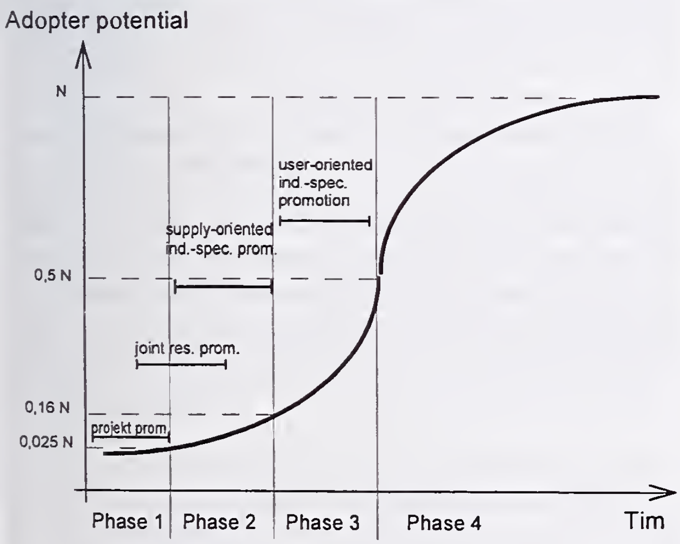
		Prerequisites for use			
Instrument	**Task**	**State of technology**	**Compatibility with adopter structures**	**Target group of promotion measures**	**Category of possible adopters**
Supply-oriented project promotion	Development of new variants, stabilizing suppliers	open; need not be mature for application	Not necessary	Tend to be larger suppliers, research institutes	innovators
Demand-oriented project promotion	Development of new variants, stabilizing suppliers, opening up new application fields, demonstration projects	open, but should be able to be 'tried out'	Not necessary	Tend to be larger suppliers	innovators
Promotion of consortia ('Verbund-projekte')	Transfer of new technology to concrete applications combining suppliers, users and research institutions	open, but the prototype stage of application should already have been performed elsewhere	Not necessary initially	Tend to be larger suppliers, users of all categories, research institutes	innovators, early adopters
Supply-oriented, indirect-specific promotion	Selecting or stabilizing individual options, increasing numbers of suppliers by financial subsidy	definable; stable, 'masterable' variants,	Medium	Suppliers	early adopters
Demand-oriented, indirect-specific promotion	Selecting or stabilizing a dominant design, accelerating diffusion by financial subsidy to users	clearly definable, low complexity, dominant design should be at least in sight	High	Adopters	early majority adopters

[14] overview in e.g. KORTMANN 1995, p. 24-29.

The importance of this adjustment process is underlined by Stoneman, Diederen 1994 who, taking as reference an optimally defined diffusion path, point to the possibility that through the intervention of policy, diffusion may take place too strongly or too soon considering optimal welfare effects. Empirical confirmation from environmental policy is provided for example by Holzschumacher 1994 and Kortmann 1995. If the determinants of technological development and the prerequisites for use coincide, then the instruments can be used effectively. If they do not coincide, sub-optimal results or even failure will be the outcome. This postulation gives rise to the resulting assignment of instruments to specific phases (see figure 4):

- Direct project promotion should take place in phase I.
- The promotion of consortia combining suppliers and users can be initiated at end of phase I and also possibly at the beginning of phase II.
- Supply-oriented, indirect-specific promotion is appropriate in phase II.
- User-oriented indirect-specific promotion does not appear to make sense before the beginning of phase III (detailed discussion in Dreher 1997).

Figure 4: Affinity of Technology Policy Instruments (financialsubsidies) to Diffusion Phases



The empirical test of this taxonomy used the promotion of advanced manufacturing technologies in Germany as an example (cf. Dreher 1997). These technologies were promoted by the German Federal Ministry of Research and Technology from 1971 - 1992, with over 1.5 billion DM. The development and diffusion of these technologies were observed together with the used technology policy instruments and the success of the individual promotion scheme. Hence, the success of the individual scheme could be assessed whether or not it has considered the above identified preconditions. As empirical sources were used: (1) a survey on the diffusion of advanced manufacturing technologies in (Western) Germany, (2) the analysis of the 20 years of promoting AMT and (3) results of independent evaluations of the individual schemes. In total 7 technologies with 25 promotion schemes were observed. The empirical results confirmed the above developed taxonomy as the examples illustrate.

The Promotion of Computer Aided Design (CAD)

CAD was promoted in Germany since 1974 starting with projects elaborating sector-specific software solutions. Until 1983 technology policy focused from 1984 to 1988 on subsidies for adopters within an indirect-specific promotion scheme. In total ca. 460 million DM were spent from 1974 to 1988.

The diffusion of CAD started in the seventies, had reached 1.5 per cent in 1980 in the target group of manufacturing technologies suppliers. In 1984 7 per cent of the firms used CAD, 1989 over 50 per cent were reached.

Evaluations of the schemes showed that in the first phase the promotion strategically opened up adopter potentials by offering supported solutions (phase I of the model). After these attempts a demand-oriented promotion pushed (cf. Lay, Wengel 1989) the diffusion successfully, fulfilling the prerequisites of phase III of the model.

The Promotion of Flexible Manufacturing Systems (FMS)

The promotion of FMS started in Germany in 1971. Exploring basic principles and solving fundamental information technology problems were the first projects. Special applications were the topic of a second round in the eighties using consortia of suppliers, users and research institutions.

The diffusion never took off to the extent policy and engineers had predicted. In the target group of manufacturing technologies suppliers in 1983 1 per cent used FMS, 1989 7 per cent of the sample used FMS.

conditions were correctly identified by prospective studies of the late seventies. But interests of big suppliers and research institutions in order to fulfill their technical 'dreams' predominated policy decisions. In the end almost 1 million DM of subsidy went into each of the implemented FMS in the target group. Compared to CAD this seems to be no success story.

The results highlighted that planning and evaluation of new policy actions should consider the characteristics of the technology and the state of diffusion together with target-group characteristics and administration procedures. This may enhance the efficiency of the technology policy actions and the indicators may support better ex-ante evaluations.

Conclusions

The paper illustrated the diversity and difficulties of governance of the German S&T-system, the history of S&T program evaluations and the roles and differences of instruments if technology – the issue all is about – is considered in its specificity's and how it will or should be used by future adopters.

The lessons learned for German S&T policies are manifold:

- The requirements the metaevaluation of the German S&T evaluation experience has identified have to be ensured in the future in order to deliver facts, information and sound policy recommendations.
- Considering the diversity of actors and interests an evaluation is not the final statement but part of an arena where it has to take some sort of a moderating task. Identifying the actors and their rationales has to be a central task of an evaluation as well in order to ensure the necessary transparency in a democratic society. A multi-perspective evaluation may offer such an opportunity.
- But if evaluation is part of a political process with no clear-cut right or wrong not only transparency is essential. For achieving a constructive role focusing on the next steps in the future instead of blaming the wrongdoers has its merits. Hence, an outlook of the developments is important which could use the methodologies of technology foresight, technology assessment, diffusion studies, patent analysis, bibliometrics etc. in order to paint a picture of the future.[15] To combine these approaches with evaluation procedures the European Commission is supporting a network of evaluation, technology assessment and foresight experts (e.g. Kuhlmann 1997).
- Technologies differ, instruments differ in their tasks. Orchestrating both may save money. This requires developed and empirical elaborated taxonomies (like the one presented) which could be easily obtained by ex-ante evaluations.

Thus, proof of the possibility of empirical foresight estimates for areas of application gives more emphasis to a promotion that is based on consistent ex-ante evaluation[16] – performed before a technology policy intervention is defined and planned. These prognoses also make it easier for other societal groups to participate in formulating the aims and means of technology policy.

Thus these and other tools improve the overall information base of policy makers for a technology policy, weakening the argument[17] of public policy from information deficits when compared with companies. Particularly in the early development phase of a technology, which is associated with high uncertainty, enterprises are by no means more knowledgeable about the broad development of the technology *supply*, although they obviously have more knowledge of their *own user context* per se. The fact that companies themselves cooperate with external research institutions underlines the possibility of the state having access to relevant information of this kind in principle, since most research institutes are run as public agencies.

Hence, more decisive are the ways of implementation of strategic knowledge in real policy, and the fact of the independence of state decisions dedicated to the furtherance of economic and societal interests. Bringing in actors that are external to policy administration – despite the involvement of individual interests – into the designing of concrete measures does facilitate implementation in day-to-day terms. Technology policy remains – first and foremost – policy.

[15] for methodologies see e.g. from Germany CUHLS 1997, GRUPP 1997.

[16] KUHLMANN, HOLLAND 1994.

[17] compare arguments of MEYER-KRAHMER 1989, pp. 222.

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ATP and the U.S. Innovation System

by Michael S. Fogarty, Amit K. Sinha, and Adam B. Jaffe.[1]

Introduction

Evidence indicates that R&D spillovers cause a large gap between social and private rates of return – a difference on the order of 50 to 100%.[2] A large 'spillover' gap creates a rationale for the Advanced Technology Program (ATP) which seeks to maximize net social benefits by supporting pre-competitive, enabling technologies. ATP's challenge is to identify and fund projects with a high social rate of return that would otherwise be underfunded, delayed, or inadequately pursued in the absence of ATP support (i.e., fund projects with a large 'spillover gap'). Our analysis indicates that ATP's funded projects will produce more influential spillovers if selection is based on knowledge of *networks* of R&D organizations that are influential sources of enabling technologies.

This paper has two primary purposes. The first is to develop a new fuzzy systems methodology for analysis of R&D spillovers.[3] The new methodology yields new, deeper insights into innovation and suggests important R&D spillover hypotheses with relevance to ATP. A second purpose is to illustrate the usefulness of the method for evaluating and improving the selection of projects by ATP. We do this by focusing on one specific technology: MEMS (microelectro-mechanical systems), which is an emerging technology being discussed by ATP as a Focused Program candidate.[4]

Methodology

Researchers studying spillovers have been constrained by not having a method that allows them to discover and analyze patterns in the complex patent data set. If the 'spillover pool' metaphor is the right one, then statistical methods and interpretations found in the literature make sense. However, if there is an underlying spillover network structure with diffusion pathways and specific spillover mechanisms embedded in the patent data, then existing methods miss crucial information. For example, R&D networks will influence the rate of invention and innovation, technology diffusion, and the geography of spillovers (i.e., the location of social benefits). The fuzzy methodology gives us a new framework and tool for analyzing long standing spillover questions, interpreting spillovers, and simulating policy interventions.

The basic unit in our model is the R&D lab. Our fuzzy system methodology gives us a way to represent the interrelationships forming R&D networks. The R&D networks are constructed from interactions between R&D labs. We analyze these interactions using patent citations, which are interpreted as a form of communication. Communication takes many forms, including reading of papers, attendance at conferences, hiring of leading consultants, word-of-mouth, analysis of patent database, hiring of university graduates, and personal communication.

By a system we mean that there exists a hierarchy of technologies, R&D organizations, and regions connected by a communication network. System effects exist when a change in any component diffuses throughout the network. The notion of an innovation system is intuitively appealing and is consistent with existing evidence on R&D spillovers: our interviews suggest that inventors and R&D directors behave as if there is a system; patent citations are more likely to be external to a region when there exists a high level of local inventive activity; and the social value of CT-scanner patents increases nonlinearly with the number of patents (i.e., the information content increases disproportionately with the number of citations).

[1] Michael S. Fogarty is a Professor of Economics at Case Western Reserve University and a member of the NBER, Amit K. Sinha is a graduate student at Case Western University, Adam B. Jaffe is a Professor of Economics at Brandeis University and a member of the NBER.

[2] Two types of R&D spillovers are particularly relevant to this study: (1) "knowledge spillovers" — These occur because knowledge created by one firm is typically not contained within that firm, and thereby it creates value for other firms and other firms' customers; and (2) "network spillovers" – These result from the profitability of a set of interrelated and interdependent technologies that may depend on achieving a critical mass of success so that each firm pursuing one or more of these related technologies creates economic benefits for other firms and their customers. See Adam B. Jaffe, "Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program," October 1996.

[3] Lofti Zadeh developed fuzzy set methods in the mid-1960s as a way to incorporate the "vagueness" or imprecision of data and other information in our lives and decisions. Statistical imprecision involves outcomes that are random (a flip of a coin); fuzzy imprecision is non-statistical (it's about time we begin our descent for a landing). The difference applies to sets. For example, "crisp" (conventional) sets involve precise conditions for membership in a set. The answer is yes or no, 1 or 0. Fuzzy sets satisfy imprecise conditions with a membership function between 0 and 1. The membership function can be used to describe "truth values" – X belongs to Y with a truth of 0.8. For a good introduction to fuzzy methods, see James C. Bezdek and Sankar K. Pal, *Fuzzy Models for Pattern Recognition* (Piscataway, NJ: IEEE Press, 1991), Chapter 1. Also see Amit Sinha, "A Study of Fuzzy Logic Based Pattern Recognition Models," (mimeo), February 19, 1998.

[4] ATP's Focused Program involves multi-year projects with well-defined technologies and clear business goals. See http://www.atp.nist.gov/atp/focusprg.htm#Ongoing.

Existing methods simply weight patents by quantity of citations to measure spillovers and the significance of the technology.[5] In other words, they assume 'all patent citations are equal' (assign a value of 1 to each citation); our fuzzy methodology allows us to develop indicative membership measures between 0 and 1 representing the strength of interaction between any pairwise combination of R&D labs, specific to organization, technology, and region. Our systems model builds the system iteratively incorporating the first, second, and then the third level of diffusion of spillovers. The result is a hierarchical R&D network system.

We can then determine the influence of particular R&D labs by technology and region. The sum of the interactions "truths" (values between 0 and 1) across an R&D network is the lab's total system value (SV) for the technology. The SV is a function of the number of links in a network and the strength of each pairwise interaction. Therefore, an individual R&D lab's SV is high when there are a large number of intensive links with other influential labs.

For each pair of R&D labs in a network we have three measures: (1) relative importance of the unit (system value or strength); (2) strength of interaction (truth value); and (3) the relative systems influence of the link between the two units (the system value of the source multiplied by the truth of interaction between the source and learning R&D labs). The results can be aggregated across the three dimensions by year – technology, organization, and region.

Our methodology represents an advance for several reasons. First, it allows us to search for and identify patterns or structure in the complex patent data. This was made possible by our new fuzzy systems algorithm that makes 'relational' simultaneous clustering of patents in four spaces possible with a UNIX workstation. The four spaces are: technology, organization, region, and time. Second, the methodology suggests new hypotheses yielding new insights about invention and the innovation system. For example, because R&D networks serve as a source as well as a user of R&D spillovers, an individual firm's value as a source of new technology depends on its ability to learn from its external environment. Third, the methodology offers a framework for developing ATP strategies to maximize spillovers and suggests an approach to evaluating ATP projects. For example, ATP should look for enabling R&D networks – not enabling technologies. The methodology can assist in the selection of ATP projects by providing measures of the significance of technologies and by exploring the likely influence of proposed project participants, including joint ventures. The methodology also permits analysis of MEMS R&D spillovers by broad industry-based technologies (automotive, aerospace, advanced materials, auto, information technology, and biomedical devices) as well as regions. Finally, the methodology also suggests a possible approach to measuring the "spillover gap."

Figure 1 illustrates one segment of a specific R&D organizational network for MEMS centered on MIT over the period 1985-95. The full network is much larger and is discussed in the following section (see Figure 4 for the top twenty-five MEMS organizations. This segment is centered on MIT, which is ranked 20th in the full network.) It illustrates that R&D networks operate as both sources and learners. One implication is that a firm's value as a source depends on its ability to learn from its external environment. The nodes in the R&D network correspond to the R&D labs and arrows indicate spillover flows between labs. The colour bar indicates importance of the R&D lab and the systems influence of interactions. The most influential node is brown; the least (not shown) is dark blue. Arrows follow the same scheme.

The analysis, which is based on real data, identifies AT&T, Honeywell and Xerox as the most important MEMS organizations in this part of the network. The full network contains more nodes, incorporating interactions involving third-order diffusion of spillovers. Next are GTE, MIT and the US Army. The figure incorporates the most important interactions – i.e., those closest members of MIT's R&D MEMS neighborhood, including first and second-order diffusion spillovers. For example, flow from MIT to Xerox is about 0.5. This means that about 50% of all R&D pairwise interactions in the full MEMS network are less intense than that between MIT and Xerox. Also shown, GTE has a second-order influence on MIT which occurs through its direct influence on AT&T.

ATP and the Case of MEMS

Our paper focuses on one application: microelectro-mechanical systems (MEMS), which is an important emerging technology being consider by ATP for its Focused Program. Our analysis is not intended to be a formal evaluation of MEMS as an ATP focused program.

MEMS combines computation, sensing, and actuation with miniaturization to make mechanical and electrical components. The bulk of applications are pressure sensors, optical switching,

[5] For example, see Zvi Griliches, "Patent Statistics as Economic Indicators: A Survey," *Journal of Economic Literature*, Vol. 92 (1990), 630-653; Adam Jaffe, "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits and Market Value," *American Economic Review* (1986); Adam Jaffe, Rebecca Henderson, and Manuel Trajtenberg, "Geographic Localization of Knowledge Spillovers as Evidence by Patent Citations," *Quarterly Journal of Economics*, Vol. 108 (1993), 577-598; and Joel Podolny and Andrea Shepard, "When Are Technology Spillovers Local?: Citation Patterns in the Semiconductor Industry," (mimeo), 1997.

Figure 1: MEMS R&D Network Around Massachusetts Institute of Technology

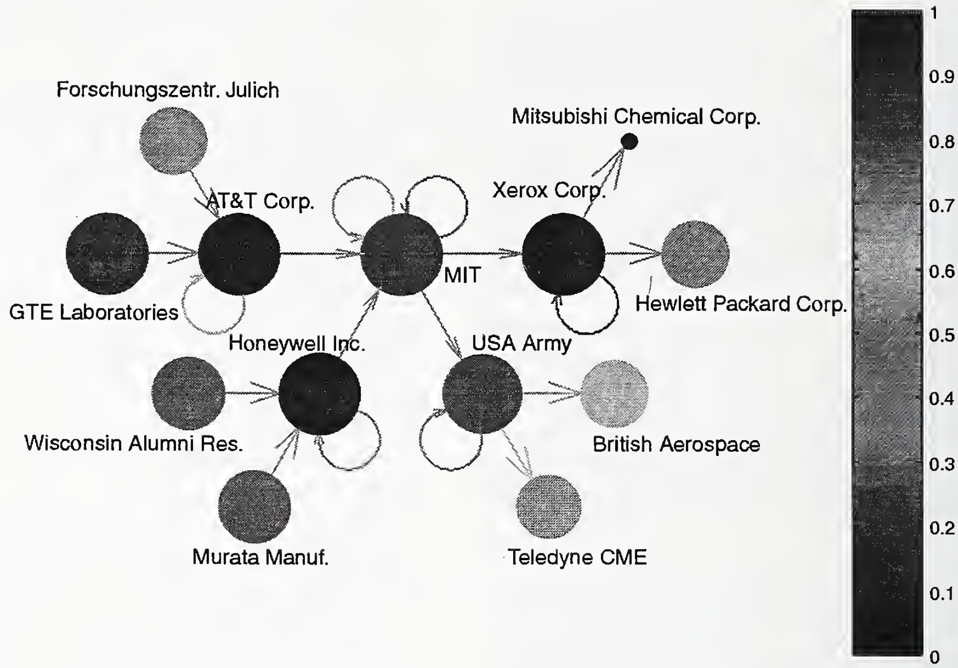

Table 1 highlights systems hypotheses with implications for ATP.

Table 1: A Summary of Selected Spillover Hypotheses and Implications for ATP

Spillover Hypotheses	Implications for ATP
1. Spillovers are becoming increasingly important to firms' performance. A firm's system position affects its rate of invention and innovation as well as the speed and geographical extent of technology diffusion. Firms will decline if they become less effective learners.	ATP will maximize spillovers by selecting projects with enabling networks. These projects involve organizations positioned in strong R&D networks, incorporating the influence of all three spaces. Joint ventures involving small firms offer a way to magnify R&D spillovers by connecting small firms' R&D to more influential R&D partners.
2. Interactions in the system focused on strong R&D networks cause increasing returns to R&D. Geographic spillovers will become increasingly concentrated by region. In the pre-competitive, enabling stage, spillovers are highly geographically concentrated and successful regions increasingly become their own source of the technology.	ATP will maximize spillovers by funding projects that draw heavily on strong R&D networks. The outcome will likely reinforce patterns of concentration, even though spillovers will be widely shared across organizations, industries, and regions. This strategy gives the U.S. an early advantage in emerging technologies.
3. Firms in the network of top universities are more influential sources of enabling technology.	ATP will maximize spillovers by selecting projects involving technologies that draw extensively from universities and government labs. Drawing on strong GUI networks leverages federa research support.

inertial sensors, fluid regulation and control, and mass data storage. These cut across a number of manufacturing industries, including: sensors, industrial and residential controls, electronic components, computer peripherals, automotive and aerospace electronics, analytical instruments, and office equipment. The industry list suggests a potential for generating a large, broad-based volume of R&D spillovers.

Our analysis suggests that R&D networks generating pre-competitive, enabling technologies may have certain characteristics, such as: (1) universities and government labs play significant roles as sources; (2) the network is sparse and evolving; (3) the technology is new (cited patents are relatively current); (4) total system spillovers increase significantly and technology gets diffused rapidly; (5) influential companies perform significant basic research; and (6) technologies become geographically concentrated in important regions serving as incubators.[6] [7]

MEMS is an emerging technology worldwide.[8] About 200 firms are actively engaged in MEMS R&D – roughly 80 are US firms; Japan is the second major player. According to DoD, the MEMS market was $1 billion in 1994. Projections for the year 2000 range from $8 to 14 billion. It is likely that MEMS interacts extensively with other technologies.

U.S. industry investment in MEMS so far has been fairly modest (about $120 million in 1995). In contrast, in the same year federal R&D support of MEMS was a large component (about $35 million), $30 million of which came from DoD (mainly DARPA).[9] Suggestive of the technology's emerging character, about 30 universities and government labs are actively pursuing MEMStechnologies. NSF's MEMS support was $3 million. Labs contributed about $2 million. Since 1989 the NSF has sponsored 124 MEMS-related projects at 61 organizations (mainly universities), with funding of about $25 million. Approximately $1.4 million consists of SBIR grants.[10]

Data and MEMS Patents

The data are drawn from the universe of patents granted by the US Patent Office from 1963 through 1995.[11] Information on patent citations begins in 1977. Electronic data on assignee is available beginning in 1969. We geographically locate patents using the inventor's address, which means that location in our analysis is the R&D lab's location – not the headquarter (assignee) location. In addition to country and state, inventors have been sorted first into counties and then metropolitan areas.

As a foundation for analyzing MEMS, we developed a core database of about 1,200 MEMS patents, starting with a short list of key inventors and federally-funded MEMS projects. Citations to these initial patents were used to identify additional MEMS candidate patents. Each candidate patent abstract and exemplary claims was read to ensure that the patent was a MEMS technology.[12]

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[6] Serious R&D organizations invest a portion of R&D to actively acquire external knowledge and aggressively search what Stuart & Podolny call the technological landscape for ideas, knowledge of competitors' technology, etc. See W. Cohen and D. Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly*, Vol. 35, 128-152. Clearly, a firm's learning process isn't random. Evidence from our interviews suggest that firms are focusing more resources on acquiring technology from external sources. See Adam B. Jaffe, Michael S. Fogarty, and Bruce A. Banks, "Evidence from Patents and Patent Citations on the Impact of NASA and other Federal Labs on Commercial Innovation," V. XLVI, No. 2, *Journal of Industrial Economics* (June 1998), 183-205.

[7] Although influential R&D organizations search in a global R&D network, in a pre-competitive, incubation phase, geography plays a critical function — the accumulation of a critical mass of strong network connections that speed growth of the enabling technology. In general, as local activity increases, the volume of important spillovers grows but an increasingly large fraction becomes external as a region develops higher order R&D organizations with world-wide connections. Because R&D labs have a specific location, an agglomeration of strong R&D networks serves a dual function — good regional sources are also good learners. Local R&D networks are strong only if they are solidly linked to the global network.

[8] For a description of MEMS, see Department of Defense, "Microelectromechanical Systems: A DoD Dual Use Technology Industrial Assessment (Final Report)," December 1995. For an interesting description of MEMS, see *Discover* (March 1998).

[9] Our research shows that DARPA presently funds 62 projects at 48 organizations (17 universities, 5 government labs, 18 large companies, and 8 small firms). DARPA is currently funding 5 SBIR projects at 4 companies; they previously funded an additional 5 SBIR projects. The Army has funded 17 MEMS-related projects at 14 firms through its SBIR program. The projects amount to nearly $2 million. NASA has sponsored 20 MEMS-related SBIR projects. (No dollar amount was available.) However, the MEMS working group at NASA-Lewis in Cleveland supported $2.5 million MEMS R&D by 17 S&Es. Moreover, Ohio MEMS-Net has funded $2.4 million for capital investments in 1995 and 1996.

[10] Ranked by total NSF support of MEMS projects, the top ten institutions include: Stanford, UC Berkeley, University of Michigan, Cornell, University of Utah, University of Pennsylvania, University of Illinois Chicago, Case Western Reserve University, University of Minnesota, and University of Hawaii. Most of the MEMS university projects are associated with fairly extensive patenting. The 61 MEMS universities currently account for 312 MEMS patents.

[11] The study uses the comprehensive patent database developed jointly by REI-NBER. REI is the Center for Regional Economic Issues at Case Western Reserve University.

[12] The anaysis of MEMS patents was done by David Hochfelder, a research assistant on the ATP project. Hochfelder has a Masters degree in electrical engineering.

MEMS – The Top Five Countries

There exists considerable international competition involving MEMS technology. The technology is concentrated in a few countries. As shown in Figure 2, our systems analysis of MEMS technologies ranks the US as first, with Japan second, followed by Germany, France, and Great Britain. Ranks are based on each country's systems value as a MEMS source (i.e., our fuzzy estimate of each country's contribution to MEMS technologies). Spillovers occur across international boundaries. Figure3 shows the balance of MEMS spillover flow for seven countries with the largest MEMS concentration (flow in minus flow out). What the data shows for MEMS is that higher-order countries are net exporters of the technology. The balance of MEMS knowledge flows between the US and Japan favors the U.S.

Figure 2: World's Top 5 Sources of MEMS

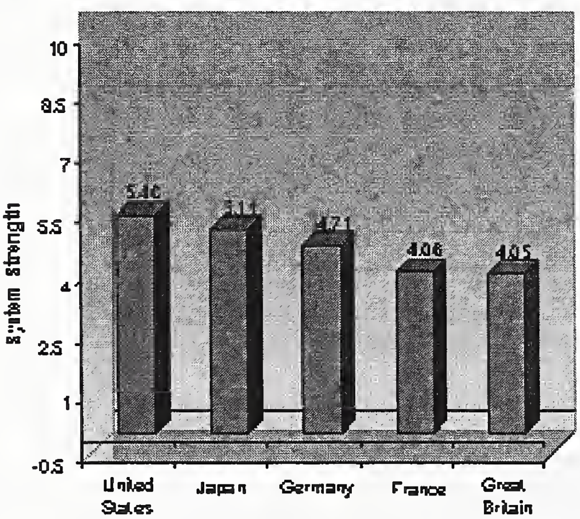
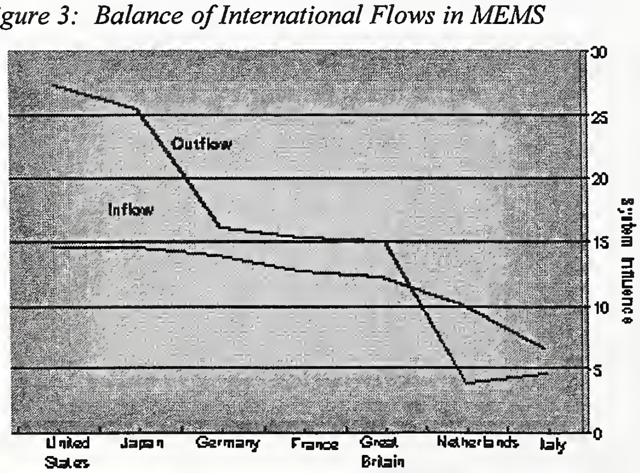


Figure 3: Balance of International Flows in MEMS



The MEMS R&D Network – A Brief Description

There exists potential for ATP to use the methodology to become more strategic in its project support by incorporating knowledge of spillover networks. For example, one important consideration for ATP would be to use knowledge of R&D networks to obtain a more favorable balance of knowledge spillover trade flows.

We can describe networks in a great deal of detail – about 400 technologies (patent classes), individual R&D labs by organization, and metropolitan region location. Only selected findings are shown here. The original paper includes additional MEMS R&D network findings by technology, organization, and region. The data cover the period 1985-95. Each member's position is simultaneously located in the three spaces. For example, only the findings for each network's most influential members as influential *sources* are shown. These particular examples characterize the R&D network *sources* of MEMS technologies. A parallel network exists for 'spillover use' networks.

Technologies

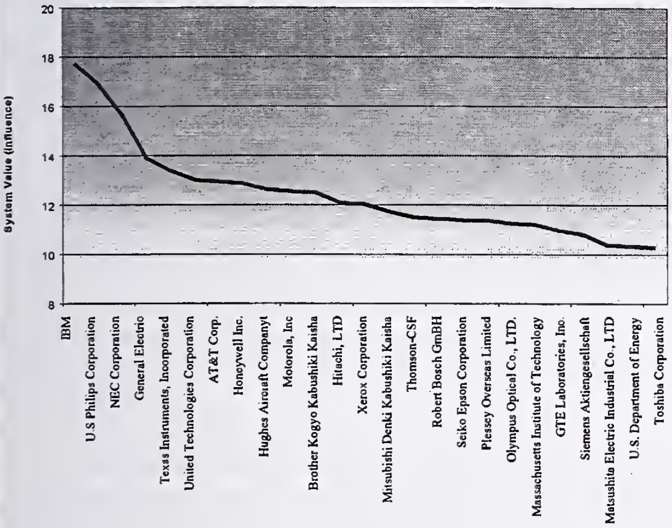
The paper illustrates the system importance of leading technologies in the MEMS network. The top five MEMS technologies are: Semiconductor Device Manufacturing Process, Metal Working, Electricity: Electrical Systems & Devices, Incremental Printing of Symbolic Information, Optics: Systems (including Communication) and Elements. Our analysis shows that each of the top five MEMS technologies plays an influential role in both auto and aerospace industry technologies.

Organizations

Figure 4 shows the top MEMS organizations ranked on system influence (i.e., spillovers). An organization's position on the list is determined by the spillover generated by its associated R&D network. The analysis shows that IBM ranks first as a source, followed by U.S. Phillips, NEC, GE, Texas Instruments and United Technologies. Some of the key universities are (in order of their influence) MIT, Stanford, and Berkeley. The full organization list (not shown) shows that federal labs and universities are prominent MEMS sources.

Each R&D network's spillovers can be analyzed across all three dimensions. This capability would provide ATP with the means to select projects associated with enabling MEMS R&D networks. One hypothesis would be that ATP's funding will be more "enabling" — draws on more basic, early-stage research, and stimulates broader, more influential spillovers across a wider spectrum of important uses — if it leverages other important federal R&D funding.

Figure 4: Fuzzy Network of MEMS Organizations



Regions

When ATP selects a project, it also selects the geography of R&D spillovers and, therefore, the benefits of ATP-funded R&D. Previously we saw that MEMS is highly concentrated in a small set of leading countries. An analysis of US regions shows that development of MEMS is also geographically concentrated in a few top regions: San Francisco, Boston, LA, NY, Chicago, andDallas account for the lion's share of the technology. Our hypothesis is that an important characteristic of enabling networks is location in a successful regional agglomeration supportive of new technology development. Both San Francisco and Boston are important MEMS sources. In other words, both regions are influential external sources of MEMS. However, only San Francisco appears to be developing significant local spillovers. Based on this particular enabling characteristic of networks, ATP investments in projects with strong connections to San Francisco's MEMS network may produce more spillovers and faster development of the technology. Investing in ATP projects located in these large R&D agglomerations will likely produce a higher social rate of return because the investment builds from critical mass, creating increasing spillover returns to R&D. ATP's investments in leading regions may also result in capture of a larger share of spillovers by the US. The reason stems from the expected increasing returns to R&D coupled with a faster rate of technology diffusion and commercialization. Even though ATP's investments are concentrated in leading regions, spillover benefits will be shared by a much larger set of US industries and regions that draw from incubator regions.

Conclusions

Our new fuzzy systems methodology offers a new, potentially powerful way to analyze and interpret R&D spillovers, yielding much deeper knowledge of R&D spillovers than existing methods. Our analysis indicates that ATP's funded projects will produce more influential spillovers if selection is based knowledge of networks of R&D organizations that are influential sources of enabling technologies. MEMS provides an important example.

The key contribution of this study is the identification of R&D networks as the main spillover mechanism. Our system model is built on the assumption that patent citations between two R&D organizations occurring over a period of time identify communication and measure interactions. However, the evidence shows that patent citations are a noisy indicator of knowledge spillovers. Supportive evidence comes from a number of quantitative studies relating patent citations to measures of value; interviews of R&D directors, patent attorneys, and inventors; and at least one case study. The evidence is clearly more supportive at the R&D lab level over time, which is the basic unit of this study, than at the individual patent level. But more validation is clearly needed. The authors have begun a pilot national survey of inventors that will seek to determine the conditions under which patent citations can be used to measure communication and knowledge spillovers. Importantly, our survey will also be used to validate the system structure identified by the new model. In addition, there is a need for more R&D lab interviews and case studies focused on the structure of R&D networks. These would help to identify the specific spillover mechanisms that ATP's projects can influence to maximize social benefits by funding projects with a large 'spillover gap.'

Our methodology may provide a way to evaluate the spillover gap associated with projects. ATP seeks projects with both a high social and private rate of return. The following is only suggestive. First, set a minimum private rate of return and then calculate the total system value of each project across the network (such as MEMS). Second, separate the system value into two components: (a) internal to the project's participants (private gain) and (b) external to the project's participants (social gain). An approximation of the spillover gap is simply the difference between estimated social gain and private gain. The calculation requires taking into account the fact that ATP project participants draw spillovers (learn) from the full network. Where multiple projects are funded, we also need to evaluate inter-project spillovers. These are specific to organization, technology, region and time. The last step is to rank projects by the spillover gap.

A comparison of spillover ranks based on the existing method and our method shows that while the ranks are correlated there are significant differences that stem from differences in the strength of the networks. An important next step in developing the methodology is to develop a fuzzy measure theoretic basis for our method. Statistical hypothesis testing requires that the underlying model satisfies the conditions of measurability. Since fuzzy measures do not necessarily satisfy classical measure properties, fuzzy models cannot be readily used for standard statistical hypothesis testing. One of the authors is currently developing the theoretical basis that would make such testing possible.

Comments on ATP and the U.S. Innovation System: A Preliminary Report

by James D. Adams[1]

This paper is an ambitious attempt to measure elements of system-wide R&D spillovers. By system-wide I mean the effect of spillovers throughout the economy, as opposed to the immediate effects among firms in the same locality and industry. The paper employs a new approach to patent citations in order to reach this goal. The method used by Sinha, Fogarty, and Jaffe (hereafter SFJ) is based on the mathematics of fuzzy sets. Fuzzy set theory is concerned with the assignment of "truth" values, which indicate the likelihood that an object belongs to a set when membership in that set is not known with certainty. In the specific context of this paper the objects are R&D laboratories, and the question is whether the laboratories belong to a specific citation network.

The principal reason for the emphasis on defining the likely limit of the citation network is that the influence wielded by citations presumably depends on the importance of the citing R&D laboratory in the network. Previous papers have treated all citations as equally valuable, effectively visualizing the citation network or system as a citation "sphere" in many dimensions surrounding the R&D laboratory being cited. The promise offered by this paper lies in its potential to define a broader citation system, so that the influence of a citation is not rigidly set equal to 1.0, but instead depends on how often, and by whom, the citing R&D laboratories are themselves being cited. In this way the multi-dimensional citation sphere turns into a much larger and more irregular citation "solid". In addition the secondary citations are themselves weighted by the influence of tertiary and higher order citing R&D laboratories, and so on to the edges of the network. If the methodology succeeds in this goal, then a picture of the importance of patents and the issuing R&D laboratories emerges that is closer to capturing the influence of ideas than the older, single stage citation methodology.

The methodology would have obvious potential relevance to ATP, since ATP is interested in high risk, enabling technologies. Network externalities, and by inference citation networks, can be expected to accompany such technologies. Thus the social benefits of technologies in which ATP is interested are likely to exceed the firm level benefits. It follows that techniques for identifying networks could help ATP in selecting its portfolio of projects.

If the potential of the method is this large, does it have any shortcomings? I believe that there are some, but in making this assessment I am driven to say that the mathematics of the paper are not carefully spelled out in the version of the paper that was available to me. It follows that the interpretation that I place on the methodology of SFJ may differ somewhat from the formulae that are actually being used to derive the results.

First, it is my understanding that the measures of citation influence are based on citation fractions to and from pairs of laboratories A and B, normalized relative to a population of citation fractions. If this is correct—and page 14 of SFJ says that it is—then this aspect of their measurements takes out scale of the laboratories. In my view this biases the influence of larger laboratories downward compared with smaller laboratories. Of course, in their empirical application to the MEMS technology (Micro-Electro-Mechanical Systems), SFJ find that larger geographic centers of research have larger influence, partly because of the multiple layers of citation involving such centers. It would appear that their systems methodology makes up in breadth of citation some of what it loses in scale of the R&D laboratory or research center. Nevertheless, the direct effect of size of large laboratories should be fully taken into account.

Second, SFJ should demonstrate whether their corrected citation influence measure outperforms the traditional single stage citation measure in explaining performance of the citing laboratories. That is, in an econometric framework, they should demonstrate whether their system-wide spillovers have an incremental effect over and above single-stage spillovers in explaining patenting, stock market value, total factor productivity, and other indexes of industrial success.

Third, in their paper SFJ apply their methodology to two technologies that are already known to have large network externalities. What would be more helpful to ATP is a predictive method that would catch the technologies at an early stage and based on their characteristics at that time, allow us to predict which technologies are likely to develop into full-blown networks.

I submit that some of these characteristics are already known at this time. Candidate technologies in some sense would have to be beyond the ability of the private sector to commercialize. Candidate technologies would often originate in basic science; they would be high risk, and their applications would be largely unknown; they would be subject to standardization, once applied, thereby rendering them more useful; and their external benefits would be immense. It remains to be seen how these literary characteristics translate into the fuzzy set mathematics of this paper, applied to technologies born in the past few years or so at the time of the analysis.

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[1] Dr. Adams is Professor of Economics at the University of Florida and is a Research Associate of the NBER.

EVALUATION OF NATIONAL PROGRAMS

SECTION

C

R&D, Government Support, and Firm Productivity in Israeli Industry

by Zvi Griliches and Haim Regev[1]

Background

In the last two decades or so, Israel has engaged in concerted wide-ranging efforts to develop and promote its science-based high technology sectors. The premise was that given its lack of natural resources on the one hand and the availability of a highly educated workforce on the other, economic policies aimed at overcoming market failures usually associated with innovation and technical change would lead to higher economic growth.

To implement this overall policy, various support institutions and programs were created over the years. The main ones are:

1. R&D subsidies granted by the *Chief Scientist of the Ministry of Industry and Trade* to support commercial R&D projects performed by the private sector. This is the largest (and oldest) support program and it has been widely credited with propelling the tremendous growth of Israel's high technology sector in the last decade.
2. The "*Magnet*" program, also from the Ministry of Industry and Trade. This program supports consortia engaged in developing "generic" technologies expected to be relevant to the members of the consortium, and possibly also to others in the same field. That is, it supports precompetitive R&D, and does so by encouraging (and then subsidizing) the creation of collaborative projects that include firms operating in similar or related areas and sometimes also academic institutions.
3. The "*National S&T Infrastructure*" program, backed by the Ministry of Science and the National Council for Research and Development. This program identifies critical areas of science and technology that have potential commercial applications, in which Israel may have (or may develop) a comparative advantage, and supports projects conducted primarily by consortia of academic research groups and also some members from industry.
4. The various *Binational* programs (such as with the US), involving support to collaborative R&D projects between Israeli and American researchers and companies.
5. R&D projects supported by the *Ministry of Defense*, having potential civilian applications.
6. Support to basic research at universities and other academic institutions.

This paper examines the overall role of government-supported R&D in Israeli industrial firms, especially its contribution to growth in their productivity.[2] Subsequent work will focus more specifically on the project-level data available in the records of the Chief Scientist. The analysis of the Israeli data may also be helpful in understanding the working of R&D support programs in other countries, especially in the US, where the Advanced Technology Program (ATP) is operating in a somewhat similar manner.

Most OECD countries have government-funded R&D support programs that encourage and complement private investment in civilian R&D. There seems to be a rather wide consensus among economists in the OECD countries that government action to promote research and development is well advised. The analysis of Israeli data may be also helpful in understanding the operation of R&D support programs in other countries because efforts to evaluate such projects have been rather scanty, at least in the sense of econometric studies based on firm-level data (see Klette, Moen, and Griliches,1998, for a recent review).

The mission of ATP is relatively new in the history of government support to R&D in the US. Most of the previous federal support to R&D went either directly to universities and similar institutions or was largely contract research funded by national defense and space agencies. Direct support of industrial R&D with no quid pro quo is something new in the US, though it has been a long established practice in Israel, Japan and other countries. Evidence of the social effectiveness of federal R&D expenditures in US industry is rather scant and largely negative (see Griliches and Lichtenberg (1984) and Griliches (1986)), and its defenders have been reduced to looking for possible inducement effects on private R&D expenditures (Archibald and Peirera, 1996). But that evidence is largely irrelevant for assessing the potential benefits of the Israeli support programs, since that support is given to companies to help them pursue *their own* goals.

[1] Harvard University and NBER and The Central Statistical Bureau of Israel respectively.

[2]This article is part of a more extensive research project that includes a study (by Dr. Saul Lach of the Hebrew University of Jerusalem) on additionality in R&D and studies on subsidization of physical capital (Bregman, Fuss, Regev, 1998) and labor (forthcoming) in Israeli industry.

It should be noted that we will not be able to address one of the major topics of interest in such studies: the role of spillovers from government-supported R&D. We are limited to confidential individual firm data within the Israeli CBS, though we can also look a bit more broadly at industry-wide effects. Given that most of the output of these firms is exported, we have no good way to trace the effects of this R&D further downstream. But analyzing the first-order effects of government-supported R&D on productivity at the firm level is of interest in itself. So far, the results obtained for US data have been largely negative. Since the goal of R&D support has been different in Israel—much closer to what ATP is trying to achieve in its own program—the results for Israeli data are also likely to be different, and possibly much more positive.

The Period in Review

The two decades covered in this study were a period of political and economic turbulence in Israel. The period began with the energy crisis following the 1973 Yom Kippur War, which set off an inflationary process that peaked in the mid-1980s. The salient events that left their imprint on this period include:

- The *change in ruling party,* as the Likud acceded to power in 1977 and introduced economic liberalization.
- The *inflation process,* which peaked at triple-digit levels in the first half of the 1980s.
- The 1985 *economic stabilization plan,* which drastically reduced inflation and began an era of economic restructuring.
- The *exposure of Israeli manufactures to competing imports.* Practically speaking, the process began with the Free Trade Area Agreement with the European Common Market, concluded in 1975, and continued with the signing of an FTA accord with the United States in 1985 and the elimination of nontariff import barriers between 1985 and 1990.
- *Mass immigration* in the first half of the 1990s, mostly from the former Soviet Union, which led to a significant increase in trained manpower that was integrated into Israeli industry and made a major contribution to the perceptible growth of that industry during this time.
- The *peace process* that began at the end of the period, affecting Israel's international trade, foreign investments in its industry, and the overall economy.

The world economy also underwent far-reaching changes during this period. Globalization and greater openness led to a freer flow of goods, information, and people; greater competition; and a rising share of high-tech industry in many countries.

Israeli industry seems to have adjusted well to these changes. The specific question explored in this paper concerns the effects of government-supported R&D on productivity at the level of the firm and also the national economy as a whole.

Economic Examination of R&D Support Programs—A Conceptual Perspective

There are several ways of looking at government support of private R&D. The simplest way is just to think of it as a decline in the real price (cost) of R&D facing a firm. If the government contributes 50 percent of the cost of a project, then the price of doing this project is half of what it would be otherwise. If the production function is of the Cobb-Douglas form, including also its R&D capital component, then a decline of 50 percent in the price of R&D will lead to a doubling of R&D.[3] That is, the full effect of the R&D support is the increase in total R&D that it induces. There is nothing further to look for in the production function. All the other effects are R&D effects in general, including its various spillover externalities. The only question here is by how much did the grant increase total R&D? Was it complementary to the firm's own expenditures or did it substitute for them? That is the issue of *additionality.* In terms of the production function for output, this assumes that only total R&D matters and that privately financed and government-supported R&D are perfect substitutes.[4]

An alternative view denies that the source of funding does not matter and looks for differences in the effectiveness with which such funds are used by firms. Governmentally supported R&D may be used less efficiently if it is subject to various constraints or if the entrepreneurs do not treat grants as "their" money. It could, on the other hand, yield a higher rate of return if both the application and the selection processes choose the more promising projects, i.e., if the agencies can actually "pick winners." The simplest way of formulating this view is via the concept of "*effective*" R&D capital, where certain R&D expenditures may create more (or less) capital than is indicated by the budgeted or reported figures.

"Effective" R&D capital can be written as:

$$(1)\quad R_e = R_o + (1 + \delta)\ R_g = R_T\,(1 + \delta s)$$

[3]In fact, the price will not decrease by the full 50 percent if the firm has to remit royalties to the government if the R&D succeeds—as is the case in Israel—but the idea is still the same.

[4]Our inquiry found that one dollar of government subsidy for R&D expands the firm's own R&D by $0.83 and that the difference relative to 1 is not statistically significant. As stated above, this matter is being explored in an additional study.

where R_o and R_g are own and government-granted R&D capital respectively; δ is the effective premium or discount on supported R&D; $R_o + R_g = R_T$ is the total reported R&D; and $s = R_g / R_T$ is the share of R&D grants in total R&D expenditures. If effective R&D enters the production function logarithmically, then we can rewrite its logarithm approximately as: $\log R_e = \log R_T(1+\delta s) \cong \log R_T + \delta s$, provided the last term is small enough.

Even if it is not small, one can still think of adding the share of governmentally supported R&D to the list of the included variables in an estimated production function as a Lagrange multiplier test, since under the null hypothesis of equal effectiveness its coefficient should be zero.

Thus the first view leads to looking at firms' own R&D expenditures and asking what happened to them as a result of the availability of governmental support, while the second looks for differential productivity effects between own and government-supported R&D. One can, of course look for other effects at the firm level, such as export performance and employment expansion. But the most interesting other effects are the externalities generated by such R&D expenditures, in terms of information made available to other firms in industry, in terms of helping to create a newly trained labor force, and in terms of providing new, higher quality, and cheaper goods and services to consumers both in the original country and abroad.

While the last aspect, that of externalities, may be the most important in evaluating the success of such support programs, our data will not allow us to pursue it. We shall focus mainly on the second aspect, the question of the relative efficiencies of different sources of R&D for increasing the measured productivity of the "receiving" firms. The first topic, that of the effectiveness of the inducement process, will be taken up only briefly in the more detailed report of our research, since a more complete analysis is currently being pursued by us and by Saul Lach.

Thus, the effect of government support of R&D, R , on a firm's output is a function of the extent to which this R&D enhances output (is effective). We may view this by setting it within a Cobb-Douglas production function, in which we include R&D capital services as an input:

$$(2)\quad \log y = \sum_k x_k \beta_k + \gamma \log R_T + \gamma \log(1+\delta s)$$

where γ expresses the effectiveness (elasticity) of total R&D.

Obviously we cannot perform these and other computations without estimates of δ and γ. We obtain these estimates by estimating the production function (2).

First we used a standard method (OLS) to estimate the log linear production function, adding firm fixed-effects and dummy variables and the percent-of-support variable, using the approximation: $\log(1+\delta s) \approx \delta s$. This approximation works when δs is "small." Since we obtained rather large estimates of δ, we cannot assume that this approximation is entirely suitable in our case. But when we used non-linear least-squares to estimate equation (2) directly, the results were rather similar.

The Data

This work is based on a unique data set that brings together statistics from various sources on output, inputs (intermediates, labor, and physical capital), and R&D (human resources, expenditures, grants, capital stock, etc.). All the data are at the firm level and are based mainly on two sources: surveys performed by Israel's Central Bureau of Statistics (CBS) and data obtained from the Chief Scientist of the Ministry of Industry and Trade, whose office provides the bulk of industrial R&D support in Israel.

This unique data set organizes the large amount of information assembled by the CBS from industrial firms over many years into long-term panels that allow us not only to examine the structure of industrial firms at a point in time but also to follow their development over the years. The use of panels seems especially appropriate in a study on the implications of R&D support for firms' performance, because it reveals correspondences between productivity at different points in time and R&D investments, activity, and funding type in previous periods.

The basic data—derived from CBS annual surveys (on industry and R&D) and periodic surveys (every 5 years on skilled manpower and every 10 years on capital stock)—were used to estimate the variables needed to calibrate a production-function model. This study placed special emphasis on calculating the R&D variables, i.e., R&D capital stock and the percent of government support to it.

R&D Variables

The CBS has been performing annual surveys of industrial R&D since 1970. Until 1980, they included all enterprises reported in the records of the Chief Scientist of the Ministry of Industry and other sources as having engaged in research and development. Since 1980, they have included a sample of firms engaging in R&D. These samples are replaced every few years, and then "R&D censuses" are collected. The censuses are used, among other things, as a framework for the drawing of new samples. One of the main sources from which the sample is selected is a list of firms that applied to the Chief Scientist of the Ministry of Industry and Trade for R&D support. Another important source is the annual Industry and Crafts Survey, collected by the CBS since 1955, which occasionally examines R&D activity.

To calculate the R&D variables that we needed to estimate the production function, we gathered data on each firm's annual R&D expenditure and grants in four periods, corresponding to the years in which the samples were replaced.

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1990–1994—five annual surveys;
1985-1998—three annual surveys (1985, 1987, 1988);
1979-1982—three annual surveys (1979, 1980, 1982);
1975-1977—three annual surveys (1975, 1976, 1977).

On the assumption that an R&D project has a seven-year lifetime,[5] annual estimates were computed for gross capital stock, net capital stock (gross stock less cumulative depreciation), and capital services (computed as annual depreciation *plus* 5 percent of net capital) in total R&D capital, with a distinction drawn between R&D capital originating from the firms' own sources or from R&D grants. As stated, to estimate R&D capital stock, seven consecutive years of data are needed for each firm. For firms that appear in the R&D samples during more than one period, all the requisite data were usually available. For firms that appear only intermittently, the missing data were estimated (for total R&D only, irrespective of support) on the basis of data from the R&D censuses performed in 1970–1979, 1984, and 1990, and on the basis of the Chief Scientist's records. All the estimates were expressed in 1990 dollars using the Consumer Price Index to deflate current values.[6]

Productivity and Economic Performance Data

Most of the basic economic data were taken from the regular industry surveys of the CBS. These surveys provide conventional data on domestic sales and exports; expenditures on intermediate inputs; employment, labor hours, and labor costs; changes in stocks; annual investments in buildings, equipment, and motor vehicles; and characteristics of firms such as industry and sector. These data were used to generate estimates of gross output, intermediates, and labor input.

Assembling the Data into Panels

The copious data obtained from the industry surveys were organized into consistent panels. The industry surveys use a sample of approximately 2,000 enterprises that employ five persons or more. The sample is usually replaced every five years, although in the 1980s it took more than a decade to make the replacement and an update took place in the middle of that period. Usually firms that had seventy-five employees or more were retained in the samples and not replaced. During the period of concern in this paper, the samples were replaced in 1979, 1990, and 1995. By the nature of things, one may construct full panels only for periods in which a full sample was used. This is shown in detail in Tables 1 and 2, which present the numbers of firms and observations of the three panels on which this study is based. Table 1 presents summary data for each period while Table 2 presents the average figure per survey.

- The full panel consists of 24,775 observations that were included in the twelve industry surveys between 1975 and 1994. Information about R&D activity was provided in 14 percent of the observations, and information on R&D support was obtained for 5 percent of firms in the panel (averaging about 100 firms annually).
- The early 1990s panel includes the five annual industry surveys performed between 1990 and 1994. The surveys investigated 2,920 firms, of which 1,661 operated throughout the whole period, and contained 11,158 observations. Supported R&D was reported in approximately 5.5 percent of the observations; unsupported R&D was reported in an additional 10 percent.
- The 1980s panel spans the 1979–1988 decade and includes about 8,000 observations, of which 4.5 percent reported R&D support.
- The panel for the second half of the 1970s includes findings from three industry surveys performed between 1975 and 1977. There were 5,730 observations, of which 4 percent reported R&D support.

Table 1. Firms and Observations in Panels, by Periods

Period -1-	Surveys -2-	Number of observations -3-	Number of firms -4-	Firms active throughout period -5-
1990–1994	1990, 1991, 1992, 1993, 1994	11,158	2,920	1,661
1979–1988	1979, 1982, 1985, 1988	7,887	2,819	1,297
1975-1977	1975, 1976, 1977	5,730	2,324	1,703
Total, 1975-1994		24,775		

Table 2. Firms in Panels, by Periods and by R&D Activity and Support

Surveys		**All firms**	**Firms engaging in supported R&D**	**Firms engaging in unsupported R&D**	**Firms not engaging in R&D**
-1-	**-2-**	**-3-**	**-4-**	**-5-**	**-6-**
1990–1994	Firms	2,232	124	224	1,884
	Percent	100%	5.6%	10.0%	84.4%
1979–1988	Firms	1,973	91	189	1,693
	Percent	100%	4.6%	9.6%	85.8%
1975-1977	Firms	1,911	75	90	1,746
	Percent	100%	3.9%	4.7%	91.4%

Findings

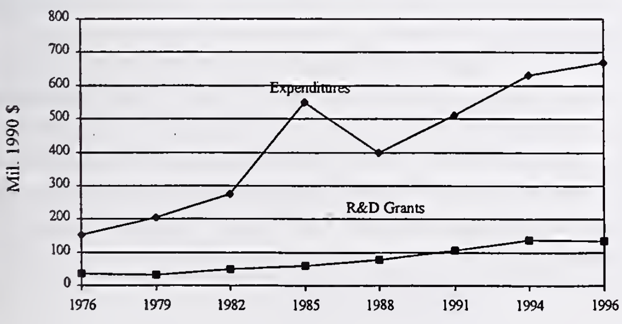
In this section we present our main empirical findings. First we present some descriptive data on the extent of R&D and support in Israeli industry, as reflected in the R&D surveys of the CBS (Figures 1 and 2). Secondly we show (in Figures 3-4) the share and performance of 3 groups of firms:

- R&D-Supported Firms. *This group includes firms that reported conducting R&D and receiving grant(s).*
- R&D-Unsupported Firms. *Includes firms that reported R&D expenditures but didn't report any grant.*
- *NORD Firms* that didn't report any formal R&D activity.

Finally we present in Tables 3-5 the production function estimates.

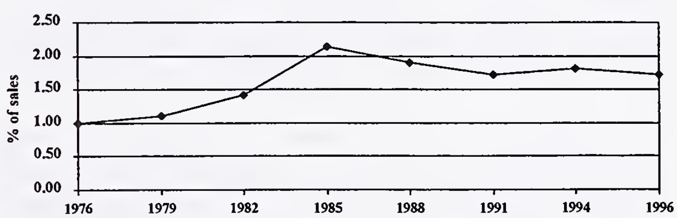
R&D Expenditures and Grants. In the twenty-year period covered by our study Israeli industrial firms increased their annual investment in R&D by a factor of 4.4 (an annual rate of 7.7%) which came close to 700 million in constant 1990 dollars in 1996. Figure 1a which presents the data also shows that during most of the period reviewed R&D support fluctuated within a range of 18-20 percent of industrial firms' R&D outlays. There were several outliers—23 percent in 1976–1977 and 11 percent in 1984–1985.

Figure 1a: R&D Expenditures and Grants 1976-1996



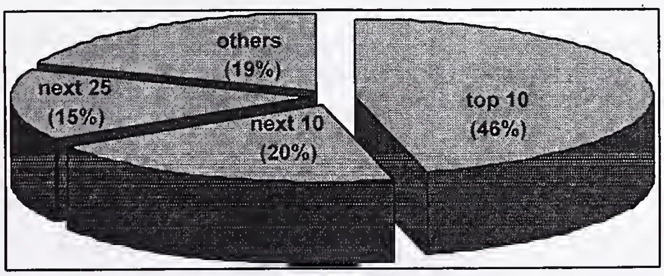
Share of R&D in Industrial Sales. Figure 1b shows that in the late 1970s about 1 percent of industrial sales was invested in industrial R&D. R&D expenditure continued to grow rapidly until the mid-1980s to more than 2 percent of sales. The watershed year was 1985, when R&D expenditure began to decrease—in a process that coincided with the termination of development of the Lavi aircraft—and stabilized at 1.6–1.8 percent of sales.

Figure 1b. R&D Expenditure as a Percentage of Sales



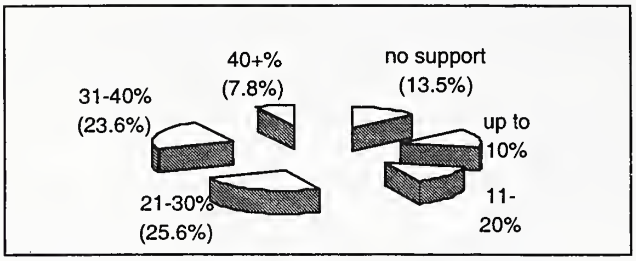
Concentration in R&D. Figure 2a shows that R&D is quite concentrated. Ten firms carry out 46 percent of R&D and 45 firms do more than 80 percent.

Figure 2a. Concentration of R&D Expenditures, 1996



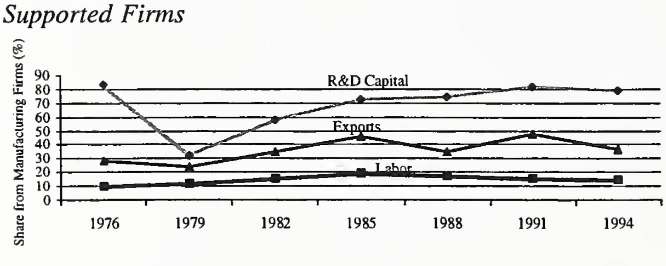
R&D Support. Figure 2b shows that 13 percent of R&D is done by firms that receive no grants and that 31 percent of R&D is done by firms that cover 31 percent or more of their R&D outlays with grants. An additional 25 percent of R&D is performed by firms that are supported at the rate of 21-30 percent.

Figure 2b. Distribution of R&D Expenditures by Rate of Support, 1996



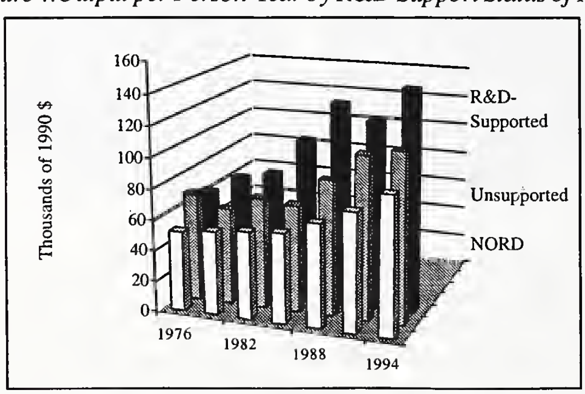
The Contribution (Share) of the R&D-Supported Firms. The R&D-supported firms' share in employment was around 10 percent at the beginning of the period, it grew substantially during the first decade to 20 percent in 1985 and declined during the second decade to 14.5 percent in 1994 (Figure 3). Yet they accounted for a majority of R&D capital services, reaching about 80 percent in 1994, despite the decrease in labor share. Figure 3 also reveals that from 1982 onward R&D-supported firms accounted for 35 to 48 percent of Israeli industrial exports.

Figure 3. Share of Labor, Capital R&D and Exports of R&D-Supported Firms



Output (Figure 4). Throughout the period reviewed (except for 1976), output per person-year was 20–50 percent higher in firms that received support than in firms that engaged in R&D without support. This effect was especially strong in 1985 and 1988, with the disparity reaching some 50 percent. In 1994, the difference contracted to 30 percent. Throughout this period output per worker was usually 20–30 percent higher in unsupported R&D firms than in non-R&D-performing firms.

Figure 4. Output per Person-Year by R&D Support Status of Firms



Findings of the Production Function. Table 3 presents our production function estimates for Israeli industrial firms. The explained variable is output per person-year, and the explanatory variables are intermediate inputs, labor, capital input (physical and R&D), quality of manpower, and dummy variables for firm size, industry, sector, survey year, R&D activity, and method of estimating physical capital (imputation).

Columns 2 and 3 present the results of estimating the production function for the entire period from 1975 to 1994, using all available observations.[7] They are based on an unbalanced panel of 24,775 observations culled from eleven industry surveys. Column 2 presents the simple version that was used, for example, by Griliches and Regev (1995), which assumes that R&D support has no differential effect on productivity, i.e., that different sources of R&D funding are perfect substitutes.

Table 3. Production Functions for Total Output, 1975-1994 and Intermediate Periods Dependent Variable: Output per Person-Year, Logarithms of Absolute Values

Period -1-	1975–1994 excl. gov. grant var. -2-	1975–1994 incl. gov. grant var. -3-	1990–1994 incl. gov. grant var. -4-	1979–1988 incl. gov. grant var. -5-	1975–1977 iocl. gov. grant var. -6-
Observations R^2 RMSE	24,775 0.887 0.296	24,775 0.888 0.294	11,158 0.890 0.253	7,887 0.842 0.317	5.730 0.850 0.324
Intermediate Input	0.659 (294)	0.660 (294)	0.664 (194)	0.677 (15.3)	0.624 (149)
Physical Capital Services	0.078 (29)	0.077 (29)	0.106 (27)	0.057 (10.9)	0.055 (7.4)
R&D Capital Services	0.034 (9.7)	0.028 (7.6)	0.036 (7.2)	0.028 (4.4)	0.023 (2.1)
R&D Grants as a Fraction of the Total		0.183 (4.4)	0.134 (2.7)	0.291 (4.2)	-0.180 (-1.0)

Estimated t ratios in parentheses.

The regression includes additional control variables: industry, size of firm, year, and sector.

The coefficients are very similar to those reported by Griliches and Regev (1995) and other studies that based themselves on similar data.

In Column 3, we add the variable *R&D grants as a percent of total R&D capital services* and obtain a positive and statistically significant (t=4.4) coefficient of 0.18. In Columns 4–6, we present the same regression for interim periods and obtain positive and significant coefficients for 1990–1994 and 1979–1988. However, the coefficient for the 1970s period is not statistically significant.

If the null hypothesis of perfect substitutability is correct, we would expect to find a zero coefficient for this variable. If government-supported R&D is used less efficiently, we would expect its coefficient to be negative. In fact, the estimated coefficient is positive and, in most sub-periods, statistically significant. Thus, our first result shows that *such support is not wasted in the Israeli economy and may even have a higher rate of return than privately-financed R&D.*

These production-function results are subject to a variety of left-out variable biases. Firms that perform R&D and receive government assistance are not a random sample in the population of all "appropriate" firms. Although a lengthy list of control variables was included, significant aspects may have been omitted in the characterization of these firms—e.g., quality of management and other resources which cannot be measured by the econometrician but are related to present success and present R&D policy. We can deal with this problem in two ways. First, we may assume that such attributes of firms that were left out are largely constant, at least over a period of five to ten years, and may apply methods that try to solve such problems, such as "fixed effects" or changes between the beginning of the period and its end. This eliminates the unobserved fixed firm characteristics and doesn't allow them to contaminate the estimated coefficients of the relevant variables.

Second, we can estimate a parallel model of firms' decisions to perform R&D and to apply for grants and incorporate its implications into the estimation of the production function to account for the selectivity problem. In this paper, we focus on the first choice. We intend to pursue the second possibility (the more elaborate one) in a subsequent paper.

"Fixed Effects" and "Long Differences" Production Functions. Table 4 provides an estimate of the production function using the "fixed effects" method. These estimates reflect the "within" dimension of the data and eliminate the influence of fixed differences among firms on the estimated coefficients. The functions were estimated for two main periods, the 1980s and the 1990s, in balanced panels (firms that were active throughout that time) and unbalanced panels. We also estimated production functions for changes between the beginning and the end of each period (long differences). These methods show that both the coefficient of total R&D and the implicit benefit of its governmental component are positive and have become statistically more significant in the 1990s. As for changes between the beginning and the end of the period, the picture resembles that elicited by the fixed-effects regressions, although the statistical significance of the R&D-support variable declines.

Estimating the Contribution of Support to Firm Productivity. Table 5 gathers the estimates of d—the effectiveness of R&D support—as obtained by the various estimation methods: ordinary least-squares, fixed-effects, and changes from beginning to end of period.

These different estimation methods yield similar results: in the 1990s, d falls within the range of 2–4. In the 1980s, d is very high—in the range of 7–10. In the 1970s, it is not statistically significant. Although the coefficient of the percent-subsidized variable, d g, is positive and statistically significant, d, the premium on government-supported R&D is difficult to estimate accurately. This happens because d is estimated as a ratio of two coefficients, each of which is estimated with reasonably large standard deviations.

We attempted to examine the distribution of d by using the bootstrap sampling technique. For example, in a balanced panel for 1990–1994, in a sampling of 100 samples, estimates of standard deviation were obtained that pointed to a confidence interval for d of about 0.4 to 7. Similar results were obtained when Feiler limits were used, as shown in Griliches (1967), pp. 109-110.

Table 4. Estimated Fixed Effects and Long Differences Production Functions, 1990-1994 and 1979-1998 Dependent Variable: Output per Person-Year, Logarithms of Absolute Values

Period	1990–94 Unbalanced	1990–94 Balan- ced	1990–94 Long Differ-ences	1979–88 Unbalanced	1979–88 Balanced	1979-88 Long Differ-ences
Observations R^2	11,158 0.658	8,305 0.656	1,654 0.685	7,887 0.619	5,188 0.61	1,297 0.59
Intermediate Input	0.610 (110)	0.606 (98)	0.671 (55)	0.651 (78)	0.64 (68)	0.63 (40)
Physical Capital Services	0.069 (13)	0.067 (12)	0.047 (4.3)	0.076 (7.2)	0.084 (7.6)	0.087 (5.1)
R&D Capital Services	0.096 (13.7)	0.086 (11.6)	0.050 (4.0)	0.031 (4.4)	0.034 (4.1)	0.036 (3.6)
Grants as a % of Capital R&D Services	0.146 (2.7)	0.173 (3.5)	0.149 (1.5)	0.129 (1.3)	0.131 (1.9)	0.165 (1.5)

Estimated t-ratios in parentheses.

Table 5. Summary of Findingsa: Estimated Coefficients

	Period	$\delta\gamma$	γ	δ
		-1-	-2-	-3- (1/2)
Indirect Measurement				
1. Production Function	Full period	0.183	0.028	6.5
	1990–1994	0.134	0.036	3.7
	1979–1988	0.290	0.028	10.3
	1975–1977	−0.180*	0.023	−7.8*
2. Fixed Effects, balanced	1990–1994	0.173	0.086	2.0
	1979–1988	0.131	0.043	3.0
3. Long Differences	1990–1994	0.149	0.050	3.0
	1979–1988	0.165	0.036	4.6
4. Direct (non-linear)	1990–1994			4.0
	1979–1988			7.3

* *Not statistically significant.*

Consequently, the premium on support is indeed positive, but at the present stage of the study we cannot estimate it with much precision.

Conclusion

As we have seen, the coefficients of the grants variables are positive and statistically significant in almost all of the estimated models. However, they are much higher than one would have predicted. It is hard to believe that government support is at least twice as effective, and in other periods seven times as effective, than the firms' own R&D investments. This finding indicates

[7] A fuller version of these figures and tables will be given in the more extensive report on this study (in preparation).

that the specification of our model may be incorrect or may exclude some relevant variables. There may well be an upward bias and a selectivity effect that originates in the way grant-receiving projects or firms are chosen. If this selectivity is based on permanent attributes of the firms, it can be dealt with, in principle, by including individual fixed effects variables or using long-term changes. However, if the selection process successfully identi fies and predicts future success—and allocates resources accordingly—then even "within" estimates may be upward-biased.

Another possible interpretation is that firms are heterogeneous in terms of their technological potential (g) and that the Chief Scientist's apparatus is able to pinpoint these differences, albeit only partly.

Importantly, these reservations do not diminish our main finding: that the mechanisms that allocate R&D dollars seem to be doing their work properly in most cases, and the more they manage to "pick winners" the better. However, our estimates should be treated cautiously and should not be used in an attempt to predict what will happen if R&D support budgets are increased or cut. Success may hinge on the ability to continue diagnosing correctly a firm's potential.

We should also note that our study used R&D grant data as obtained from CBS surveys but did not use the detailed database of the Chief Scientist of the Ministry of Industry and Trade, which was made available to the CBS. By adding these detailed data to our panels and calibrating these models and others, we may shed further light on the topics at issue. Also, the Bank of Israel is doing research on additionality, using CBS data, and we also intend to investigate our data further.

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Comments on R&D, Government Support, and Firm Productivity in Israeli Industry

by François Sand[1]

Mr. Regev started his presentation by giving us an overview of the context of R&D support in Israel. He briefly introduced the various institutions and programmes which aim at supporting R&D policy in his country. He quoted six of them:

- *R&D subsidies* granted by the Chief Scientist of the MIT
- *The "Magnet"* program
- *The "National S&T infrastructure"* - consortia of academic research and members from industry
- *Binational programs* (USA and Israeli) - support collaborative R&D
- R&D projects supported by the *Ministry of Defense*
- *Support to basic* research at Universities

He addressed the Method of Analysis outlining the following elements:

- Estimating Production Function, including R&D Capital Measures.
- Calculating Rates of Return to the various Capital Measures.
- Descriptive Statistics by R&D activity and government support.

The production Function Variables concerned were also presented as follows:

- *Dependent*: Production per person-year
- *Inputs*: Intermediate, Capital Services. R&D Capital Services (All per Person-Year)
- *Control Variables*: Quality of Labor, Size, Branch, Sector, Age, Cohort, Shadow-of-death (continuity).

Mr Regev addressed the goal of the paper as the examination of the overall role of government supported R&D and its contribution to the growth of productivity in related industries. He reported on the practical methodology based on the "Longitudinal Panels," documenting the sources of data used by them, and the types and time span concerned (every year over the 1990/94 period, and less frequently before, with up to a 40 year period covered in some cases).

He then discussed the R&D capital variables and services and the manner in which the analysis is both currently performed and will be performed in future developments. In the presentation, I was impressed by the volume of data involved in the study and made available not only by the OCS but also by the participants. It would be a dream to have just a small fraction of it in our case, regarding participants in EUREKA projects.

He then proceeded to talk about levels of funding and at this point, I have a question for Mr Regev. On the Web, in "Israel Start ups and Innovations: Overviews", Dr. Orna Berry, the Chief Scientific officer quotes the figure of $1.25 million as the total overseas investment in Israel in 1996. How does it compare with the total national support and could this affect the results of your study in any way?"

Then statistics were presented indicating a high concentration of R&D. It was said that 14% were not supported: 14% of what (firms, total expenditure?). A high concentration exists also in certain sectors. Then the production account by R&D activity was considered. It resulted that the return on investment was higher for firms with R&D. At that point, I was not well seated and could not read the figures related to the effect of subsidies? Was it positive or negative?

Professor Zvi Griliches presented some conceptual considerations. I was very interested, following the talk that Professor Zvi Griliches gave the evening before, to hear the conclusions on this matter. He stressed the differences that exist between funding by government investment and private investment, questioning how worthwhile the first one could be. One could wonder indeed if the money allocated by government is really a full increase in the R&D budget or whether there is a partial displacement of capital towards other types of investment within the firm? Regarding the matching of figures, a study is underway.

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[1] Dr. Sand is with the EUREKA Secretariat where he is responsible for the Continuous and Systematic Evaluation of the EUREKA Initiative.

He then addressed Secondary effects. He particularly underlined two opposite effects depending on whether people interested consider the subsidies as "their money" or not? The question that entrepreneurs treat public support as if it were their own money or not can be addressed, but how could we measure such a "subjective" behaviour? He referred to the previous studies (the U.S. case in the 70s and 80s) on the rather negative effect of U.S. federal R&D expenditures on industry (the 1986 results looks different). It would be interesting to see if such an effect is comparable in the context of Israel. Apparently, it looks more favourable. It even looks more positive than the Norwegian results that were reported earlier. Is it a matter of chance?

He went on with Selection related problems. I shall at this point ask a question which I consider of basic importance in this matter: You said that "supported R&D could yield a higher rate of return, if the application and the selection processes 'pick the winners.'" I am wondering whether there is not some type of vicious/disturbing approach here. Indeed, should public money be invested in companies that could possibly be as efficient themselves without public support? This type of question must be addressed clearly by any governmental agency. I think that in Germany, for example, the most successful firms are not necessarily the ones that are supported by government funding.

Several questions relating to the model to be addressed: Could bottom up not be advisable? Is money the critical factor? How to control the average conditions of the firm? What is happening to the productivity of the firm over time? A "Change" metric?

It appears a very high premium of 300%? How realistic is the result? Could Instrumental Variable Techniques be used in the future?

In the future, new approaches are to be considered such as:

1) Impact on R&D: what are the differences between supported and not supported projects.
2) Back payment of successful projects: the corresponding effects have not yet been analyzed.

It is wise to underline how important the large data set from NO, U.S. (ATP) etc., will be in connection with many methodological questions.

In conclusion, before letting the other participants ask their questions, I would like to remind you of two of mine, i.e.: "How do you discriminate the effects of the overseas investments in Israel ($1,215M in 1996) and those of the national support?" and "Is it the role of the National support schemes to pick the winners?"

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

by Tor Jakob Klette and Jarle Moen[1]

Abstract

Economists, in particular Bresnahan and Trajtenberg (1995), have recently drawn attention to the importance of generic or general purpose technologies (GPT's) and their significance for economic growth. An interesting part of this research identifies coordination problems in the introduction of GPT's, and the potentially large benefits in coordinating research and product development. Thinking about information technology as a GPT, with the associated coordination problems, seems to fit well with the motivation behind governmental support schemes to IT and related high-tech industries in Norway. The first part of our study focuses on a series of such IT programs that have been implemented in Norway from the early 1980s with the objective of coordinating the development of information technology and its application throughout the economy. We examine in some detail the largest of these IT-programs through its planning and implementation stages and emphasize how closely it is connected to recent economic analysis of GPT's. The second part of our study examines to what extent these governmental plans and subsidy schemes have been successful in creating economic results in terms of growth and profits in the IT and IT-related industries. In the final part of the paper we discuss some of the lessons about the problems with technology policy at a practical level.

Introduction

Information technology has been recognized as a 'generic technology' with 'strategic importance' for economic development by many commentators and governments. In this spirit a number of countries, including Norway, have implemented governmental programs to promote the production and application of information technology. Economists have had a hard time making sense of terms such as a 'generic technology' and a technology being of 'strategic importance', at least until Bresnahan and Trajtenberg introduced the notion of 'General Purpose Technologies', and examined their potential importance for economic growth. GPT's 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 externali ties 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 GPT's, 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 by the total expenditures amounting to NOK 4.4 billion ($620 M) 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.

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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',' [2] while other equilibria correspond to the industry 'taking off' and starting on a cumulative growth process.[3] 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 are far from settled, and the practice of technology policy vary substantially across countries, technological fields and various stages of the innovation process.[4]

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 that 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, 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'[5] (hereafter GPT's), 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 GPT's 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 GPT's 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 GPT's. 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

[2] 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.

[3] See e.g. Murphy, Shleifer, and Vishy (1989), Milgrom, Qian, and Roberts (1991), and for a survey, Matsuyama (1995).

[4] See Mowery (1995).

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

the developer of both Windows and other software, by not disclosing as soon as possible features in new versions of Windows. The general point is that there might be a significant advantage for the developers of various applications to have detailed insights into the research and development of the basic technology, i.e. the GPT itself.

Bresnahan and Trajtenberg conclude that arm-length market transactions between the GPT and its users will give 'too little, too late' innovation. Difficulties in forecasting 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 GPT's 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:[6]

> 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:[7]

> 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 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.

To sum up, the Norwegian policy initiatives on information technology in the 1980s and 1990s were motivated by an understanding of the broad set of potential applications for IT and the inter-action 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 GPT's 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 concerns about the state of the domestic information technology industries with an emphasis on the following three sets of problems: (i) Fragmentation of public funds for R&D, innovation and utilization of IT-technology, (ii) too many small and independent firms, and (iii) little long term planning and originality in product development.[8] The promotion of the IT-industry in the period we

[6] 'Statsbudsjettet 1986/87', St.prp. nr. 1, p. 40. Our translation.

[7] Harlem et al. p. 235. Our translation.

[8] See e.g. Murphy, Shleifer, and Vishy (1989), Milgrom, Qian, and Roberts (1991), and for a survey, Matsuyama (1995).

consider from 1982 to 1995 was organized and coordinated through a number of plans and programs of various size.[9] The largest plan in this period was the aforementioned National Program for Information Technology,[10] lasting from 1987 to 1990. This program had a total budget of NOK 4.4 billion[11] and included a number of 'subprograms' (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,[12] 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'.[13] This last program was small in terms of its independent budget, and its main objective was to coordinate ongoing public support schemes related to information technology.

In the rest of this paper we will refer to the various support schemes for industrial applications of information technology as the 'IT-programs'. Before we turn to an overall evaluation of the economic impact of the IT-programs, we will discuss more closely the National Program for Information Technology. As stated, this was the most important and ambitious of the programs, and its implementation and organization are extensively documented in Harlem et al., 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.[14] Even though the original plan had a very broad scope, the actual implementation of the program focused heavily on manufacturing of electronics and other IT-products. According to Harlem et al. (1990):[15]

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

The project funds were very unevenly distributed across firms, with the ten largest recipients receiving 35 percent of the funds. These firms were producing electronic products, telecommunication equipment, instruments and computers.[16] The largest recipient, Norsk Data, received by itself more than 12 percent of the budget allocated to firms.[17]

Table 1 presents the expenditures for the National Program for Information Technology 1987-90. To illustrate the considerable magnitude of the numbers in Table 1, one should notice that, e.g., publicly funded technological and scientific R&D in universities and governmental labs in 1989 in total amounted to NOK 2542 Mill.[18]

As can be seen from Table 1, a significant part of the National Program for Information Technology's budget went to education and to a lesser degree also to basic research related to IT. At least the educational part of the program has been considered successful by Harlem et al. (1990) and others, but our focus is on the substantially larger parts of the IT-programs that were targeted more directly at industrial production and applications of information technology.

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

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

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

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

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

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

[15] P. 64, our translation.

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

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

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

Table 1: Expenditure within the "National Program for Information Technology 1987-1990" broken down by field and year. Million NOK

	1987	1988	1989	1990	Total
Education	306	373	426	427	1 532
Research	138	132	135	130	534
Product development	134	151	239	221	745
Applications	329	369	398	474	1 570
Total	907	1 025	1 197	1 252	4 381

Source: Harlem et al. (1990).

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 GPT's, 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 has been strongly supported 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.[19]

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 1,250 kroner per employee in the high tech industries.[20] 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 increased 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

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

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

performed better then 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 together from the R&D surveys conducted by the Royal Norwegian Council for Scientific and Industrial Research (NTNF) in the years 1982-1989 and by Statistics Norway in the years 1991-1995.

The R&D subsidy dummies are based on the share of subsidies to total R&D over the three years prior 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.[21] 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 1,958 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 6,000 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 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 partially, 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.[22]

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 V°apenfabrikk, 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.[23] In passing, we notice that the results in Table 2 also show that R&D firms have on average grown more slowly than non-R&D firms, both in terms of man-hours and sales.[24]

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

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

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

[23] This effect is given by the sum of the two coefficients. Testing robustness, we have found that the results presented in Table 2 are largely unchanged if we neglect the firms receiving large, defense related R&D contracts.

[24] This is consistent with the findings reported in Klette and Forre (1995).

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 differences between the intensity of privately financed R&D in subsidized and non-subsidized firms. In an ongoing companion study, Klette and Moen (1997), 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 a little effect on private R&D expenditure.

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

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

Longer Run Effects

Studying the effect of R&D within the high tech industries, it is customary to assume a one year lag between the R&D investments and the first effect on production. This is justified by the short-term nature of much commercial R&D, but it seems likely that the peak of the impact has more than a one year lag. For this reason we defined our subsidy dummy in the last section using a three year 'window'. However, it could be that R&D projects supported by public agencies have a particularly long-term nature, and it has been argued that the effect of the subsidies given in the late 1980s has not been visible until lately.[25] Against this, one might argue that the growth experienced dur-

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

	Growth in manhours	Growth in sales	Return on assets	Return on sales	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

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

ing 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.[26] 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 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.

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.

[26] In an earlier version of this paper, Klette and Moen (1998), 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.

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.[27] 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.

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 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.[29] 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.[30]

Table 4: The importance of high technology and IT relative to ttal 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.

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 (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. defense related research that benefits the IT industry. Furthermore, in several OECD countries significant amounts of public R&D support are given in terms of tax relief, and such tax allowances are not reflected in the numbers reported in Table 4.[28] 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

Summary of Economic Results

Most countries support IT and related high tech industries. In Norway, the R&D subsidies were particularly large in the second half of the 1980s, both in a national and probably also in an international perspective. In this section we have investigated the effect of these subsidies, using several different approaches and data sources. First, comparing subsidized and non-subsidized firms within the high tech industries, there is little evidence in favor of the subsidized firms being more successful. Second, looking at these industries relative to aggregate Norwegian manufacturing, their importance have not increased. Third, comparing the development of the Norwegian IT industry to the IT industry

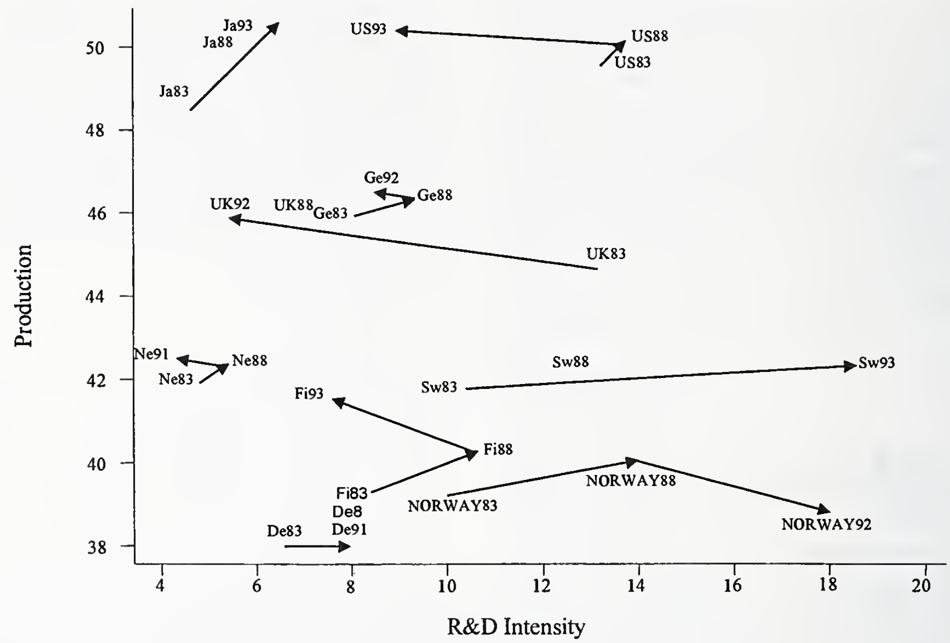
[27] Defining the manufacturing IT-industry as most of NACE sectors 30-33, gives the same conclusion.

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

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

[30] 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 and BERD).*

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

Coordination Problems And Technology Policy In Practice

The IT-programs: coordination failures at the policy level

We have pointed out that GPT's often create co-ordination problems that will tend to slow down the development of the GPT's 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 benefited 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.[32]

[31] In that case, however, it would still be difficult to argue in favor 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).

[32] See Hervik and Guvag (1989).

In the overall evaluation a year later, Harlem et al. (1990) concluded that the plan has undoubtedly failed in improving co-ordination and integration of policy towards information technology."[33] 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 co-ordination, as described in Harlem et al. (1990), ch. 5.[34]

Two years later, in the government's report to the Parliament on the research activity in the Norwegian economy, reference was made to this negative conclusion by Harlem et al. (1990) and the report elaborated on it.[35] The main conclusion is that [the research programs including the research activities within the National Program for Information Technology] did not lead to the intended coordination for the programs as a whole, not in the relationship between the government agencies and the private agents, nor between the various government agencies." Furthermore, the research programs have not been successful as policy tools, neither with respect to organization, planning or information. Research activities have to a large extent remained as fragmented as before the programs were implemented." These conclusions were based on an assessment of 9 research programs, including research programs on biotechnology, offshore and other activities, in addition to information technology which was by far the largest among them.

Given these clearly recognized problems with the coordination efforts up to 1992, it is a bit depressing to read the main conclusions of the report on the evaluation of the 'National Plan for Improved Utilization of Information Technology in the Norwegian Industry 1992-95' presented in Olsen et al. (1997):[36]

> [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, GPT's 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 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.

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

[34] See also Buland, especially chs. 9 and 10.

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

[36] 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.

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 co-ordination 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.[37] 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 co-ordination 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 co-ordination 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,[38] 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.[39] 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

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

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

[39] See Coase (1988) where he has elaborated on this argument.

to a large extent been ignored in economic studies of technical change and in recent research on 'new' growth theory.[40] 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.[41] These four firms are quite different; one is e.g. making identification system for the police and defense, while another is making measurement instruments for opticians and eye-doctors.

Industry associations are another set of private institutions which are important in facilitating co-ordination of innovative activities.[42] In a theoretical study, Romer (1993) has examined new institutional arrangements to improve the co-ordinating function of such organizations. However, it must be left for future research to examine the empirical performance of such organizations in co-ordinating R&D activities and privately funded research joint ventures more generally. Our point here is only to illustrate the widespread co-ordination 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.[43]

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 co-ordination 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

[40] See, however, the recent literature on research joint ventures, e.g. Kamien, Muller, and Zang (1992).

[41] Dagens Naeringsliv, 13.11.97, p.8.

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

[43] 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.

interesting to examine more directly the role of such cooperative activities.[44]

Data Appendix

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

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

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

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

Are Swiss Government Programmes of Promotion of Advanced Manufacturing Technologies (AMT) Effective? An Economic Analysis Based on Micro-level Survey Data

By Spyros Arvanitis, Heinz Hollenstein and Stephan Lenz[1]

Summary

This paper describes the approach applied and the results of an evaluation of the effects of the Swiss programme to promote the diffusion of Advanced Manufacturing Technologies (AMT) in terms of velocity, broadness and intensity of AMT adoption in the period 1990-1996. This evaluation study was undertaken on behalf of the Swiss Ministry of Economic Affairs.

The analysis is based on (mainly qualitative) firm data collected in the course of the Swiss Innovation Survey 1996. The available information refers to the time profile of the introduction of nineteen AMT elements covering all relevant fields of manufacturing activity (design, production planning, production techniques, handling, quality control, communication/control) and includes also a whole series of factors which presumably *determine* the firms' adoption behaviour. The final data set contains 667 firms representing all manufacturing industries as well as firm size classes. About 80% of them were using AMT in 1996 (with a median AMT-intensity of seven technology elements), and 20% of the users have been promoted by some component of the governmental support programme (information/training, consultation as well as R&D-projects). However, our data suffer from an important shortcoming: the time dimension is accounted for only for the adoption variables because we could not collect time-indexed data for the explanatory variable (reflecting the limits of retrospective data collection).

The method used is based on estimating an *adoption equation* which, in addition to the main explanatory variables as proposed by the theory of technology diffusion, takes account of variables depicting policy intervention (promotion yes/no, type and intensity of promotion). For the econometric estimation we used probit and ordered probit models. Special attention was given to the size dependence of policy effectiveness by estimating the adoption equation separately for two different firm size classes. The most delicate problem to be solved at this first stage of analysis has been the construction of an adoption variable specific to the time profile of the promotion programme. We constructed several variables, but we report here mainly on a variable measuring the change of adoption intensity between 1990 and 1996. In a next step we also estimated a *policy equation* with a set of firm characteristics as regressors. As a result of the "single equations approach" (i.e. separate estimation of the adoption and the policy equation) we found that promotion - primarily through information/training as well as consultancy - did lead to a faster, broader and more intensive adoption of AMT especially for small firms (less than 200 employees). Even if we succeeded in extracting a significant positive impact of the policy variable(s) there still remained the problem of causality between adoption and promotion to be ultimately resolved only in a simultaneous equation framework. Our main finding of the single equation approach was confirmed by estimating simultaneously the adoption and the policy equation (simultaneous probit model).

Introduction

The main feature of Swiss technology policy is the low weight it places on direct measures for fostering innovation in the economy. It is primarily oriented towards creating a favourable environment for the introduction of new products and production techniques, whether such innovations rest on firm-internal research and development or on the adoption of novelties generated by other firms or institutions.

This framework-oriented policy is supplemented by a number of specific measures to encourage, first, cooperation between public research institutions and private enterprise through joint projects either by a bottom-up approach (without restrictions with regard to the field of technology) or by the top-down support of "oriented research in the pre-competitive stage" in specific technology areas such as optoelectronics, material sciences, etc. Second, there are some policy initiatives to support rapid diffusion of selected basic technologies which are considered to be relevant for a broad spectrum of industrial activities. To be mentioned are primarily two "programmes of action" in the field of "Advanced Manufacturing Technologies" (AMT) and "Micro electronics" respectively, which offer to firms information and training services as well as subsidies for consultancy and development projects; the latter are in most cases based on joint ventures between firms or between firms and research institutions embedded in regional networks. The working of these programmes is restricted to a couple of years, i.e. the policy concept is to give an initial support for technological adjustments which, as in the case of AMT or microelectronics, pose a challenge for many firms and/or industries. The policy measures rest on the hypothesis of the existence of significant bottlenecks in an early phase of diffusion; secondly, and in a more general perspective, it is assumed that a strong linking of a firm's knowledge base with external know-how is a key factor to secure a high

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innovation performance, a proposition supported by empirical work with data for Swiss manufacturing firms (see Arvanitis and Hollenstein, 1994, 1996, 1998a). In addition, these programmes are based on an approach which, in a balanced way, takes account of human, technical and organizational factors and restrictions (in Switzerland labelled as MTO approach "Mensch-Technik-Organisation").

In this paper we address the problem of evaluation of technology policy with regard to the Swiss program of promoting the diffusion of AMT which has been initiated in 1990 and ended in 1996. In section 2 we briefly characterize our approach and point to some differences to other methods of evaluation; we also introduce the model of technology diffusion we used in this investigation. In section 3 we describe shortly our data base and the econometric methods applied in the empirical part of the work. In section 4 the specification of the adoption and policy equation respectively are presented in some detail. Section 5 contains the empirical results. We conclude by an assessment of the proposed procedure and some recommendations for evaluating specific policy measures.

Theoretical Background

Evaluation Concept

The majority of evaluations of public support for technology diffusion, not only in Switzerland, is primarily directed to the efficiency of such programmes in a rather narrow sense. The topics covered by such evaluations are typically the following: Is the target group well informed on the support measures available? Do firms to which policy is targeted take part to a satisfactory degree? Are management and procedures of a programme efficient? In what way do firms decide whether they should commit themselves, and what may be concluded from this regarding the effectiveness of the programme? What are the motives for participating? Are barriers of diffusion as perceived by firms sufficiently addressed by the policy measures? This type of evaluation, though useful, does not yield an assessment of the economic effects of diffusion-oriented measures, because it concentrates on 'programme-immanent' performance measures and does not take account of firms not participating (no control group analysis).[2] The same type of critique is put forward by Stoneman and Diederen (1994)[3] (see also Karshenas and Stoneman 1995).

In contrast, the present investigation is focussed on the results of policy intervention. More specifically, it is asked whether the primary goal of public support, i.e. a more rapid and broader diffusion of AMT compared to firms standing aside (i.e. the control group), is actually attained. In addition, we try to identify the relative effectiveness of the main elements of the support programme, i.e. information/training, consultancy projects as well as R&D projects. The analysis concentrates on a single policy programme without taking account of the role it plays within the national system of innovation, although the results of a specific measure presumably are influenced by such 'systemic conditions'. It does also not (directly) contribute to 'policy benchmarking' because the necessary conditions for such an exercise, i.e. the application of comparable methods to similar policy measures in several countries, are not (yet) given.

The envisaged type of evaluation requires an econometric analysis based on the theory of technology diffusion using micro-level firm data for a (representative) sample which contains subsidized firms as well as not supported ones. More specifically, we estimate equations of technology adoption based on general factors determining the use of new production techniques as well as policy variables to identify the marginal effect of policy intervention.

Formally, the evaluation approach may be summarized by

$$A = a_0 + a_1 X + a_2 P + a_3 A^* \qquad (1)$$

with A standing for the adoption of AMT, X as a vector of variables determining technology adoption, P as a vector of policy instruments and A* representing the intensity of AMT use in the year the supporting measures became effective.

A difficult problem in any evaluation of policy effectiveness is the identification of the direction of causality. Is it promotion that leads to a more rapid technology diffusion, or is the opposite true, i.e. are the firms which are taking up the new technology in an early stage anyway those looking successfully for public support? In a cross-section analysis there is an endogeneity problem unless the direction of causality is fixed a priori.[4] Even in

[2] Typical examples for Switzerland are Freiburghaus et al. (1990) who evaluated the promotion of joint research of universities and firms, and Balthasar et al. (1997) who assessed the effectiveness of the Swiss participation in technology programmes of the EU; for Austria see, for example, Polt et al. (1994) who assessed the public support measures for the introduction of AMT. A recent report by OECD (1995) with respect to the diffusion of information technologies in SMEs, drawing on a number of country studies, is also primarily based on this type of evaluation, which does not sufficiently take account of economic performance measures or changes of technology adoption (an exception, to some extent, is the country study „Canada"). See OECD (1997) for an assessment of the state of the art in technology evaluation.

[3] Stoneman and van Diederen (1994, 928): „The DTI in the United Kingdom. for example, legitimates its diffusion policy with reference to market failure but evaluates its diffusion programmes predominantly in terms of the efficiency of their management, the accuracy of targeting, the appropriateness of their tool mix and the appreciation of the recipients of information."

[4] This problem could be circumvented if we were able to introduce for P a lead in relation to A. However, this procedure is not feasible because we do not dispose of time-indexed information for the policy variables.

the case of a longitudinal analysis the identification of the causality might be difficult because of the known problem of 'post hoc ergo propter hoc'.

In this perspective, we intend to tackle the problem, though not to solve it, by estimating two equations, one for technology adoption and a second one for government promotion, (i) separately and (ii) simultaneously (simultaneous probit model) and then compare the results for both procedures. Formally spoken:

(2a) $A = a_0 + a_1 X + a_2 P + a_3 A^*$

(2b) $P = b_0 + b_1 Y + b_2 A$

(vector Y stands for factors which determine whether a firm gets government support).

An Eclectic Model of Technology Diffusion

The main element of our procedure is the estimation of an equation explaining the adoption of AMT based on a set of "general" factors determining the adoption decision and suitable measures of policy intervention. Given the state of the art of theoretical and empirical research of technology diffusion, the theoretical approach used in deriving the explanatory variables is eclectic in nature. It is based on the general framework proposed by Karshenas and Stoneman (1995).[5] According to these authors the main (neo-classical) models of diffusion may be categorized in four groups (epidemic, rank, stock and order model) which can be fused to a "higher order model" containing the specific features of the different approaches. Economically spoken, the general framework is given by factors reflecting anticipated benefits and costs of the adoption of a new technology which are taken into consideration by the adopting firm when assessing the profitability of an eventual technology adoption.

Within this general framework we distinguish a whole series of explanatory variables (vector X in the equations above) capturing both benefit and cost factors (see Arvanitis and Hollenstein 1998b). These variables refer to:

- the technology market: transparency; uncertainty as to the effectiveness of the technology, information costs; general range of application (technological opportunities); market concentration; (expected) price of the technology;
- the product market: demand perspectives, intensity of price and non-price competition, market concentration;
- the factor markets: availability of qualifications important for technology adoption; internal and external financial restrictions;
- adoption-specific firm characteristics: know-how in the field of AMT; firm-specific potential for the application of this technology depending on the type of products and production processes; compatibility of AMT with the existing physical, human and knowledge capital as well as the organizational and managerial structures inducing AMT-specific adjustment costs.

Some of these variables cannot be directly measured and should be considered as latent variables. However, survey information related to specific 'bottlenecks/obstacles to adopt AMT,' the 'objectives pursued by introducing such technologies,' the 'factors enforcing the adoption of AMT' and information referring to a firm's characteristics in general as well as to its innovative activities may reflect such 'latent variables' to a sufficient degree and could be used as proxies.[6]

Data and Method

The analysis is based on firm data collected in the course of the Swiss Innovation Survey 1996 as a supplement to the standard questionnaire, thus allowing the combination of AMT specific information with basic data on innovation and technology use. The available variables are to a large extent qualitative in nature, i.e. categorical or ordinal measures. As far as AMT is concerned the questionnaire yields data on the time profile of the introduction of nineteen AMT-elements, the linking of these technologies, the assessment of a whole series of objectives pursued by introducing AMT as well as the significance of factors impeding its application, the impact of AMT on competitiveness, employment requirements and organizational structure and, finally, information on government promotion of AMT.[7]

The survey has been addressed to manufacturing firms based on a sample (innovation panel) stratified by industry (17 2-digit industries) and firm size (3 industry-specific size classes) with full coverage of the upper size class in each industry. Additionally, the questionnaire was sent out to firms not contained in this panel which have been involved in the programme of AMT promotion. The response rate has been about 34% with a somewhat higher percentage for non-panel firms. 80% of the respondents used at least one AMT element in 1996 with a median AMT-intensity of seven technologies and 20% have got promoted by one or more element(s) of the government support programme.

[5] See Sarkar (1998) for a survey on the theoretical development in this field.

[6] See Ewers et al. (1990) and Fritsch (1991) for an example for this type of approach.

[7] The questionnaire is available in German, French and Italian and can be handed out at request.

The final data set used in the econometric estimations contains 463 firms fairly representative for all manufacturing industries as well as firm size classes in the original sample (see table A.1 in the annex).[8]

Table 1 contains some information on the adoption rates of 19 elements of AMT in Swiss manufacturing since 1993 (including planned application of these technologies till 1999). The degree of diffusion (percentage of firms using a certain technology) in 1999 and the diffusion velocity (increase of the percentage firms using a certain technology element in the period 1993-1999) varies quite strongly among the technology elements listed in table 1. For example, the degree of diffusion of CNC machines being already an 'old' technology was quite high and changes only slightly between 1993 and 1999. On the other hand, 'new' technologies such as 'simulation' and 'rapid prototyping' or FMS are used only by a small share of firms but this share is going to double until 1999.

Owing to limited resources we could not perform a non-response analysis, so we cannot exclude that some kind of selectivity bias as to the adoption behaviour of the responding firms may exist in our data. However, we minimize the risk of being confronted with this kind of bias by building our empirical analysis not on the (presumably biased) information on adopting AMT in general, but on the specific use of some AMT elements for firms already being an adopter of AMT (see subsection 4.1). Further, the estimates of programme impact may be biased due to self selection (see e.g. Maddala 1983). Self selection arises when firms are not randomly assigned to policy-promoted and non-policy-promoted (control) groups. However, the simultaneous consideration of a policy equation permits us to also address this kind of econometric problem.

For the estimation of the single equations we used a probit (for dichotomous dependent variables) or an ordered probit model (for ordinally scaled dependent variables with more than two measurement levels). A two-step procedure (first, estimation of the coefficients of the reduced form of the original simultaneous equation system, then estimation of the structural parameters based on the covariance matrix of the reduced form coefficients) was applied to estimate the simultaneous probit model according to the algorithm implemented in the MECOSA software developed by Schepers and Arminger (1992).

Specification of the Empirical Model.

Adoption Equation.

Dependent Variable

Throughout the paper we use an ordinal measure of the change of the AMT intensity between 1990 and 1996 (DAMTINT) as adoption variable. Thus, we implicitly presume that government promotion becomes effective within 1 year. The AMT intensity is measured as the number of technology elements (out of a list of 19 such elements in table 1) already in use in a firm in a certain year. We constructed a three-level ordinal variable which contains the following categories: no change or change by 1 AMT element (29.9% of the firms which had adopted at least 1 AMP element till 1996); change by 2 to 4 elements (45.2% of the adopting firms); change by more than 4 elements (24.9% of the adopting firms). By defining the adoption variable as a measure of intensity change we avoid to some extent identification problems which arise, first, because we do not know which specific technology is supported in every single case of promotion and, secondly, we do not have data for the explanatory variables which are differentiated by technology and time.

Explanatory Variables

We distinguish six groups of explanatory variables (besides two adoption-specific control variables and industry dummies; see table 2). A first group of determining factors refers to objectives of and motives for the adoption of AMT which we interpret as proxies for anticipated revenue increases due to the use of new technology. Such an interpretation can be justified on ground of some evidence on the degree of the attainment of the pursued firm objectives related to AMT adoption (measured on a five point Likert scale): about 48% of the firms having adopted AMT reported a very high degree of attainment of their objectives; some 40% of them reported a middle degree of attainment and only 12% of the AMT adoptors answered that their degree of goal attainment had been very low.[9]

The six metric variables listed in table 1 under the heading 'objectives/motives' are the factor scores resulting from a principal component factor analysis of 26 single objectives of AMT

[8] In addition to the data collected by this survey we dispose of some information made available by the institutions responsible for the implementation of the programme, that is, in the first place, seven regional AMT centres set up in 1990. These data refer primarily to some quantitative measures indicating the intensity of promotion (number of projects, amount involved, etc) but without differentiation as to the type of support. However, the quality of the information does not come up to the requirements of an evaluation exercise and is not presented here (see Arvanitis et al. 1998, ch. 6).

[9] Small firms show in general a higher degree of goal attainment than large ones (see Arvanitis and Hollenstein 1998b).

included in the questionnaire (see Arvanitis and Hollenstein 1998b for details). Two of these factors are related primarily to product improvements (DEV, QUAL), two further ones seem to be connected more closely to changes in the production technology (COST, FLEX). A fifth factor, TOP, refers generally to anticipated revenue potentials due to technology lead. For all five variables we expect to find a positive influence on the adoption variable. The sixth variable, FINCOMP, has a somewhat different character and cannot be linked directly to revenue increases. It contains elements of a 'defensive' adoption strategy (favourable financing conditions; competition pressure). It is not a priori clear whether these factors lead to an early or late technology adoption; thus, the sign of the coefficient of this variable is undetermined.

A second group of variables is related to factors impeding the AMT adoption. The six metric variables TECH, KNOWPERS, RESIST, INVCOST, UTILIZ and COMPAT, which were also constructed by a principal component factor analysis of 26 single adoption impediments, can be interpreted as proxies for several types of adjustment costs caused by an introduction of ATP which may lead to a late technology adoption. Thus, we expect a negative sign for these variables.

A third category of explanatory variables represents the market conditions under which the firms are operating: medium term expected change of demand (D; measured on a five point Likert scale for the period 1993-1999);[10] intensity of price and non-price competition (IPC and INPC; measured on a five point Likert scale); product market concentration (measured by three dummies for firms confronted with markets with varying numbers of competitors). Favourable demand conditions leading to a quicker pay back of investment in AMT may have a positive influence on the propensity to adopt; thus, we expect a positive sign for this variable. The same holds for the intensity of non-price competition being closely related to demand shifts. Not clear is the direction of the effect of the intensity of price competition: the introduction of cost-reducing AMT may be favoured by strong price pressure; on the other hand a profit squeeze caused by sharp price competition may severely limit the investment options of the firm. The sign of the effect of market structure on adoption is also not quite clear. Hypotheses for both a positive (Schumpeter effect) and a negative effect (free competition effect) can be found in literature, so the problem has to be resolved at the empirical level.

A further group of variables serves to characterize the products and the production technology of the firms. The main idea is that the product type and the existing production technology of a firm play an important role in identifying the extent and the limits of AMT use in this firm (see Ewers et al. 1990). For example, we expect that the benefits for applying AMT in producing customer-specific (PDUSER) or otherwise highly differentiated products (PDMARKT) would be rather small, so that a negative sign for this variable is quite probable. On the other hand, we postulate a positive influence on the adoption variable for large-batch (LBATCH) as well as for mass or continuous flow production (CONTFLOW), where scale effects are possible and AMT can unfold its full potential; analogously, we expect no effect for small-batch production (SBATCH). However, the use of sophisticated AMT permits not only the realization of scale economies but also an increase of production flexibility, thus enabling the firm to adapt quickly and efficiently to external or internal changes. This second effect works in the opposite direction to the first one, in this way weakening somewhat the overall influence of product and process technology on adoption behaviour. All these variables are (0,1)-measures.

Table 1: Use of Advanced Manufacturing Technologies (AMT) in Swiss Manufacturing (Percentage of responding firms; 1999: planned application)

Technology Element	1993	1996	1999
Design			
Computer-aided design and/or engineering (CAD/CAE)	50.6	57.0	60.8
Computer-aided design/manufacturing (CAD/CAM)	34.4	42.5	47.8
Simulation, rapid prototyping	5.0	7.7	11.4
Planning			
Digital firm data representation	40.1	48.7	64.2
Computer-aided (manufacturing) planning (CAP)	40.8	50.7	62.9
Production			
Computer numerical controlled machines (CNC/CND)	48.9	52.8	55.0
Materials working lasers	8.8	10.7	13.1
Pick-and-place robots	19.9	23.2	26.7
Complex robots	8.1	11.8	13.4
Flexible manufacturing cells (FMC)	10.1	13.8	20.0
Flexible manufacturing systems (FMS)	8.6	13.1	18.8
Handling			
Automatic storage and retrieval systems	25.0	32.2	41.5
Transport systems	10.8	13.2	16.5
Quality control			
Quality control (CAQ) on material	22.4	28.7	41.2
Quality control (CAQ) on final products	21.9	30.0	42.8
Communication			
Local area network for technical data (LAN-T)	25.9	36.2	47.1
Local area network for factory use (LAN-F)	22.2	31.8	44.1
Production planning systems (PPS)	41.9	54.8	67.3
Interfirm networks	6.6	15.8	37.3

[10] It is obvious that this variable is irrelevant for AMT adoption before 1993 unless it can be shown that differences in the demand potential among firms are persistent.

A firm's ability to absorb knowledge from external sources and exploit it for its own innovative activities is a major determinant of innovation performance (see e.g. Cohen and Levinthal 1989). We use two variables to proxy the capacity to absorb external knowledge, first the share of employees with high vocational qualification (HUMCAP) and second the binary variable 'R&D cooperation activities yes/no' (COOP). The latter is a measure of a firm's embedding in existing knowledge networks, the first one reflects the overall ability to assess technological opportunities; both seem to enhance considerably the absorptive capacity of a firm. Thus, we expect a positive sign of the coefficients of these variables in the adoption equation.

Firm size is another important factor which influences adoption behaviour and is included as explanatory variable in most studies of adoption behaviour (see e.g. Colombo and Mosconi 1995; Karshenas and Stoneman 1993; Stoneman and Tiovanen 1997). We specified this variable either as a series of dummy variables (see table 4) or as a polynom with respect to the number of employees (linear and quadratic term; see tables 7a and 7b). We expect a positive effect of firm size. However, there is a disturbing aspect to this approach: one does not know exactly what is measured by this variable; firm size can be used as a proxy for various economic effects connected with the innovation or technology adoption process, but there is no comprehensive theory available to explain the observed size effects. In our case we found statistically significant correlations at the 5%-level with firm size (number of employees) for some of the explanatory variables listed in table 2. Positively correlated with firm size are the variables HUMCAP, COOP, PDMARKET; also positively but somewhat weaker are correlated the variables FLEX, INPC, LBATCH and CONTFLOW. Further, negative correlations were found for PDUSER, SBATCH (and FIRMAGE). For these variables the effect on adoption behaviour is itself size-dependent. Therefore, in a first step we chose to estimate our model both with and without firm size as an independent variable in order to assess the extent of interdependency of size with the other variables. In a further step, we also estimated the model (together with the policy equation) for a subsample of small firms, thus taking full account of the size-dependency of the independent variables.

Finally, we included some industry dummies, firm age (FIRMAGE) and the AMT intensity in year 1990 (start of the promotion programme; INT90) as control variables in the adoption equation. FIRMAGE should capture the effect of an older firm having a larger chance to adopt a new technology than a younger firm; thus we expect a positive correlation of this variable with the adoption variable. We hypothesize that the negative adoption effect for firms with a high AMT intensity in 1990 being near a 'saturation point' with regard to the application of AMT would dominate over the positive effect of 'knowledge accumulation' (or 'learning effect') due to the early use of AMT, so we expect a negative sign for this control variable.

Table 2: Specification of the Explanatory Variables (Adoption Equation)

Variable	Description	Sign
1. Objectives of/motives for the adoption of AMT		
(Scores of a principal component factor analysis of 26 objectives of AMT; six factors)		
FINCOMP	Favourable financial conditions; competitive pressure	?
COST	Cost reduction	+
FLEX	Higher flexibility	+
DEV	Improving product development	+
QUAL	Better product quality	+
BEST	Securing technological lead/best practice	+
2. Impediments to the adoption of AMT		
(Scores of a principal component factor analysis of 26 barriers to AMT ; six factors)		
TECH	High technological costs / uncertainties	-
KNOWPERS	Lack of knowledge / lack of adequately qualified personell	-
RESIST	Intrafirm resistance to new technology	-
INVCOST	High investment costs	-
UTILIZ	Uncertain capacity utilization	-
COMPAT	Compatibility problems (e.g. with installed machinery, etc)	-
3. Market conditions		
D	Medium-term (expected) change of demand	+
IPC	Intensity of price competition in the product market	+
INPC	Intensity of non-price competition in the product market	?
CONC16-50	Three dummy variables for market concentration based on the number of	?
CONC11-15	Principal competitors in the world (product) market	?
CONC1-10	(16-50, 11 to 15, 1 to 10 competitors; 50+ as reference group)	?
4. Type of production/products		
Product characteristics (dummy variables with 'standardized products' as reference group)		
PDMARKET	Product differentiation	.
PDUSER	Products according to user specifications	-
Process characteristics (dummy variables with 'single-piece production' as reference group)		
SBATCH	Small-batch production	?
LBATCH	Medium- / large-batch production	+
CONTFLOW	Continous flow / mass production	+
5. Absorptive capacity		
HUMCAP	Percentage share of highly qualified personnel	+
COOP	Cooperation in R&D activities (dummy variable)	+
6. Firm size	Four dummy variables (50-99, 100-199, 200-499, 500+; 1-49 employees as reference group)	+
6. Control variables		
FIRMAGE	Number of years	+
INT90	Intensity of use of AMT 1990	-

Policy equation

Policy Variables

Table 3 contains some information on government support of AMT in the period 1990-1996. About 20% of the firms in the final data set have been supported by some element of the government AMT promotion programme. Subsidies for R&D projects connected with the introduction and/or extension of AMT has been the type of support most frequently applied (about 60% of the firms); training and consulting services were claimed by about two fifths of the firms. A more detailed view of this information shows that there are considerable differences among industries and firm size classes with respect to promotion frequency and mode of promotion. Not surprisingly, mechanical engineering/vehicles and electrical engineering/electronics having a very high potential for AMT use had benefited more-than-average from government support. For these industries promotion was concentrated primarily in R&D projects, whereas in metalworking and other industries the support was focussed on consulting and, somewhat lesser, training schemes. Very small (less than 50 employees) and large firms (more than 500 employees) have more frequently received AMT support than medium-sized firms. Finally, there is a close relationship between mode of promotion and firm size: very small and large firms received more-than-average support in R&D, medium-sized ones in training; firms with up to 200 employees were stronger promoted through the offering of consulting services. The promotion of small firms may be a reasonable policy goal, but it is difficult to find some justification for the support of large firms being for himself already intensive users of AMT. Is it a policy failure? This is an important point to be clarified by the analysis below.

Table 3: Government Promotion of AMT

	Number of firms	Government-supported firms		Type of government support		
				Training	Consulting	Development
	N	N	%	(% of government-supported firms)		
Total manufacturing	463	96	20.7	37.5	43.1	60.2
Groups of Industries						
Metalworking	99	23	23.2	43.5	62.5	43.5
Machinery/vehicles	101	28	27.7	25.8	34.5	76.7
Electr.machin./electronics	95	25	26.3	32.1	25.0	71.4
Other industries	168	20	11.9	54.6	57.1	40.9
Firm size (number of employees)						
Less than 50	83	22	26.5	18.5	53.9	63.0
50-99	87	13	14.9	50.0	61.5	66.7
100-199	127	20	15.8	55.0	57.9	45.0
200-499	100	20	20.0	55.0	31.6	31.6
500 and more	66	21	31.8	24.0	20.0	88.0

To model the impact of government AMT promotion (policy effect) we constructed two types of variables: simple dichotomous variables 'promotion yes/no', overall and differentiated by type of support (information/training, subsidies for consultancy and for R&D projects), and variables based on a firm's assessment of the stimulus from promotion (overall, by type) on a five point Likert scale. These stimulus measures were subsequently transformed to a binary variable (value 0 for stimulus of 1 and 2, value 1 for stimulus of 3 to 5 on the original five point scale); this binary variable has been used throughout in this study.[11] We report the estimates for both types of policy variables in the 'single equation' framework and only for the stimulus variable (CIMTHM) in the 'simultaneous equation system' framework.

Explanatory Variables

A policy equation was specified on grounds of 'ad hoc' plausibility arguments. Specifically, several firm-specific factors were taken into consideration. First, firm size and industry dummies were inserted in the equation to control for general characteristics of the firm influencing the probability of getting government support. Because of limited financial resources small firms have a larger incentive to claim such support as large ones. Moreover, the promotion of small firms has been an explicit goal of the Swiss AMT programme.[12] We expect thus a negative correlation of the policy variable with firm size. Casual observation of the data shows that the frequency of AMT promotion varies considerably among industries thus justifying the inclusion of industry dummies as regressors in the policy equation. Second, we considered two institutional characteristics which may be related to the probability of being supported by a government programme, i.e. status as affiliate or parent-house and affiliate of a foreign enterprise. However, it is not a priori clear in which direction these variables could influence the policy variable. Third, firms confronted with serious problems of financing innovation projects should be more inclined to claim government support than other firms. We constructed a proxy for 'limited financial resources for developing/adopting new technology' by calculating the means of the statements of the responding firms with respect to five impediments of innovative activity related to financial problems (measured on a five point Likert scale).[13] We expect a positive sign for this variable. Fourth, we included a dummy variable measuring the previous experience of a firm with other government technology promotion programmes (positive sign). We also experimented with variables such as measures of intensity of innovation activities, labour productivity and export share which capture several dimensions of firm performance; however, these variables were omitted in the final estimates of the policy equation because they showed no effect on the policy variable in all estimates.

Empirical Results

Estimates of the Single Equations

Adoption Equation

Table 4 contains the estimates of the adoption equation (DAMINT as dependent variable) based on 461 observations for firms having adopted at least one AMT element. The coefficients of an estimate of the full technology adoption model as specified in section 4 are listed in column 1. Column 2 contains only those coefficients which were statistically significant at the 10%-level (backward elimination). An estimate of the model without firm size dummies containing only the variables with statistically significant coefficients at the 10%-level is found in column 3.

[11] 26% of promoted firms report an overall 'high' policy stimulus; the corresponding figures for training, consulting and R&D are 28.9%, 22.7% and 15.0% respectively.

[12] One could also argue the other way round stating that large firms have better chances to get government subsides than small ones because they can spend more in lobbying and have possibly greater experience in this field. However, we use a specific variable to cover 'promotion experience', thus we expect that with respect to firm size the 'small firm' effect will dominate.

[13] These impediments are: high innovation costs, long pay-back period for innovation projects, lack of internal and external financial resources, high tax burden.

The main contribution to the explanation of adoption behaviour (in addition to the control variables) comes from three groups of variables: objectives of adoption of AMT reflecting anticipated revenue increases related to the application of AMT, knowledge absorptive capacity and firm size.

Four out of six variables representing the influence of adoption objectives have positive signs, one of them a negative one; all signs are in the expected direction. The variables FLEX ('higher flexibility') and BEST ('remaining on top of technological improvements') seem to have the largest weight among these variables. We could not find any significant effect for the sixth variable in this group DEV ('improving product development').

As expected, human capital (HUMCAP) and the propensity to cooperate in R&D (COOP) are also very important in explaining adoption behaviour. This is a result similar to that obtained in most innovation studies. A comparison of the coefficients of these variables in columns 1, 2 and 3 confirms our correlation calculations between firm size and HUMCAP, COOP mentioned in section 4 which showed a considerable size dependency of these variables.

All size dummies in column 1 are positive and of increasing magnitude indicating a positive and monotonous relationship between adoption and firm size. We could not find any significant effect related to the variables for various possible cost-increasing hindrances to AMT adoption except for INVCOST ('high investment costs') having the right negative sign.

In accordance with earlier results for the innovation behaviour of Swiss manufacturing firms the variables reflecting market conditions show no significant influence on adoption behaviour. However, we report some reserve with respect to the result for the variable D (demand expectations) being possibly not properly measured (see also section 4). The modes of existing production technology and existing types of products do not seem to play a major role for explaining the intensity of AMT use; only firms with medium-/large-batch production adopt, as expected, AMT more intensively than other firms. There are two contrary effects (scale economies vs. flexibilty possibilities) affecting the overall influence of these variables which, according to our results, counterbalance each other.

Finally, we obtain also for the control variables the expected signs, the coefficient of FIRMAGE being positive but not statistically significant probably due to the short period covered by their change variable DAMINT.

In sum, the anticipated new revenue potentials are seemingly much more relevant for the firm's decision to adopt (or intensify the use) of AMT than the costs which are associated with the introduction and adaptation of these new technologies. A high capacity to efficiently absorb and apply new knowledge supports an earlier and/or more intensive adoption of AMT. Financing the investment for the new technology is found to be a problem especially for small firms causing a postponing of the adoption of AMT. Large firms seem to have a general advantage in adopting AMT earlier than small ones. Finally, previous use of AMT does not lead to a more intensive application of this technology later on, that is the 'saturation effect' is dominating the 'learning effect'.

Policy Effects in the Adoption Equation

Table 5 contains estimates of the adoption equation including two alternative policy variables (government support: yes/now; stimulus) as additional explanatory factors. The estimation of Equation 1 was based on all available observations ('total sample'; N=463). For the estimation of equation 2 we used a sample of those firms which at the launching of the promotion programme in 1990 did not yet apply AMT in production ('reduced sample'; N=330). Thus, testing for the policy effect in equation 2 is more restrictive than in equation 1. We estimated the adoption equation also for the subsamples of small (less than 200 employees) and large (200 and more employees) firms.

All coefficients of the policy variables in table 2 are positive. However, for all firms, i.e. independent of size, we find only in one case a significant coefficient of the policy variables at the 10%-level (reduced sample; stimulus variable). The policy effect is significant in all estimates based on the subsample of small firms for both types of policy variables with and without 'before-1990-AMT adoptors'. On the contrary, we cannot find a significant policy effect for subsample of the large firms.

In sum, as to the 'single equation framework' there is an unequivocal positive influence of small firms getting government support on the probability of increasing the intensity of AMT use. This is a first hint that policy does reach its specific target of supporting the diffusion of AMT in small firms.[14]

Policy Equation

Estimates of the policy equation are found in table 6. According to these results there exists a negative relationship between firm size and the probability of being a government-supported firm (see columns 1 and 3); this relationship is stronger when the 'total sample' (N=463) is used (see column 1). Taken together with the findings that, first, AMT diffusion and firm size are positively correlated and, second, that there is a positive effect of policy variables on adoption, this result can be interpreted as an additional indirect hint that the causality between adoption and policy intervention runs from policy to adoption and not the other way round.

[14] More detailed estimates not presented here show that the overall positive policy effect can be traced back mainly to the effects of consulting and training, whereas R&D promotion does not seem to contribute to a faster adoption.

Table 4: Determinants of the Change of the AMT 1990-96 Adoption Intensity (Ordered Probit Estimates of the Adoption Equation)

Explanatory Variables	DAMTINT 1	2	3
Objectives			
FINCOMP	-.13** (.06)	-.12** (.06)	-.16** (.05)
COST	.09 (.06)	.10* (.06)	.12** (.05)
FLEX	.21** (.06)	.23** (.06)	.23** (.06)
DEV	.04 (.06)		
QUAL	.13** (.06)	.11** (.06)	.10* (.05)
BEST	.19** (.06)	.19** (.06)	.20** (.06)
Impediments			
TECH	.03 (.06)		
KNOWPERS	.02 (.06)		
RESIST	-.03 (.06)		
INVCOST	-.10 (.06)	-.10* (.06)	-.12** (.06)
UTILIZ	.06 (.06)		
COMPAT	-.06 (.05)		
Market conditions			
D	.02 (.06)		
IPC	.08 (.06)		
INPC	-.06 (.06)		
CONC16-50	.08 (.17)		
CONC11-15	.03 (.15)		
CONC01-10	.06 (.15)		
Type of production			
PDMARKET	-.01 (.12)		
PDUSER	.00 (.14)		
SBATCH	.05 (.12)		
LBATCH	.29** (.12)	.29** (.11)	.36** (.11)
CONTFLOW	-.12 (.16)		
Knowledge			
Absorptive capacity			
HUMCAP	.01 (.01)		.009* (.004)
COOP	.19 (.12)	.21* (.12)	.30** (.12)
Firm size			
S50-99	.33* (.19)		-
S100-199	.52** (.19)	.29** (.14)	-
S200-499	.57** (.21)	.28* (.16)	-
S500+	1.2** (.26)	.85** (.20)	-
Control variables			
FIRMAGE	.00 (.00)		
INT90	-.18** (.02)	-.16** (.02)	-.13** (.02)
N	461	461	461
McFadden R^2	.129	.116	.092
LR-statistic	127*	114*	90*
% concordance	73.3	72.3	70.2
Equal slope test	44	25*	10

*The first equation contains all model variables; the second and the third equation (without dummies for firm size) contain only the variables with statistically significant coefficients at the 10%-level (backward elimination). Standard errors are included in brackets under the estimated parameters (**, * indicate statistical significance at the 5%-level and 10%-level resp.) Intercepts and the coefficients of industry dummies have been omitted.*

Further important factors which correlate positively with the probability of government support are the lack of financial resources and, partly, previous experience with government support in other programmes and the status of being an affiliate of a foreign enterprise. The effect of industry dummies is negligible (except for the metalworking industry).

To test for the direction of the interrelationship between adoption and policy we also inserted the adoption variable DAMINT as additional regressor in the policy equation (columns 2 and 4). We obtain a significant positive coefficient for the adoption variable when using the 'reduced sample' (N=330; column 3). This is a hint that also the opposite causality works; thus, we need a simultaneous equation framework to clarify this issue.

Table 5: The influence of Policy Variables (Ordered Probit Estimates of the Adoption Equation)

Policy Variable	Adoption Variable DAMINT N=463 1	N=330 2
Government Support: yes/now		
all Firms	.17 (.14)	.24 (.28)
Small	.33* (.19)	.51* (.22)
Large	.18 (.24)	.04 (.36)
Government Support: stimulus		
all Firms	.24 (.17)	.46* (.22)
Small	.53* (.21)	.67* (.25)
Large	.18 (.34)	.29 (.68)

The table contains only the coefficients of the two alternative policy variables used in the estimations; the standard errors are included in brackets under the coefficients (indicates statistical significance at the 10%-level). Both policy variables are binary; the stimulus variable was originally measured as an ordinal variable on a five point Likert-scale and subsequently transformed to a binary one (value 0 for stimuli of 1 and 2, value 1 for stimuli of 3 to 5 on the original scale). Equation 1 was estimated for all firms. For the estimation of equation 2 we used a sample of those firms which at the start of the government promotion programme in 1990 did not yet apply AMT in production. 'Small' refers to a sample containing only firms with less than 200 employees, 'large' to its complement containing firms with 200 employees and more.*

Table 6: Probit Estimates of the Policy Equation

Explanatory Variables	CIMTHM (stimulus) N=463		N=330	
Firm size	1	2	3	4
S20-50	-.58 (.36)	-.56 (.36.)	-.08 (.35)	-.08 (.35)
S50-99	-.95* (.37)	-.89* (.37)	-.56 (.37)	-.50 (.36)
S100-199	-.67* (.35)	-.64* (.35)	-.15 (.34)	-.15 (.34)
S200-499	-.94* (.37)	-.93* (.37)	-.72* (.40)	-.75* (.40)
S500-999	-.86* (.43)	-.81* (.43)	-1.09* (.60)	-1.00* (.60)
S1000+	-.61 (.45)	.58 (.45)		
Groups of industries				
Metalworking	.44* (.22)	.45* (.23)	.30 (.27)	.29 (.27)
Machinery/vehicles	.20 (.24)	.21 (.24)	.31 (.29)	.32 (.28)
Electrical machinery/ Electronics	.15 (.25)	.18 (.25)	-.25 (.34)	-.15 (.33)
Chemicals/plastics	-.43 (.42)	-.37 (.41)	-.03 (.47)	.08 (.46)
Ownership status				
Affiliate company	-.04 (.18)	-.02 (.17)	-.01 (.22)	.05 (.21)
Firm in foreign Ownership	.39* (.23)	.39* (.23)	-.01 (.34)	.03 (.33)
Financing difficulties	.28* (.16)	.27* (.16)	.39* (.20)	.38* (.20)
Previous experience with governm. support	.28 (.18)	.28 (.17)	.39* (.22)	.38* (.22)
Adoption variable DAMINT	.14 (.11)	-	.27* (.14)	-
N	463	463	330	330
McFadden R^2	.078	.073	.105	.088
LR-statistic	27*	25*	24*	20*
% concordance	70.7	68.9	72.9	70.4

Simultaneous Estimates

We estimated a simultaneous probit model with an adoption and a policy equation each of them containing as additional explanatory variable the dependent variable of the other one. We conducted the simultaneous estimation only with the variables which in the single equations showed statistically significant coefficients at the 10%-level. Table 7a contains the estimates for both the 'total' and the 'reduced' sample for all firms, i.e. independent of firm size, table 7b shows the corresponding estimates for the subsample of small firms (less than 200 employees). We applied the same specification as in the 'single equation' framework for all independent variables except for firm size. In this case we used a polynom with respect to the number of employees (linear and quadratic term) for the estimates in table 7a and a linear term for the estimates in table 7b.

The basic pattern of the model estimates for both equations is the same indicating to a certain robustness of the underlying relationships. The results are quite clear with respect to the influence of the adoption variable on the policy variable: the coefficient of DAMINT (adoption variable) is not statistically significant in all four estimates in tables 7a and 7b. The hypothesis of the causality running from the policy to the adoption variable is confirmed for the 'reduced sample' (more restrictive condition) both for all firms and the subsample of small firms.

Table 7a: Simultaneous Probit Estimates of the Adoption and the Policy Equation (all Firms)

Explanatory Variables	DAMINT total sample	CIMTHM	DAMINT reduced sample	CIMTHM
FINCOMP	-.14* (.07)	-	-.14* (.08)	-
COST	.11* (.05)	-	.11 (.07)	-
FLEX	.23* (.06)	-	.27* (.07)	-
QUAL	.10* (.05)	-	.13* (.06)	-
BEST	.19* (.06)	-	.20* (.07)	-
INVCOST	-.12* (.06)	-	-.06 (.07)	-
LBATCH	.33* (.11)	-	.26* (.13)	-
COOP	.25* (.12)	-	.22 (.14)	-
L (number of employees)	.33* (.16)	-.03 (.27)	1.53* (.63)	-1.68 (1.30)
L^2	-.02 (.02)	.01 (.04)	-.42 (.54)	.08 (1.70)
INT90	-.15* (.02)	-	-.20* (.03)	-
Firm in foreign Ownership	-	.46* (.23)	-	.28 (.34)
Financing problems	-	.13 (.16)	-	.17 (.20)
Previous experience with govern. support	-	.41* (.17)	-	.51* (.22)
CIMTHM (policy variable)	.08 (.12)	-	.28* (.16)	-
DAMINT (adoption variable)	-	.07 (.13)	-	-.09 (.15)
N	463		330	
$Q_T(\Theta: \aleph^2 = 21.1; df=14)$	24.5		15.8	
ρ	.101 (.09)		.213* (.12)	
R^2	0.250	0.087	0.239	0.087

Conclusions

The paper applies a procedure of analyzing the impact of public promotion of AMT on the diffusion of such technologies based on the estimation of an adoption equation within the framework of diffusion theory by using (primarily qualitative) firm data. The approach takes account of the interdependency of adoption and government promotion and brings to light some econometric evidence on the direction of the casuality between these two variables, thus helping to assess the economic impact of the AMT promotion programme.

According to the technology diffusion model on which our analysis builds the most important factors influencing the adoption behavjior of a firm are: positively, a series of anticipated new revenue potentials (e.g. through cost reduction, higher flexibility, etc.); the high capacity to efficiently absorb and apply new technology; firm size; negatively, adjustment costs which are associated with the introduction and adaption of these new technologies (primarily investment costs).

Has the Swiss government programme to promote AMT been effective? Our evidence shows that the policy goal to foster the diffusion of AMT was clearly attained in the case of small firms (with less than 200 employees) and/or for firms adopting AMT for the first time or characterized by a low intensity of AMT use with some overlap between these two categories. The promotion instruments have, however, no influence on the adoption strategy of large firms. The support through training programmes and consultation seems to be more effective than by subsidizing R&D projects. Especially for large firms it is quite doubtful whether subsidized R&D projects in the field of AMT are more than just a substitute for a firm's own activities.

We are convinced that this type of a analysis should be a core element of policy evaluation. An improvement of the data base could significantly raise its reliability because the weaknesses of the approach lie primarily at the empirical level. Therefore, it is indispensable that the preconditions for an evaluation should be secured from the very beginning of policy implementation, i.e. already in its preparatory stage. This means, among other things, that the institutions responsible for policy implementation should be obliged to gather the necessary data and get the competence to enforce the promoted firms to deliver the information needed.

However, we are aware of the shortcomings of a procedure based only on 'hard' evidence which does not account sufficiently of "soft factors" relevant to the adoption of AMT (e.g. the organizational environment). Presumably these are of particular importance in the case of AMT because the introduction of such technologies often has a significant impact on the system of production as a whole. Thus, we propose as a general strategy the parallel use of several methods to evaluate a certain policy measure. For example, in the case presented in this paper we are in favour of supplementing our approach, first, by undertaking a number of in-depth interviews at the level of firms with specific characteristics which seem important according to the present analysis.[15] Secondly, we find it useful to conduct comparative studies of the promotion of AMT in different countries using a similar methodological approach. The latter work could contribute to "policy benchmarking" found nowadays useful to improve policy making at the national or regional level.

[15] Two further studies in this direction were effectively conducted parallel to our work.

Table 7b: Simultaneous Probit Estimates of the Adoption and the Policy Equation

(small Firms; less than 200 employees)

Explanatory Variables	DAMINT total sample	CIMTHM	DAMINT reduced sample	CIMTHM
COST	.15* (.07)	-	.22* (.08)	-
FLEX	.20* (.08)	-	.22* (.09)	-
DEV	.29* (.07)	-	.33* (.08)	-
QUAL	.17* (.06)	-	.18* (.07)	-
BEST	.21* (.07)	-	.16* (.08)	-
INVCOST	-.11 (.08)	-	-.06 (.62)	-
COMPAT	-.15* (.13)	-	-.26* (.07)	-
IPC	.15* (.08)	-	.17* (.09)	-
LBATCH	.39* (.15)	-	.20 (.17)	-
COOP	.22* (.15)	-	.49* (.17)	-
L (number of employees)	2.71* (1.40)	.69 (1.90)	1.52 (1.60)	-.09 (2.1)
INT90	-.18* (.03)	-	-.20* (.04)	-
Firm in foreign Ownership	-	.62* (.33)	-	.48 (.39)
Financing problems	-	.19 (.20)	-	.08 (.23)
Previous experience with governm. support	-	.24 (.22)	-	.36 (.25)
CIMTHM (policy variable)	.20 (.14)	-	.34* (.19)	-
DAMINT (adoption variable)	-	-.04 (.13)	-	-.09 (.14)
N	297		227	
$Q_T(\Theta: \aleph^2 = 22.3; df=15)$	33.9		20.9	
ρ	.233* (.13)		.331* (.14)	
R^2	0.306	0.058	0.295	0.062

See table 7a.

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Table A.1: Description of the Used Data Set

	N	%
Total manufacturing	463	100
Industry		
Food, beverage	19	4.1
Textiles	14	3.0
Clothing, leather	5	1.1
Wood	10	2.2
Paper	15	3.2
Printing	13	2.8
Chemicals	14	3.0
Pubber, plastics	24	5.2
Glass, stone, clay	16	3.5
Metals	99	21.4
Machinery	84	18.1
Elektrical machinery	27	5.8
Elektronics, instrum.	83	17.9
Vehicles	17	3.7
Other manufacturing	23	5.0
Firm size (number of employees)		
5-49	83	17.9
50-99	87	18.8
100-199	127	27.4
200-499	100	21.6
500 and more	66	14.3

Comments on Are Swiss Programmes Of Promotion Of Advanced Manufacturing Technologies (Amt) Effective? An Economic Analysis Based On Micro-level Survey Data

By Ron Jarmin [1]

Data Issues

Retrospective data

Respondents can not remember, some evidence in the U.S. of de-adoption (McGuckin, Streitwieser and Doms Economics of Innovation and New Technology, (1998, forthcoming)).

Can respondents answer all questions accurately?

Can the same person accurately answer questions on market structure and technology adoption?

For what period are the control variables measured?

I assume they are measured at the end. This is after any impacts that may have altered their values (e.g., size market conditions)

Sample selection?

Two types of survey non-response that determine final sample

34% response rate leads to N=667

What yields regression Ns of 463, 330? Item non-response? If so, for what questions? How did both types of non-response vary across treated and non-treated firms? Also, a panel was drawn. Then some treated plants were added. Do you re-weight the responses?

Methodological Issues

1. Need to know more about the policy interventions.

   We want to know how firms are selected into the program. Do they approach the program of visa versa? What is the nature of the interventions and how much variation is there?

2. Consider changing the rationale and interpretation of the two equation model.

   Adoption: $A = a0 + a1X + a2P + e$

   Policy: $P = b0 + b1Y + u$

   This is the basic selection model in Maddala 1983. Need in instrument in Y that ?s not in X. Or panel data if the unobserved characteristic in e that is related to P is fixed over time (e.g. managerial quality).

3. Is there evidence adoption of AMT ?s improves the perfor mance of Swiss firms?

   US evidence (Mcguckin et al and Doms, Dunne and Troske QJE 1997) suggests that adopters performed better both pre- and post adoption.

4. Provide a table of descriptive statistics that compare treated and untreated firms.

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METRICS OF EVALUATING PUBLIC R&D PROGRAMS

SECTION

D

Citations from Patents to Papers: A Measure of Public Research Spillover into Private Industry

By Francis Narin and Dominic Olivastro[1]

Abstract

Recent research carried out for the National Science Foundation, and other agencies has measured the direct spillover effects of publicly supported research onto industrial technology by tracing hundreds of thousands of references from recent U.S. patents to the underlying scientific papers they cite. For example, it was found that the citation of U.S.-authored papers by U.S. patents had tripled between 1987/88 and 1993/94. This increase is continuing with more than 8,000 non-patent references per week appearing on the front pages of U.S. patents in late 1997.

It was also shown that close to 75 percent of the papers cited by U.S. industrial patents had their origin in publicly supported research institutions, at universities, medical schools, and government supported laboratories and similar institutions in the U.S. and abroad. It was also found that the cited research, especially in the biotechnology area tends to be very basic, quite recent, with the papers originating at the most prestigious universities and laboratories, including NIST, and heavily supported by NSF, NIH, and other organizations.

This paper will both bring the previously reported data up-to-date by adding two additional years to the basic statistics, and add new information on the localized linkages and spillover effects. In the previously reported data it was shown that each country's inventors in the U.S. patent system tend to preferentially cite their own country's papers by a factor of 2 or more. Data just emerging from this research indicates that there are, in fact, similar local effects of this spillover, and that patents from inventors in a given state show a substantial preferential citing of papers in their own state and surrounding geographic areas. This identifies, for the first time, a very local component of the spillover from basic research conducted in public institutions, to local industrial technology.

Introduction

Among both scientists and economists it is widely accepted that public science — scientific research that is performed in academic and governmental research institutions and supported by governmental and charitable agencies — is a driving force behind high technology and economic growth. Our recent paper (Narin, Hamilton & Olivastro, 1997), from which much of this paper is drawn, provided quantitative evidence of both the magnitude and the direction of that force, based on tracing tens of thousands of references from recent United States patents to the scientific research papers they cite. Those citations from patents to papers are direct evidence of a massive spillover from basic research to industrial technology.

The premise that academic research makes an important contribution to economic growth is well accepted across the political spectrum. For example, in his statement on Technology for America's Economic Growth in February 1993, President Clinton stated that "Scientific advances are the well-spring of technical innovations. The benefits are seen in economic growth, improved health care, and many other areas."

The economic impact of science has, of course, long been a motivation for the government's support of academic research. During a period of tight research budgets some 30 years ago, Weinberg (1963) eloquently discussed the criteria for scientific choice, mentioning "technological merit" as one of the important factors in determining the support of a scientific field. The importance of this support was recognized even earlier in the fundamental assessments of science by Vannevar Bush (1960, first edition 1945), at a time when science was just emerging as a major area of governmental concern, and has recently been reviewed by Martin and his colleagues (1996) in a report to the U.K. Government.

Furthermore, Rosenberg and his colleagues (1990) have attributed much of the "Western Miracle" to the ability of the free western economies to absorb and utilize scientific knowledge; they specifically assert that "close links between the growth of scientific knowledge and the rise of technology have permitted the market economies of the Western nations to achieve unprecedented prosperity."

The notion that technology springs from a scientific base was originally embedded in the "linear model" of innovation: from basic research through applied research continuing into technology and resultant economic benefit. This simple linear model has been supplanted by much more complex views of the process, with many feedback loops and major contributions of technology to science, but the origins of research knowledge in basic research still lie at the core of the process (Turney, 1991).

[1] Dr. Francis Narin is President of CHI Research, Inc. Dominic Olivastro is on the staff of CHI Research, Inc.

This paper will review our large-scale evidence detailing a massive, contemporary linkage between industrial technology and public science, with a tripling of the knowledge links from U.S. technology to U.S. science in just six years. That analysis of more than 100,000 patent-to-science references provides evidence that public science plays a crucial role in patented industrial technology. For example, the data showed that only 17 percent of the science references on the front pages of drugs & medicine patents are to U.S. industry papers, while 50 percent are to U.S. public science, and 33 percent are to foreign science, most of which is also public. The data also show that (1) the patent-to-science linkage has a strong national component, with U.S.-authored scientific papers particularly heavily cited by U.S.-invented patents; (2) the linkage is appropriately subject specific, with chemical patents citing chemistry papers, drugs & medicine patents citing biomedical papers, and so forth; and (3) that the linkage is quite contemporaneous and quite basic, with the references on U.S. patents citing recent papers situated at the basic end of the research spectrum. The present paper shows that these linkages are still increasing at a rapid rate, and adds two major new dimensions: evidence for the broadening of this linkage, and evidence that this linkage has a localized state-by-state spillover effect.

Methodology

This paper is based on an analysis of the more than 750,000 non-patent references (NPR's) which were listed as "other references cited" on the front pages of the U.S. patents issued since 1989. For regular U.S. patents issued in 1993 and 1994, on average there were 8.6 references/patent to U.S. patents, 1.9 references/patent to foreign patents, and 1.5 non-patent references/patent.

The "references cited" on U.S. patents are a fundamental requirement of patent law. When a U.S. patent is issued it has to satisfy three general criteria: it must be useful, it must be novel, and it must not be obvious. The novelty requirement is the primary factor leading to the references which appear on the front page of the U.S. patent, since it is the responsibility of the patent applicant and his attorney, and of the patent examiner, to identify, through various references cited, all of the important prior art upon which the issued patent improves. These references are chosen and/or screened by the patent examiner, who is "not called upon to cite all references that are available, but only the best" (Patent and Trademark Office, 1995).

Non-patent references (NPR's), as they appear on the front pages of U.S. patents, are a mixed set of references to scientific journal papers, meetings, books, and many non-scientific sources such as industrial standards, technical disclosures, engineering manuals, and every other conceivable kind of published material.

All of the NPR's underwent a standardization process to put them into various categories, such as science references, abstracts, and books. Roughly 55 percent of the NPR's are science references — that is, citations to scientific journal papers, scientific meetings and other scientific publications; roughly 75 percent of these science references are citations to papers published in the 4,000 or so journals covered by the *Science Citation Index (SCI)*, and 75% of these are complete and accurate enough to match to the cited paper.

Most of the unmatched references were either incomplete or erroneous; for example, a reference might omit the author's name, or misspell it, or give the wrong volume or page numbers.

Three final methodological notes are important. First, the data are extremely complex, in that there are many different ways counts can be made. A given paper may be cited in several patents and a given patent may cite a number of different papers. In addition, a paper often has authors from more than one institution, and may be supported by more than one agency. This combination of many patents citing many papers with many different institutional addresses and support sources gives rise to various complexities in counting and presenting data.

The second methodological note concerns the limitation of this analysis to the science references on the front pages of the U.S. patents, omitting any analysis of references in the body of the patents. The reasons for this are both theoretical and practical. Theoretically, the front page references should be the most important ones on a patent, since they are the ones relied upon, as mentioned previously, by the examiner in establishing the patent's novelty. Furthermore, from a practical viewpoint it is far more difficult to extract the non-patent references scattered through the text of a patent.

In one brief study conducted to evaluate the representativeness of the front page science references, we found that approximately half of all the science references are on the front page, and that there was great similarity between front page and full text science references (Narin et al., 1988). As a result it is quite reasonable to assume that the science references analyzed here are representative of all of the science references in the patent and probably underestimate the dependence of technology upon science by a significant factor. The increasing dependence of modern technology on science revealed in this paper is, almost certainly, a very conservative estimate of that important linkage.

Finally, the data presented herein measure linkages in codified knowledge, as reflected in patents and papers, and understates the important contributions that public science makes to industry through research training, which predominates in technology-based industries such as automobiles and aircraft.

Overall Linkage Characteristics

The U.S. patent system is quite representative of the world's technology. Approximately half of the inventors of U.S. patents are foreign, and each country's inventors patent in the U.S. in rough proportion to their country's Gross Domestic Product (GDP) (Narin, 1991). In addition, the patent system covers the whole range of technology, from old but still active classes representing such basic mechanical technologies as railroads, to the most modern human genetics technology.

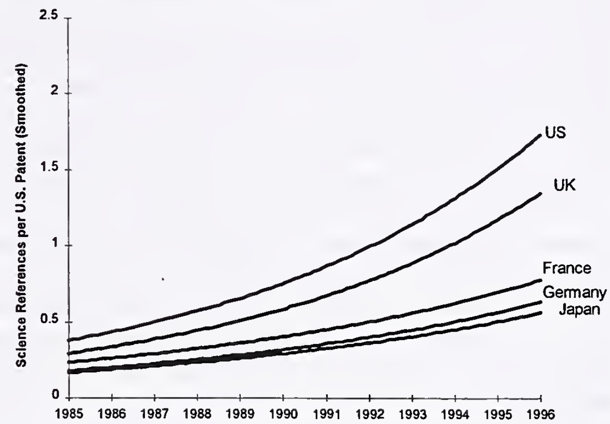
Across all of these countries and technologies there has been a steady increase in science linkage for at least two decades. The last decade of this increase is shown in Figure 1 on a country-by-country basis, and in Table 1 on a country-by-technology basis. Figure 1 shows that science linkage is increasing fastest for U.S. and U.K.-invented patents, but also increasing steadily in U.S. patents with French, German, and Japanese inventors, as it is for patents from almost all other inventor countries. The highly science-linked position of the U.S. and the U.K., compared to the other three major countries, is the result of a combination of two factors: a tendency within all technologies for U.S. and U.K. patents to be more science-linked, and the comparatively high level of U.S. and U.K. patenting activity in drugs and medicine, biotechnology, and medical instrumentation, all of which are highly science-linked.

Table 1: Patents by Industrial Technology

Inventor	Chemical Patents			Drug and Medicine Patents			Electrical Component Patents			Prof & Sci Instruments Patents		
Country	1985	1990	1995	1985	1990	1995	1985	1990	1995	1985	1990	1995
U.S.	0.94	1.85	4.63	3.05	5.48	11.61	0.53	0.93	1.28	0.58	0.84	1.72
U.K.	0.68	1.05	2.50	1.33	2.66	5.26	0.44	0.70	1.20	0.39	0.76	1.35
Japan	0.44	0.67	1.28	1.06	1.57	3.26	0.31	0.46	0.69	0.13	0.17	0.42
France	0.32	0.63	1.05	1.24	1.27	2.49	0.54	0.64	0.79	0.31	0.43	1.02
Germany	0.44	0.63	1.34	0.97	1.67	3.54	0.44	0.64	0.98	0.24	0.33	0.55
All Countries	0.74	1.30	3.18	2.17	3.78	8.66	0.45	0.73	1.00	0.41	0.58	1.27

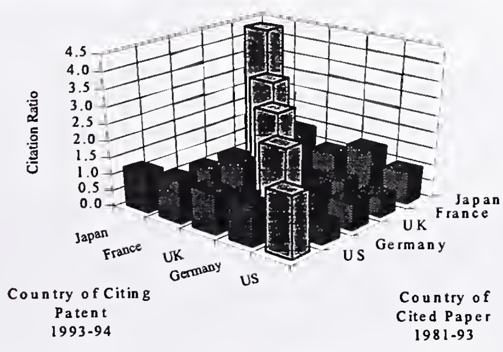
Another important characteristic of science linkage is that it is very subject specific. Drugs & medicine patents invented in all countries cite almost exclusively to papers in the scientific fields of clinical medicine and biomedical research. Similarly, chemical patents cite chemistry papers heavily, and electronics patents cite to physics and engineering papers, and there is throughout the linkage phenomenon a subject-specific couple between the technology of the patent and the science upon which it is building. The linkage is also quite recent; the peak cited year for papers cited in drugs & medicine patents is 4-6 years prior to patent grant, only a year or two slower than citing from biomedical papers to biomedical papers.

Figure 1: Science Referencing. The average number of science references per U.S. patent are consistently higher for U.S. and U.K. invented U.S. patents.



Another important characteristic of this linkage is the strong national component. Each country's inventors in the U.S. patent system cite their own country's papers two to four times as often as expected, when adjusted for the size of a country's scientific publication rate. For example, approximately 7 percent of all the papers in the *SCI* are authored by scientists at German institutions. Compared to that, approximately 17 percent of all of the science papers cited on the front pages of German-invented U.S. patents are German-authored papers. The ratio of those two percents represents a national citation ratio of approximately 2.4, in German-to-German patent-to-paper citation. This is a completely general phenomena, and is apparent for all the five major countries in Figure 2. If each country's inventors were equally likely to cite any of the world's science, then the height of each column in Figure 2 would be 1. The fact that the diagonal columns are significantly greater than unity, ranging from 2 to 4, indicates the strong domestic component that exists in science linkage, showing that each country's inventors are preferentially building upon their own domestic science. Science linkage has a distinctly national component.

Figure 2: International Inventors in the U.S. Patent System



It should be noted that the same national preference is apparent when looking at cross-national citations from papers-to-papers and patents-to-patents. In both of those cases there is just as strong a national component in the linkage; all of these citing phenomena show that there are still very strong national ties between scientists within a country and inventors within a country, and between national inventors and scientists, implying that a strong scientific base is necessary for a strong national technology, in science dependent areas of technology.

The final general point about this linkage is that the papers cited in patents are published in prestigious, mainstream, basic scientific research journals. Table 2 shows the 25 journals most heavily cited by 1993-1994 patents for the four most heavily cited scientific categories: biomedicine, combining clinical medicine and biomedical research, chemistry, physics and engineering & technology.

Table 2: Numbers of Citations and Cited Papers for Top 25 Journals.

BIOMEDICAL JOURNALS	# Cites	# Papers	CHEMISTRY JOURNALS	# Cites	# Papers	PHYSICS JOURNALS	# Cites	# Papers	ENGINEERING & TECH JOURNALS	# Cites	# Papers
P NAS US	3835	2134	J AM CHEM S	1394	811	APPL PHYS L	2210	1356	IEEE T	1812	1206
NATURE	2398	1175	TETRAHEDR L	991	673	JPN J A PHY	773	535	ELECTR LETT	721	521
SCIENCE	2344	1129	J ORG CHEM	945	632	J APPL PHYS	771	569	IEEE ELEC D	345	220
J BIOL CHEM	1874	1243	J CHEM S	590	412	J VAC SCI T	670	435	IEEE COMMUN	233	143
J MED CHEM	1136	646	ANALYT CHEM	472	324	APPL OPTICS	472	372	J AM CERAM	181	144
CELL	1121	644	J ELCHEM SO	460	346	PHYS REV L	349	168	P IEEE	166	91
NUCL ACID R	1072	669	J CHROMAT	379	270	OPTICS LETT	347	242	IEEE COMPUT	164	103
J IMMUNOL	979	686	MACROMOLEC	314	194	IEEE J Q EL	299	195	IEEE J SEL	163	104
BIOC BIOP R	922	524	TETRAHEDRON	307	188	J LIGHTW T	298	204	SENS ACTUAT	162	110
BIOCHEM	821	543	J CRYST GR	277	216	THIN SOL FI	286	174	J MATER SCI	152	99
GENE	737	406	J POL SC	241	179	REV SCI INS	228	156	IEEE CONS E	122	95
CANCER RES	679	485	ANGEW CHEM	224	114	NUCL INSTRU	222	182	IBM J RES	122	78
EMBO J	679	420	MACROMOL CH	218	149	PHYS REV	203	146	IEEE NUCL S	93	75
J VIROLOGY	593	449	INORG CHEM	212	140	OPT ENG	188	120	J NON-CRYST	92	70
J BACT	496	381	CHEM LETT	204	149	SOL ST TECH	181	122	COMPUTER	89	65
ANALYT BIOC	490	308	J APPL POLY	168	101	J MAGN RES	172	108	COMM ACM	87	59
MOL CELL B	482	335	POLYMER	166	90	IEEE ACOUST	172	103	TAPPI J	86	59
J EXP MED	476	310	J PHYS CHEM	164	98	IEEE PHOTON	154	108	IEEE PATT A	73	50
INFEC IMMUN	472	380	SYNTHESIS-S	151	109	SYNTH METAL	152	77	J MATER RES	70	44
BIOC BIOP A	422	300	B CHEM S J	126	101	J PHYS	136	98	METALLURG T	70	44
J CLIN INV	409	288	J HETERO CH	112	85	J OPT SOC	134	94	J METAL	70	28
FEBS LETTER	400	266	J CATALYSIS	112	76	MOLEC CRYST	114	70	AT&T TECH J	67	43
BLOOD	380	284	POLYM BULL	112	54	PHYSICA C	102	82	J ALLOY COM	62	47
J CELL BIOL	365	256	HETEROCYCLE	100	78	APPL PHYS	92	61	IND ENG RES	60	37
N ENG J MED	362	251	ORGANOMETAL	99	66	OPT COMMUN	80	67	J ELEC MAT	56	41
						SOL ST COMM	80	56			

The journals shown on Table 2 are clearly prestigious and influential, and for the biomedical and chemistry papers, quite basic.

The physics journals, however, are not as basic, with much of the physics cited in patents published in applied physics journals, rather than the more basic theoretical and high energy physics journals. The *Physical Review*, for example, the largest and one of the most prestigious physics journals, is only thirteenth on the physics list, led by more applied journals. As would be expected in engineering & technology, many of the journals are electrical engineering journals, since there is such a very large amount of patenting in the electronics field, and many of these patents cite to papers in *IEEE* and other electronics-related journals.

Cited U.S. Science

This section will describe the U.S.-authored scientific papers cited in 1987-88 and 1993-94 U.S. patents. Because of the tendency for U.S.-invented patents to cite U.S. papers, the high activity of the U.S. in science-linked areas of technology, and the large size of the U.S. scientific establishment, approximately 58 percent of the *SCI*-covered papers cited in patents in the four years had at least one U.S. author, a total of 44,765 papers. An attempt was made to locate each of these papers in the library, in order to verify the institutional addresses of the authors, and to tabulate the research support acknowledgements.

Figure 3 shows the most dramatic finding: that there has been remarkable increase in linkage between U.S. patents and U.S.-authored scientific papers; in just six years the number of U.S.-authored papers cited in patents has more than doubled, the number of citations to these papers almost tripled, and the number of research support acknowledgements on the papers more than tripled. Since ober this period of time the number of patents in th U.S. system has only grown by 28 percent, an increase in science linkage of 200 percent is truly remarkable, and indicative of a rapidly increasing dependence of patented technology upon contemporary science.

Figure 3

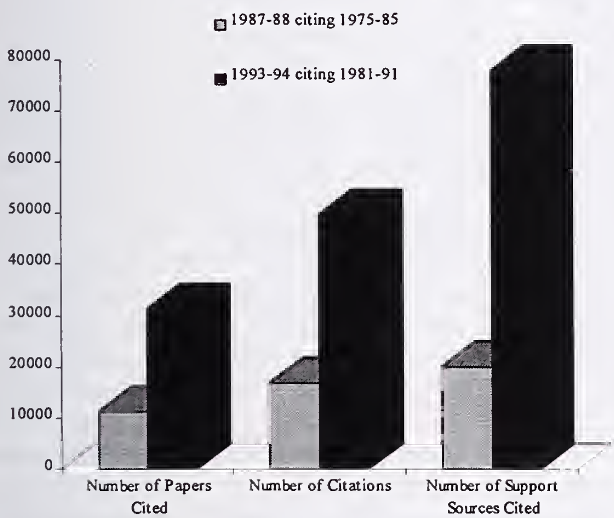
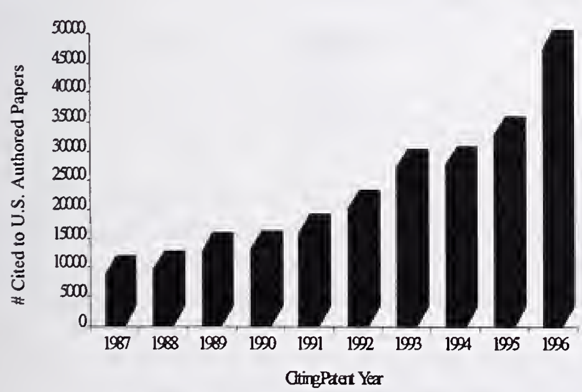


Figure 4 shows that this dramatic increase continued through 1996, increasing another 50 percent in the 1995-96 time period. Although not yet matched, preliminary observatjions indicate this increase continued through 1997.

Figure 4



Note: The data is based on a 12-year window with a 3-year lag. For example: 1996 patients are citing 1982-1993 papers. 1995 patents are citing 1981-1992 papers, and so on.

A second important point is that these cited research papers are authored at prestigious universities and laboratories, just as they were published in prestigious journals. This is shown in Table 3, which lists the top 25 author institutions for the four categories. Note that in Table 3 we have combined the universities and their medical schools. Most of the biomedical papers listed there as Harvard University are papers which are published at Harvard Medical School. Note also that those are whole counts of citations. In a whole count, if a paper has authors at two institutions, say Harvard and Stanford, it is counted as one citation to each institution. In a fractional count, used in some of the data later on, a cited paper with authors at Harvard and Stanford would be counted as one-half a citation to each.

For the biomedical papers it was not surprising that the National Cancer Institute (NCI) appears very high on the list, since NCI has a large Intramural research program. The high ranking of the Veterans Administration (VA) was somewhat surprising. However, almost all of these VA papers are co-authored with scientists at the medical schools associated with the VA hospitals, indicating a close and productive linkage between the VA and the academic community.

A number of the major private companies are high on the list for chemistry papers, with DuPont listed as fourth, Lucent's Bell Labs sixth and IBM seventh. For both physics papers, and engineering & technology papers, the top two cited organizations are Bell Labs and IBM, both of which have large numbers of patents, and many Bell Labs and IBM patents cite their own company papers. However, there is also much citation from other patents to the Lucent and IBM papers, and this is by no means a reflection of excessive company self-citation. For example, only 19 percent of the patent citations to Bell Labs papers come from Lucent itself, while only 21 percent of the cites to IBM papers come from IBM patents.

Note also that in physics and engineering some of the major national laboratories also appear quite high on the list, as well the private companies and major universities; this list clearly shows a high degree of interdependence between the academic, industrial and governmental R&D communities.

The Science Base of U.S. Industry

This section will look at the patent-to-paper linkage data from the perspective of U.S. industry patents. The data show that even when the data are restricted to patents assigned to U.S. industry, the dependence on U.S. public science is very substantial. In this section the set of citing patents was restricted to those patents whose assignees were U.S. non-governmental, non-academic organizations, almost all of which are U.S. industry. Within these lists there may be a few small clinics or hospitals; however, almost all the patents are from U.S. industrial companies.

Table 3. Numbers of Citations and Cited Papers for Top 25 Cited Journals.

BIOMEDICAL PAPERS		CHEMISTRY PAPERS		PHYSICS PAPERS		ENGINEERING & TECH PAPERS	
Harvard Univ	2506	MIT	171	Lucent Bell Labs	854	Lucent Bell Labs	471
Nat'l Cancer Inst	1279	U Texas, Austin	171	IBM Corp	566	IBM Corp	428
Veteran's Administration	1033	Harvard Univ	160	Stanford Univ	300	U Cal Berkeley	189
Univ Cal San Francisco	930	Dupont Co	142	Bellcore	174	MIT	174
Stanford Univ	920	U Cal Berkeley	139	USN, Res Lab	167	Stanford Univ	162
Univ Washington	845	Lucent Bell Labs	130	Lincoln Labs	150	General Electric Co	111
MIT	756	IBM Corp	122	MIT	133	Tex Instruments Inc	96
Scripps Clin and Res Fdn	690	Merk & Co Inc	102	Univ Illinois	120	USN, Res Lab	88
Univ Cal Los Angeles	642	Cornell Univ	96	U Cal Santa Barbara	110	N Carolina State Univ	84
Mass Gen Hosp	625	Texas A&M Univ	95	Cornell Univ	106	Bellcore	78
Johns Hopkins Univ	610	Penn State Univ	89	U Cal Berkeley	100	Xerox Corp	69
Washington Univ	588	Univ Wisconsin	87	Xerox Corp	95	Univ Illinois	64
Univ Cal San Diego	534	Purdue Univ	83	Univ Pennsylvania	93	Penn State Univ	60
Univ Pennsylvania	517	Univ Illinois	83	N Carolina State Univ	90	U Cal Los Angeles	59
Merk & Co Inc	484	U Cal Los Angeles	79	Caltech	87	Lincoln Labs	57
Yale Univ	463	Univ Massachusetts	72	Sandia Natl Labs	83	Sandia Natl Labs	54
Nat'l Inst Allergy & Infectious Dis	456	Va Polytecb Inst	71	Lawr Livermore Nat'l Labs	80	Carnegie Mellon Univ	53
Univ Wisconsin	448	Rice Univ	70	General Electric Co	74	U Texas, Austin	53
Univ Michigan	447	Univ N Carolina	70	Lawr Berkeley Lab	74	Hewlett Packard Co	51
Cornell Univ	432	Dow Chemical Co	67	Gen Motors Corp	65	Motorola Inc	51
Genentech Inc	432	Stanford Univ	67	Jet Prop Lab,Caltech	64	Cornell Univ	48
Columbia Univ	428	Univ Florida	66	Los Alamos Nat'l Labs	63	Univ Michigan	48
Duke Univ	413	Univ Nebraska	66	Natl Bur Standards	62	Univ Southern Cal	48
Univ Colorado	409	U Cal San Diego	65	Hewlett Packard Co	60	Univ Washington	44
Rockefeller Univ	405	Iowa State Univ	63	U Cal San Diego	56	Oak Ridge Natl Lab	43
				Univ Houston	56		

The citing data consists of papers published in 1988, the peak cited year for science references in 1993-1994 patents. The reason for restricting the data to one cited year is that, while sector and institution had already been assigned to all the U.S. institutions, the same had not been done for papers with foreign-authored addresses, and therefore a time-consuming assignment of an organizational sector to the cited foreign papers had to be carried out. Confining the data to one cited year kept the effort within reasonable bounds.

The overall data are shown in Table 4, both for all industry patents, and for industry patents in three subsets: drugs & medicine (including biotechnology), chemicals (excluding drugs & medicine), and electrical components & accessories & communication equipment. The table shows the strong reliance of U.S. industry patents on public sector science; overall, only 20.4 percent of the cited papers are from U.S. industry, 6.3 percent from foreign industry, and the remaining 73.3 percent are from public science, in the U.S. and overseas. This implies that U.S. industry is far from self-sufficient in science. The great majority of the science base of U.S. industry comes from the public sector; public science appears to be crucial to the advance of U.S. industrial technology.

As shown in Table 4, the area with the largest private science base is electrical components, for which approximately half of the cited papers are from industry. In the case of electronics, the large electronics companies, IBM, Hitachi, AT&T, and others, publish heavily, and this private sector component of the scientific literature is quite heavily utilized in patents. Nevertheless, even in this case half of the science base is public. For drugs & medicine, chemicals, and almost all of the rest of the database more than 75 percent of the science base of U.S. industry, as expressed by these citations, has its origin in public science. The U.S. public science component is larger than the foreign, but foreign public science is still an important contributor.

Table 4: Institutional Origin of Papers Cited in 1993-1994 U.S. Industry Patents

	All Patents	Drug and Medicine Patents	Chemical Patents	Electrical Component Patents
US Industry	20.4%	16.7%	18.3%	37.5%
US Public	43.9%	50.3%	42.7%	29.6%
Foreign Industry	6.3%	4.2%	6.0%	13.3%
Foreign Public	29.4%	28.8%	33.0%	19.6%
	100.0%	100.0%	100.0%	100.0%
# of Matched Cites	5217	1584	1784	585

Data from Fran (12/30/96)
which he got from refsec41.xls.
These are percentages of references.

The Spreading of Science Linkage

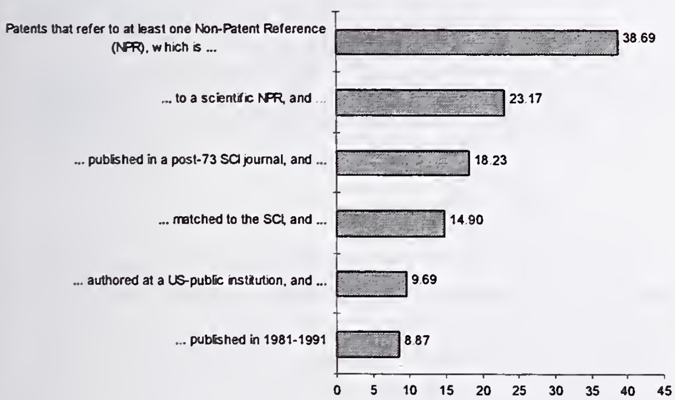
In the previous sections we have shown that the intensity of linkage between patented industrial technology and public science has increased markedly over the last decade. In this section we will show that simultaneous with the increase there has been a broadening of the science dependence.

The conservative nature of our approach is reflected both in the type of references we chose, and in how we culled down to the ones actually matched and analyzed.

As mentioned previously, we chose to use only the references on the front page of the patent, those that had been placed there with the acquiescence of the examiner; we omitted the science references in the body of the patent, even though an earlier study showed that there were as many science references in the body of the patent as there are in the front page, and that the characteristics of the references – the fields, subfields, and so forth, to which they referred were rather similar.

Figure 5 shows the selection process used just for those references from the front page, the ones upon which all the previous data was based. The data there are for the years 1993 and 1994, and they show that in that year 38.6 percent of the U.S.-invented, assigned, Type 1 (regular) U.S. patents had at least one non-patent reference (NPR).

Figure 5: Selection Process



As mentioned earlier, we standardized those non-patent references, and identified those which were to scientific papers, including papers in journals, presented at meetings, and so forth. Twenty-three percent of the patents had at least one of those science references.

We then limited our analysis to those papers published in a *Science Citation Index (SCI)*-covered journal dated after 1973, since that is the science database to which we were matching the science references; this reduces the percent of patents citing science papers to 18 percent.

After the matching process, we were reduced to 14.9 percent of the patents that had an NPR that was matchable to the *SCI* post-1973. The 3.25 percent difference is basically due to incomplete or incorrect references in the patents. Sometimes the author name is missing, sometime the year or page are missing or incorrect, there are spelling errors all through the data, and so forth.

We then looked at what percentage of those matched references which were authored at U.S. public institutions, which again reduces it significantly. The other cited papers were authored at U.S. private companies or at foreign institutions.

Finally, for the detailed library lookup we considered only an 11-year window which was, for patents issued in 1993/94, the years 1981 to 1991. Thus, the data upon which the analysis is based are, in a sense, very conservative.

We will now take a closer look at the second bar of Figure 5, the percent of U.S.-invented, assigned, regular patents which cite to at least one scientific non-patent reference. This percentage has been steadily increasing over the last decade as shown in Figure 6 for all areas of patenting, and in Figure 7 for drugs and medicines, the most scientifically linked area of patenting. In particular, Figure 6 shows that in 1985, 15 percent of all those patents cited at least one scientific reference, rising to 29 percent by 1996, just 11 years later. Similar rises are shown in the number of patents that have multiple science references: in 1985 only 3 percent of the patents had 5 or more science references, rising to 12 percent by 1996 and, in fact, by 1996, 3 percent of all patents had 20 or more science references on their front pages. Most of those patents, of course, are in the extremely highly science-linked areas of biomedicine, such as genetics, although there are some very highly science-linked patents in electronics and other advanced areas of technology.

Percent of US-invented, Assigned, Type-1 (Invention) Patents at different levels of citing to Scientific Non-Patent References

		# pats	# sNPR	# NPR	# References				
					>=1	>=5	>=10	>=15	>=20
1985	14	655	2013	2830	366	60	18	3	1
1990	14	1079	6100	7883	692	197	63	26	14
1996	14	2058	30872	34860	1725	939	510	296	185

		# pats	# sNPR	# NPR	# References				
					>=1	>=10	>=20	>=30	>=40
1985	14	655	2013	2830	56	9	3	0	0
1990	14	1079	6100	7883	64	18	6	2	1
1996	14	2058	30872	34860	84	46	25	14	9

Figure 6 and 7. Percent of US-Invented, Assigned, Type-1 Patents in Durgs & Medicines iwth N References to Science Papers.

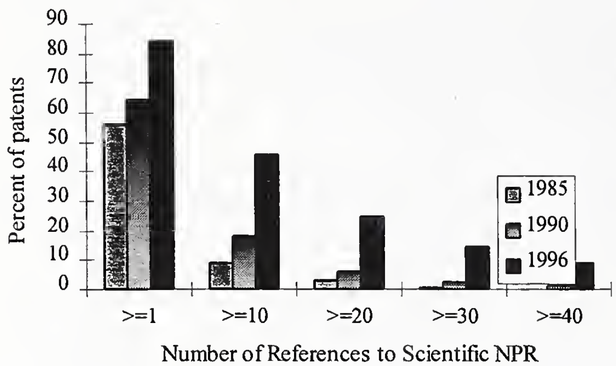


Figure 7 shows similar data, but in this case restricted to the broad area of drugs & medicine, which is the most science-linked of all the broad areas of technology. In the case of drugs and medicine the increase is still dramatic, although by 1985, 56 percent of the patents had at least one science reference, rising to 84 percent by 1996. There is also a marked rise in the patents with large numbers of non-patent references: for example, 9 percent had 10 or more in 1985, but 46 percent did in 1996, a remarkably strong dependence on, as we have demonstrated, contemporary, basic mainstream scientific research. A full 9 percent of the drugs and medicine patents had 40 or more science references on their front pages in 1996.

Thus, in this section we have shown that the growing linkage between patented technology and basic research has also been a spreading linkage, to include a wider and wider percentage of patents.

Within State Linkage

In an earlier section of this paper we showed that there was a very strong within country linkage preference, with each country's patents citing papers from their own country two to three times as frequently as expected, adjusted for the number of papers published in each country. In this section we will show that there is analogous geographic preference operating within the United States, with a noticeable tendency for industry patents within a given state to cite to papers originating at institutions within that same state.

We will illustrate the results for basic biomedicine, from a study we did for New York State. In that study we defined basic biomedicine as all journals in our two fields of clinical medicine and biomedical research, which were categorized as being in Level 4, Basic Research, or Level 3, Clinical Investigation (Narin, Pinski & Gee, 1976). Thus, this set of journals represents the most basic kinds of scientific research, produced, of course, predominately at universities, colleges, and medical schools, and such governmental basic research institutions as the National Institutes of Health.

For this illustration we have removed government and university owned patents, so that the data reflect the crucial spillover from public science to private industry.

Figure 8 shows the raw citing data for the seven largest patenting states, tracing all patent cites to their basic biomedicine papers. The graph shows the number of linkages from patents invented in the given state, to papers authored at institutions in the cited paper state, for patents issued in 1983-96 and papers published in 11-year windows, for example, 1983 patents citing to 1973-83 papers. Note the prominence of the within state citing. Of course, this is very strongly affected by the number of patents and the number of papers within the state; a state with large number of biomedical patents and papers, such as California will, of course, heavily cite to California papers.

Figure 8 and 9

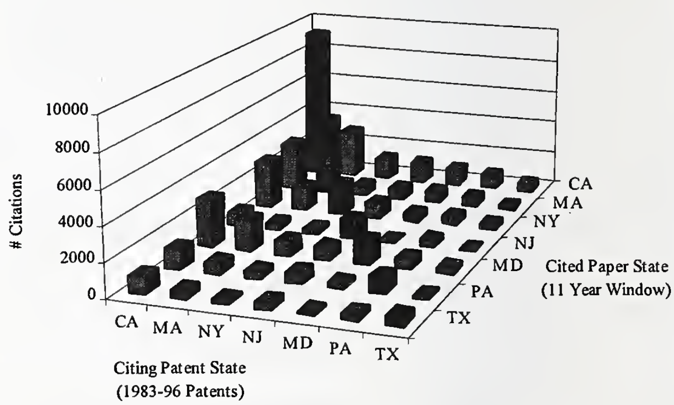


Figure 9 adjusts for this within the data set itself, showing papers in the database of papers cited by patents, which is not perfectly related to number of papers from the state, in general. However, if a given state's patents were citing papers in a geographically random manner within the set of papers cited by patents, then the height of each of those bars would be 1. That is clearly not the case; the average withing state bar is close to twice as high as would be expected, showing a within state preferential utilization of science by that state's industrial technology, of a factor of 2.

Conclusions

Therefore, we conclude that public science plays an essential role in supporting U.S. industry, across all the science-linked areas of industry, amongst companies large and small, and is a fundamental pillar of the advance of U.S. technology. The underlying hypothesis described in the beginning of this paper – that public science is a driving force behind high technology – is clearly supported by the data shown herein. Furthermore, the data shows that the science that is spilling over into high technology is mainstream; it is quite basic, quite recent, published in highly influential journals, authored at major universities and laboratories, and supported by public and charitable institutions.

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Comments on Citations from Patents to Papers: A Measure of Public Research Spillover Into Private Industry

by Sylvia Kraemer[1]

The passage in 1993 of the Government Performance and Results Act (GPRA) put federal Agencies on notice that, beginning with their FY 1999 budget requests, they would have to project for the Congress what they intended to accomplish in the next year, in concrete and measurable terms, and be held accountable for those results. The ramifications of this legislation for the pervasive culture of the Federal bureaucracy can not be overestimated.

First, for 30 years both the existence and the funding, of numerous Federal agencies have been the principal means by which the Congress and the White House have attempted to demonstrate to their various constituencies that they would make good on their campaign promises. Create an agency, increase its budget — constituencies would accept those "inputs" as proof that something would be done. Whether something was actually done — whether cancer got cured, poverty eradicated, schools got better, or the welfare-dependent discovered the joys of work — was and remains very difficult to ascertain, much less to measure.

Secondly, the GPRA put Federal R&D agencies on special notice that they, too, would have to demonstrate returns on the public's investment in research and development. However, unlike the agencies whose mission has been to somehow alter or improve the behavior of millions of Americans, science agencies have had a ready-made ideology, the constant incantation of which might seem to relieve them of the need to measure the returns on Federal funding for research. That ideology, of course, was best captured in Vannevar Bush's 1945 report, *Science — The Endless Frontier.* Bush maintained that science was the bedrock of technological progress and its associated economic returns. Science — at least, basic science — was done largely in university laboratories. Thus the Bush paradigm attracted a powerful constituency that combined the friends of large research universities like M.I.T. with the thousands of individual and institutional beneficiaries of the post-WW II "GI bill" education benefits.

A measure of the power of the higher-education and university research constituencies has been the persistence of the Bush paradigm in our discussions of R&D investment and policy, notwithstanding that it was seriously undermined in the early 196O's and continues to be challenged as an ideology that has outlived its time[2]. Bush's argument rested on two assertions. One was the quintessentially American equation of technology with wealth and happiness. The other was the view, traceable to antiquity, that those who work with their minds operate at a higher level than those who work with their hands. The modern variant of this view is that *basic* science is the font of technological progress. The first of these two assertions took an almost fatal beating from the human catastrophe that was the bombing of Hiroshima and Nagasaki. The second assertion was also seriously challenged when the economist Jacob Schmookler tried to identify the inspiration behind 934 "important inventions" made during the period 1800-1957. Schmookler found that:

> In the majority of cases, no stimulus to the invention was identified. But in a significant minority of cases, the stimulus is identified, and for almost all of these that stimulus is a technical problem or opportunity conceived by the inventor largely in economic terms.... When the inventions themselves are examined in their historical context, in most instances either the inventions contain no identifiable scientific component, or the science that they embody is at least twenty years old.[3]

Schmookler was by no means alone with his finding. Indeed, there was no shortage during the 1960's and 1970's of studies questioning the necessity of basic research to technological progress as a general rule, including studies sponsored by such "mainstream" research organizations as the National Science Foundation and the Department of Defense.[4] The emergence of the History of Technology as an independent discipline during the 1960's gave eloquent testimony to the growing body of research demonstrating that, while basic science sometimes contributed intellectual content to new technologies, that content

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[1] Dr. Sylvia D. Kraemer is Director of Special Studies Office of Policy and Plans NASA.

[2] See, for example, Daniel Sarewitz, *Frontiers of Illusion: Science, Technology, and the Politics of Progress* (Philadelphia, PA: Temple University Press, 1996).

[3] Schmookler selected his 934 inventions on the basis of their descriptions in technical and trade journals and technological and economic histories. Jacob Schmookler, *Invention and Economic Growth* (Cambridge, MA: Harvard University Press, 1966), pp. 31-32.

[4] These studies deemphasized the importance of scientific research when compared to markets, business and research management, financial incentives, communication, and simple chance. See, for examples, Richard R. Nelson, 'The Economics of Invention: A Survey of the Literature', *The Journal of Business,* Vol. 32, No. 2 (April 1959), 101-27; Chalmers W. Sherwin and Raymond S. Isenson, 'Project Hindsight: A Defense Department Study of the Utility of Research', *Science,* Vol. 156 (23 June 1967), 1571-77; James M. Utterback, 'Innovation in Industry and the Diffusion of Technology', *Science*, Vol. 183 (15 February 1974), 620-26; Illinois Institute of Technology Research Institute, *Technology in Retrospect and Critical Events in Science,* Report to the National Science Foundation (Chicago: Illinois Institute of Technology Research Institute, 1968); John Walsh, 'Scientific Opportunities Syndrome: Invoking the British Experience', *Science*, Vol. 190 (24 October 1975), 364-66; and Alan G. Mencher and Michael Beesley, 'Lessons for American Policymakers From the British Labour Government's 1964-1970 Experience in Applying Technology to Economic Objectives', reprinted in the *Congressional Record* (6 November 1975), 35428-30.

was not necessarily essential to the emergence and success of new technology. Put another way, a profitable investment portfolio for technological innovation could contain many things besides basic research performed on university campuses.

However, the question of public support for basic research continues, especially in a world of shrinking Federal budgets. And the issue continues typically to be focused more on "how much" support (as in dollars and percentages) should we give, rather than how most effectively can we give it? Which brings us to the importance of the work being done by Francis Narin and CHI Research, Inc.

As constituencies of Federal science agencies struggle to come to grips with the requirements of "The Results Act", it becomes apparent how dependent the discussion about the importance of basic science to technology has been on anecdotal evidence. Comprehensive, systematically collected and objectively verifiable data describing productivity in government research and invention is limited, to the best of my knowledge, to patent data and the Science Citation Index (SCI). Making sense of this data requires painstaking work, and, before the availability of fast computers, was practically impossible. Thus, we owe a large debt to Dr. Narin and his colleagues at CHI, Inc. Anyone purporting to comment on the productivity of research or innovation in the United States must now be familiar with their detailed analyses of massive amounts of patent and citation data.

To appreciate the magnitude of this task, keep in mind that between 1976 and 1996 the number of patents issued by the U.S. Patent and Trademark Office (USPTO) to U.S. entities *alone, annually,* increased steadily from 37 thousand to 55 thousand. (One should note that these figures represented only between 41% and 45% of all patents issued by the USPTO annually.) During 1989-1996, the period examined by Narin, the USPTO issued well over 750,000 patents in all.

All of these patents have references to other patents ("prior art") and to research papers which are typically supplied by patent applicants, patent attorneys, and patent examiners. Narin has examined more than 750,000 [sic] of the "non-patent" references appearing on the front pages of these patents, determining that about 55% of these non-patent references were to science journal papers, scientific meetings, and other science publications. About 75% of *these* references were to papers published in the SCI's roughly 4,000 journals, and about 75% of these citations were "complete and accurate enough to match to the cited paper."

Thus 41% of the non-patent references[5] are to papers appearing in the SCI. Or, roughly 41% of U.S. patents issued during 1989-1996 cite at least one SCI science reference. On the basis of these citations Narin concludes that there is a significant "linkage" between science and patented inventions, and the heart of his paper describes the salient characteristics of these linkages. From this Narin makes a courageous leap to the conclusion that these linkages are "indicative of a rapidly increasing dependence of patented technology upon contemporary science".

This conclusion, however, is premature. To begin with, "dependence" is a powerful causal statement, and statistical linkages tell us only about numerical correlations, not causal relationships among the items being enumerated. Such statements require an understanding of the dynamics, or underlying processes, that the relationships share. Because analyses of patent and citation data can play such an important role in our ability to understand the processes of invention, we should fully exploit this data to help us arrive at more persuasive generalizations about the causal relationships between invention and its many sources — sources that include economic incentive, exposure to a rich environment of informed and creative discussion, ample resources and facilities, and so on.

A good place to start might be with the other references — those references to other patents and "prior art". Let's agree, for the time being, that a citation "linkage" on the face of a patent constitutes a declaration of dependence (so to speak). If the 750,000 non-patent references in patents issued 1989-1996 represent only an average of 1.5 non-patent references per patent, while the same number of patents during the same period have an average of 8.5 references to U.S. and foreign patents per patent issued, does this constitute evidence of "significant spillover effects of publicly supported research onto industrial technology?" I think not. However, building on Dr. Narin's demonstration of the usefulness of patent and science citation data, it should prove even more valuable, for our understanding of where inventions come from, to analyze the much larger number of patent references per patent.

Secondly, I am certainly not the first — nor will I be the last — to point out that neither patents nor science citations have uniform value. Twice the number of patents does not give us twice the number of useful or commercially profitable inventions. Twice the number of science citations does not give us a twofold increase in our understanding of a natural phenomenon. At the very most, numbers of patents, numbers of citations, and numbers of references, give us indicators of productivity. And thus all of us who collect and manipulate patent and similar data need to be extremely cautious about the kinds of generalizations we draw from our scrutiny of that data.

Finally, while there are limits to what we can learn by counting patents, science citations, and patent references, they can serve as extremely useful "markers" to help us design qualitative inquiries into the nature of innovation and the dissemination of

[5] Or, 750,000 x 55% = 412,500 x 75% = 309,375, or 41% of 750,000.

scientific understanding. For example, an analysis of the patent classes to which NASA's 2,385 patents were assigned during 1976-96 reveals a much greater heterogeneity of invention than most of us, I think, would expect. Of those 2,385 patents, only 132 were assigned to "Aeronautics". If we ask, in what patent classes was NASA assigned three or more patents, we find that three or more NASA patents were assigned to as many as 58 different patent classes. Our own clustering of those same patents into technology application clusters (rather than industry product clusters) shows a broad distribution of invention in NASA across many diverse technologies, from mechanical devices to biology and human medicine, as well as from electrical, light, and nuclear energy to motors pumps and engines. The largest such cluster consists of five patent classes in the general area of measuring and testing devices, to which 282 NASA patents were assigned.

Because patent data gives us a comprehensive catalogue of inventions — comparable, let's say, to a telephone book — we can do reasonably reliable sampling. Randomly sampled patented inventions are a mountain full of precious metals waiting to be mined. Studies of randomly sampled (rather than anecdotally sampled) cases of patented inventions will enable us to form reliable generalizations about who invents, under what circumstances, with what results. Combined with licensing and commercialization information, we may begin to understand, with much greater certainty than before, where the greatest potential for R&D investment return lies waiting, whether we are investing 401(k) plans, our firm's capital, or the Federal budget. My guess is that we will find an ancient truism to be true: We will want to carry our eggs in several baskets, of which fundamental science will be only one.

A Quality-adjusted Cost Index for Estimating Future Consumer Surplus from Innovation: A Case Study for the Advanced Technology Program

by David Austin and Molly Macauley[1]

Introduction

This paper describes a method for estimating future consumer surplus from planned new product innovations. Such a capability is attractive to policy-makers and government agencies involved in supporting technology research and development (R&D), both in the private and public sectors.[2] We have used an earlier version of this model to estimate taxpayer benefits from a program to develop new technologies for space science,[3] and are deploying a newer version of the model in a study of digital data storage technologies supported by the Advanced Technology Program (ATP) of the Department of Commerce. For ATP, and other programs that invest in R&D, identifying consumer benefits from these taxpayer-supported investments is a natural way to account for an important element of their performance.

The Advanced Technology Program seeks to generate benefits from innovations enabling new medical, communications, computing, and other services, as well as from the improved price-performance characteristics of those innovations for existing services. It is the benefits for existing services that are the focus of our analysis. The new technologies are claimed to have leapfrogged beyond current best practice. Therefore we assess their benefits with respect to a baseline of existing, state-of-the-art technologies that are themselves continually being improved. We express our findings in terms of the economic value to consumers of resulting quality improvements, compared to advances that would have been expected to occur in the absence of the program.

Our focus on input performance will not capture all of the potential consumer benefits from government-sponsored R&D. These include new services enabled by ATP's advanced technology investments, which are an important motivating factor in the creation of that program. ATP investments will also create unmeasured private benefits, appropriated by the innovator or enjoyed by other firms in the form of knowledge spillovers. The public benefit from the new services is potentially enormous, and may result in increases in demand for the new technologies compared to existing ones. Prospective estimation of this benefit is problematic, however. More so than for improvements in price and input performance, forecasting the growth in demand due to quality improvements in the *outputs* (e.g., true video-on-demand, or virtual real-estate touring) is fraught with uncertainty. Measuring benefits of new services calls for predictions of the market's response to the new products, and the analyst is not always on very firm ground in doing this.[4]

All types of benefits, public and private, are of equal importance from an economic efficiency perspective. However, it may be sufficient to assess public benefits, just from improvements in the delivery of existing services.[5] These benefits are an important goal of ATP, and may suffice to demonstrate favorable agency performance. In fact, were its investments to yield only private benefits ATP would not succeed in producing market spillovers.[6] To account fully for *net* benefits, the development and opportunity costs of achieving the benefits should also be accounted for. Full cost estimates would be problematic if the technology has already undergone significant initial development before ATP got involved. In any case, cost estimation goes beyond the scope of this study. Our analysis provides a rigorous and defensible estimate of one important type of likely future benefits, those accruing directly to consumers in the form of increased service at lower cost.

This approach requires, along with forecasts of demand changes resulting from quality changes, estimates of shadow values, or consumer willingness to pay for those quality changes. We use hedonic econometric techniques to estimate values for improvements in the most important of a technology's "generic" performance dimensions. By way of example, for ATP's digital

[1] Dr. Molly K. Macauley is a Senior Fellow at Resources for the Future. Dr. David H. Austin is a Fellow in the Quality of the Environment Division, Resources for the Future.

[2] This method supports much of what the Government Performance and Results Act (GPRA) requires of government agencies.

[3] The primary "consumers" of space science is actually space scientists, rather than ordinary taxpayers. Since NASA's agency ultimate responsibility is to taxpayers, however, the distinction is only apparent. The point is these are benefits enjoyed by *users* rather than producers of a technology.

[4] By contrast, forecasting demand for new pharmaceuticals, for example, can be simply a matter of knowing the size of the population affected by the condition addressed by the new drug.

[5] This formulation is intended to include even many new technologies sponsored by ATP. In the archetypical example of ATP's flat-panel display project, new display screens would be coupled with existing computing services, for example.

[6] It may produce knowledge spillovers, benefits enjoyed by other innovating firms.

data storage program, we estimate the shadow values of the new tape units' improved storage capacity, data rate, and file access time. Hedonics involves explaining changes in price by examining changes in performance capabilities over time. Consumers' implicit willingness to pay for these quality changes are estimated as the relationship between each quality dimension and the product's market price.

As already noted, our approach is only to measure returns from individual projects, exclusive of R&D costs, although these could be accounted for with some extensions to the model. A full accounting of ATP's performance would, in addition to taking such costs into account, examine its record over a portfolio of investments. Because returns are an *ex post* measure, a finding of negative expected consumer surplus would not necessarily indicate unsatisfactory agency performance. All investments have, *ex ante,* a risk of failure or of under-performance. Indeed, a number of ATP investments have failed to reach fruition. It is only in the context of the collective returns to the program, and the market spillovers it has created, that the investment program can be judged.

In future research, we plan to extend our model to accommodate a portfolio approach to R&D investment. With slight modifications, our approach can be adapted for use in planning private R&D investment strategies as well. At the planning stage, this model can be used to assess the potential of proposed R&D investments before committing to them.

Background

We employ a cost-index approach pioneered in Bresnahan (1986). Bresnahan estimated the consumer surplus from advances in general purpose, mainframe computers between 1958 and 1972. He demonstrated the applicability of a cost-index approach (Caves, *et al.* 1982) to measuring consumer surplus using changes in quality-adjusted prices of new technologies. Under certain key assumptions this approach permits the estimation of the relevant area under the demand curve for the new technology, without having to estimate the demand curve by itself. This obviates the need for econometric estimation and, in particular, makes it possible to perform the estimation in sectors for which output quantity and quality-adjusted output price are unobservable. As Bresnahan (1986) and Griliches (1979) point out, this unobservability tends to characterize sectors in which the benefits from important technological advances have been realized.[7]

The ability of the cost-index approach to return an estimate of consumer surplus depends on the structure of the downstream market in which the technology is applied.[8] Demand for the kinds of new technologies sponsored by ATP typically has been mediated by producers using the innovations in their production processes. It is this *derived* demand, in the satisfaction of demand for output services, that is the focus of the cost-index method.[9] As long as the downstream market is competitive, or is a government agency such as NASA or the Department of Defence, then the producer acts as an agent for consumers when it uses an upstream technology. This agency aligns the producer's profit maximization with consumer's expenditure minimization, which renders the area under the derived-demand curve, calculated by the cost-index method, a measure of consumer surplus.

If the using market is concentrated, the index would measure what is being maximized by the producer, *i.e.,* profit, rather than total (producer and consumer) surplus. When downstream producers have market power, the derived demand curve for the innovation is shifted inward relative to the competitive case. This is not a difficulty with the method, since the appropriate quantity to measure would be this consumer surplus *given* the producer's market power. Rather, as Bresnahan (1986, p. 745) shows, in a concentrated market, integration of the area under the demand curve, which the index approach is implicitly doing, yields a measure that understates total surplus by some positive amount. Heuristically, since even monopoly producers typically cannot appropriate all consumer surplus, the resulting measure of profit undercounts total benefits.[10]

Bresnahan applied this methodology to the financial services sector (FSS), one of the leading users of mainframe computers at that time. The final output, financial services, is not observable in terms of quantity and quality-adjusted price. That the FSS could be treated as highly competitive allowed it to be treated as an agent for the end consumer, particularly with respect to the purchase of computers. The derived demand for computers, as an intermediate good in the provision of financial services, is mediated through final demand for those services. The market for financial services was, at that time, a competitive

[7] These are, as Bresnahan (1986) notes, "the downstream sectors—such as services, government, health care, etc.—[which] lack sensible measures of real output." This is a particular problem for measuring digital data storage benefits of the high-end, high-capacity tape "library" systems that are our focus, and where the using sectors tend to produce outputs with unobservable quality.

[8] The other "key assumption" necessary for this method's accuracy is that the price index is correct. No index perfectly satisfies all of the tenets of demand theory or conforms to all of the desirable properties of index numbers, such as transitivity, scaleability, and so forth. The index selected by Bresnahan and used in this paper satisfies most of the more important properties. See Diewert and Nakamura (1993).

[9] The notion is that the innovation is an intermediate good, and the services it provides (refrigeration, space science, data storage) are the final good. Demand for the innovation is derived from the demand for final goods.

[10] Note we—and Bresnahan—make no assumptions about potential gains from a competitive market structure in the *innovating* sector. The cost index approach measures only the expected *actual* gains.

one, which allows Bresnahan to treat the derived demand as if it was generated directly by consumers of those services. Therefore the area under the derived demand curve provides a measure of consumer surplus from the development of these computers.

Bresnahan's approach was *retrospective:* he applied his model to past innovations. Our contribution is to apply this methodology *prospectively*, to innovations that have not yet reached the market. We developed our approach in our prior research on space technologies—propulsion, communication, solar energy, imaging, and navigation systems—selected for trial and flight validation under the auspices of NASA's New Millennium Program (NMP). NASA is both the consumer of these technologies—literally, and as agent for the taxpaying public—and the producer of the downstream product, space science. The downstream market in this case provides a public good, and the consumer "agency" requirement is satisfied, not by a competitive market structure but literally by NASA's being a government agency.

The technologies of the NMP are scheduled for imminent launch on the first mission of the program, Deep Space I, set for October 1998. As such, their performance and quality-adjusted prices are already fairly well understood and provide a reasonable basis on which to predict likely values and uncertainties for several years out beyond their initial use. The ATP technologies are not as far along, so our evaluation involves predicting consumer surplus *on the basis of what we currently know* about these technologies.

Our data comprise the stated expectations of engineers, product managers, technologists, and other persons familiar with the innovation. For each technology we elicit their beliefs concerning the most likely values of current and near-future "off-the-shelf" prices,[11] performance—in each of several dimensions, the size of the market, and the rate of market acceptance. Our analysis compares these data against the same attributes of the best and most comparable of existing technologies. The change in consumer well-being resulting from each innovation is captured by a Törnqvist cost index that estimates consumers' hypothetical willingness to pay for them in a "counterfactual" world in which they were not invented.

We do not attempt a comprehensive accounting of consumer surplus in all markets in which the technology is to be used. Bresnahan focused on the major downstream market for mainframe computers, and our purpose is to identify the most important market or markets for our technologies. In this way we will capture a representative, if not dominating, portion of total consumer spillover, while avoiding details about the technologies' penetration in minor markets.

Because our data consist of expectations about the future, our explicitly incorporating uncertainty, and making specific parametric assumptions, is a critical distinguishing feature of this analysis. Bresnahan used single-point values for expenditure shares and costs. Although those numbers are no doubt approximations and probably reflect some accounting error, his data do not support an analysis of uncertainty beyond a sensitivity analysis over a pair of divergent, quality-adjusted computer price indices. In this way Bresnahan bounds the estimates. By contrast, since our technologies have no record of performance at all, we are obtaining from our subjects both their point estimates of expected values and their associated uncertainties. We can therefore express these data in probabilistic terms and implement the cost-index calculation in a decision-modelling framework. In this setting, analysis of the relative influence of each input, and of the joint implications of the many assumptions that inform the experts' forecasts, is straightforward.

The result is a flexible model which simulates the empirical probability density of consumer surplus outcomes implied by the input uncertainties. The structure of the model eases the tasks of isolating the inputs that most drive the uncertainty in the results, and analyzing the sensitivity of mean output values to fluctuations in the values of the inputs. As noted earlier, because it combines uncertainties and expected values across a range of performance attributes and adoption rates, this modelling framework may prove particularly valuable to R&D planners, public and private, whose analytical methods have to now been more piecemeal.[12]

The chief contribution of this prospective cost index approach is it examines in a proper context the implications of assumptions—about costs, performance, price, and sales—that are made in planning an R&D project. To be sure, some type of projection of expected returns is a commonplace among innovators. Within this unified framework, however, point estimates and uncertainties can all be modelled simultaneously, and compared to expectations about best-available technologies. The result is a flexible, experimental platform upon which can be conducted "what if" sensitivity analyses that can provide a fuller picture of the likelihood of different levels of success or failure, in a way the conventional one-dimensional analyses are likely to miss.

[11] As already noted, these do not include development costs. Many of the space technologies, and presumably the ATP technologies as well, have been under development in one form or another for many years, and a full accounting of their development costs over the years probably would be impossible to achieve.

[12] In our analysis we perform, for each model input, a sensitivity analysis—the effects of changing input levels on mean consumer surplus. We also carry out an *importance* analysis for each input, or the effect of input uncertainty on uncertainty in the estimate of consumer surplus.

Model

The cost index indicates how much more expensive an equivalent level of services would have been in the absence of the new technology.[13] We use the index to compare utility in the *expected* world of data services employing ATP innovations and a "defender-technology" (DT) world using best-available, non-ATP technologies. For instance, we compare a high-capacity, high-density LINEAR SCAN tape library to a currently-available line of helical-scan-based technologies with lower-densities. The performance of the ATP technologies is intended to leapfrog conventional technology capabilities. We assume innovation continues over time in both technologies, but that DT innovations come at a slower pace because the technologies have been available for awhile.

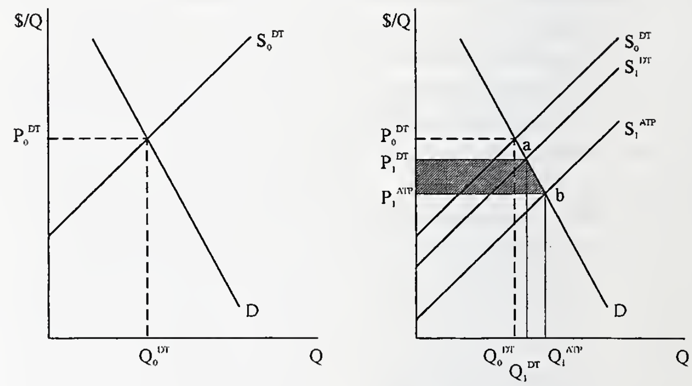
The cost index, multiplied by the share of total expenditures devoted to the technology, gives the consumer surplus, in dollars, resulting from the outward shift in the technology supply curve. This shift represents increases in output that can be supplied at a given price, because the technology has reduced costs. The defender technology's supply curve will also shift outward over time. As long as the initial shift in the ATP technology's supply curve is larger than that of the DT curve, the cost index will be greater than unity. Ignoring the cost of the R&D, the measured consumer surplus would indicate how much better off taxpayers are than in the absence of ATP. Where the shift in the DT supply curve is greater, the index will be less than one and consumers will be worse off than if the ATP technology had not been adopted.

Figure 1 illustrates the consumer surplus from the ATP innovation, or consumers' willingness to pay to move from the defender technology to the expected innovation. The shift in the ATP-technology supply curve can be due to a combination of cost reductions and quality improvements. The purpose of a quality-adjusted cost index is to account for both.

Cost Index Formula

Following Bresnahan, we use the Törnqvist cost index presented in Caves *et al.* (1982). This index is the arithmetic mean of two monetized measures of change in consumer utility. These measures, a pair of Könus cost indices, are ratios of "minimum

Figure 1. Derived Demand for New Technologies: Illustration of Net Surplus Change.



Since NASA serves the space science community as well as the public, an index of the "cost of providing space science and of making propulsion systems" is relevant.

expenditure functions" for achieving two given levels of consumer utility. For consumers facing quality-adjusted prices W^I or W^{dt} for the technology inputs[14] to production in the adopting sector (e.g., tape backup as an input to provision of information services), and aggregate prices $P^{\cdot}$ for everything else in their consumption bundle, C^{*dt} in the expression below is the relative cost of achieving utility u^{dt} in the non-ATP world, compared to its cost given I, the ATP innovation. Similarly, C^{*I} gives the relative cost of achieving utility u^I given ATP innovation I rather than the DT:

$$C^{*dt} = \frac{E^*(u^{dt}, p^{dt}, W^{dt})}{E^*(u^{dt}, p^I, W^I)} \text{ and } C^{*I} = \frac{E^*(u^I, p^{dt}, W^{dt})}{E^*(u^I, p^I, W^I)}.$$

Utility u^{dt} and u^I are the best an optimizing consumer will achieve given, respectively, DT or ATP technology. Quality adjustments to prices W are expressed relative to baseline quality for the defender technology. Prices P are assumed to be the same under both regimes, which simplifies the problem considerably.[15]

Economists term C^{*dt} consumers' *compensating variation*, the relative income required to keep consumer utility constant following a change in price. After a change in W, C^{*dt} is the relative gain or loss in income that would just compensate consumers so they are indifferent between DT and the I innovation.

[13] Bresnahan calculates a "cost of living and of providing financial services" index, based on computer expenditures for financial services as a share of the total personal consumption expenditures (PCE). If quality-adjustments and expenditures on digital data storage are too small a share of PCE, we would base the cost index on expenditures as a share of sector expenditures only. We do this for the space technologies to distinguish the cost index from unity. Since NASA serves the space science community as well as the public, an index of the "cost of providing space science and of making propulsion systems" is relevant.

[14] Expenditure functions normally take output prices and utility levels as their arguments. The assumption of perfect competition or agency allows substitution of input prices for output prices.

[15] Only the very weak assumption that substitution of I for dt does not affect general price levels is required.

Similarly, C^{*I} is called the *equivalent variation*, the amount DT consumers would be willing to pay, in terms of relative income, to achieve the optimum utility levels available in an ATP world. Both C^{*dt} and C^{*I} will be less than unity if the ATP innovation is inferior, on a quality-adjusted price basis, to what will be available at the same time from the DT technology. The indices will be greater than one if the ATP technology is superior.

As measures of consumer surplus, both C^{*I} and C^{*dt} have advantages and disadvantages, and neither is ideal for all applications.[16] The Törnqvist index is a composite measure that gives each equal weight, by averaging the two in logarithms. As is well known from the theory of index numbers, no single index satisfies all "desirable" properties or tests (e.g., tests related to scalability, transitivity, symmetry, proportionality). The Törnqvist index satisfies many of the tests (see Diewert and Nakamura, 1993).

We assume, following Caves, *et al.* and Bresnahan, that consumer expenditures E^* can be represented by a translog functional form.[17] In this case the Törnqvist index simplifies to:

$$\frac{1}{2}\ln\left(C^{*dt} \times C^{*I}\right) = \left(\frac{1}{2}(s_{dt} + s_I)\cdot \ln\left(\frac{W_{dt}}{W_I}\right)\right) \quad .(1)$$

The $s\cdot$ denote factor expenditure shares for the defender technology *dt* or innovation *I*, as a fraction of total expenditures in some appropriate setting. For NMP, we used the U.S. space science budget as our denominator, for reasons already described. Beyond swapping observable input price and quality for unobservable output price and quantity, an additional advantage of this approach is that, because the two "time periods" are contemporaneous, prices and expenditure shares for "other" goods, and quality-adjusted prices for other inputs in the adopting sector, are unchanging and cancel out of the equation.

Changes in relative prices can lead to changes in the mix of input factors in production of final output, and in the demand for that final output. Bresnahan points out that the translog functional form places no restrictions on elasticities of substitution between the new technology and other factors, or on the income or price elasticities of demand for the final good. Moreover, the translog allows for arbitrary shifts in demand, say, (in the case of space exploration) due to technical progress in unrelated computer technologies, or from taste-driven changes, not attributable to ATP, in the budget for computer technologies, as long as demand elasticities are unaffected.[18] We do not believe this latter difficulty impinges on our analysis of ATP case studies in the near term. We restrict our attention to the short- to medium-term future of 5-8 years. To the extent this issue is a concern, later years should be increasingly discounted.

The cost index describes how much higher (or possibly lower) costs would have been in the absence of the innovation. For any relative price W_{dt}/W_I the index will be closer to unity the smaller the share of the total budget (or of total private consumption expenditures) is spent on the technology. The index for an innovation that offers only small savings over the defender technology, but which is a significant share of total expenditure, would be larger.

Inputs and Output

The inputs to the model include the elements of our cost indices, as well as expectations about changes in these elements over time, and the adoption rates of the new technologies. We assume these change over time in a way that tends to increase consumer surplus. We incorporate expectations about learning-by-doing and returns to further R&D that tend to favor the new innovation over the existing defender technology, which we treat as already having benefited from lower-cost improvements. We also project the adoption of the new technology over the existing DT as a monotonically increasing function of time. Finally, we discount future price expectations to present-value terms, which favors neither technology in particular. Expected benefits reflect off-the-shelf prices (and quality adjustments) but not the cost of the R&D, and the shape of the final density function is determined by our assumptions about the uncertainties in the model.

Simulating the model a large number of times forms an empirical density function, which is the output of the model. This probability density function for consumer surplus receives contributions from each of the uncertain inputs, which all have their own specified probability densities. In each iteration of the model, we sample independently from each input distribution, and combine the values according to the cost-index expression (1). The final density function comprises the outcomes of the individual simulations.

Market Size and Expenditure Share

In the application of our model to the ATP case studies, the expenditure shares $s_{\cdot}$ in the cost index formula refer to the total outlay on digital data storage devices *by sectors using those de-*

[16] See Varian (1992) for details.

[17] The translog, aside from having desirable properties exploited by this procedure, is a flexible functional form, able to approximate well many production and expenditure functions.

[18] This paragraph paraphrases remarks in Bresnahan (1986) p. 751.

vices to produce final outputs. To calculate these numbers it is necessary to know both the expected sales, in dollars, of digital data storage devices—for the defender and the innovator; and the size of the downstream industry buying the devices. In Bresnahan's application, he further divides the technology expenditure share by the fraction of total private consumption expenditures (PCE) spent on financial services. This step is not strictly necessary, and will be troublesome for small expenditure shares.[19] Carrying out that division produces a "cost of living and of making computers" index in the Bresnahan paper, where the financial services sector is treated as buying computers "for" consumers under the assumption that price-cost margins had been competed away in financial services.

In the case of digital data storage, the "using" sector is the information services sector. Digital data storage devices are purchased to produce data back-up services, as part of a larger set of computer network services. Since this sector is also relatively competitive, it is possible to employ Bresnahan's device of treating the information sector as purchasing digital data storage devices, and providing information services, "for" consumers. In other words, because market-power distortions may be small in this sector, it is fair to think of firms acting as "agents" for consumers, as Bresnahan assumes in his paper. Were this assumption to be faulty, the result would be an *under*statement of potential consumer surplus.

Because of this agency, one can speak of consumers' "cost of living and of making digital data storage devices" (COLAMDDSD). This is the result of a calculation where the share of expenditures on digital data storage devices in the information services sector is itself divided by the share of PCE spent on information services. If the share of PCE expenditures on information services is too small, or digital data storage expenditures as a share of the information services sector, the expenditure shares s_i will be dominated by rounding error.[20] In this case it is reasonable to calculate a "cost of providing information services and of making digital data storage devices" index. This differs from the COLAMDDSD index in that the shares have not been divided through by PCE. The result will be an index that is farther from unity, and which in conversion to dollars is to be applied to information services expenditures rather than PCE.

Dynamic Trends in Prices and Adoption of New Technology

All of the adjustments and uncertainties we have presented take place in a dynamic setting. The information we have sought from the technology experts concerns the expected timing and characteristics of the new technology as it is expected to be when initially introduced. However, we are also concerned with rates of change in expected values, over the following several years. Past experience shows technology prices, for a given level of quality, decline rather markedly. At the same time, the further into the future a forecast is made, the more uncertainty there must be about all values.

We institute these dynamic elements into the model by putting time trends on some of the parameter values in the model. We expect prices to decline over time both for the innovation and for the DT. We also expect that, wherever the innovation offers positive consumer surplus, the DT will gradually lose market share as the new technology is increasingly adopted.

It is natural to assume prices for the new technology will initially decline more rapidly than for the DT, because of learning-by-doing effects. In the relatively near term for which we conduct our analysis, we assume linear price declines. This is a conservative assumption, especially with respect to the innovation. We will report sensitivities to the unequal price declines, but because we assume the differences will be small, we do not expect this parameter to affect the results very much.

We assume a variety of formulae for the adoption rate. We work with the family of Weibull distributions, which have a characteristic 'S' shape. Figures 3 and 4 depict two possible adoption rates. The flatter curve, figure 3, depicting a more protracted period of adoption, is the more conservative assumption. We can choose between faster and slower adoptions on the basis of quality-adjusted price differences. We perform sensitivity analyses on these functions.

Uncertainty

Our approach to modelling uncertainties is based on the concept of "subjective probabilities." This "Bayesian" approach rejects the notion that probability necessarily derives from frequencies that would be realized from idealized "infinite sequences" of repeated outcomes. For repeatable events the contrasting "frequentist" approach is serviceable: in this view the 50% odds of "heads" from an unbiased coin-flip is based on the expected outcome of an idealized, infinite sequence of coin tosses. However, such formulations are not well suited to non-repeatable events, such as probable future costs or adoption rates. In our model, for instance, cost uncertainty stems more from what is not known about the technology than from randomness in the data-generating process of some idealized, repeated innovation experiment from which actual costs will be just one draw.[21]

[19] Small shares will be dominated by rounding error.

[20] In the extreme, expenditures on digital data storage devices would represent a zero share of PCE and the COLAMDDSD index would equal unity.

[21] This is a subtle but important distinction. Some of the uncertainty in expert opinion does arise from randomness in real manufacturing costs over time.

For space technologies, our probability distribution of likely off-the-shelf costs blends the subjective beliefs of technology experts with our own beliefs about the likely biases of these experts. For ATP, the uncertainty is less over expected market price than it is over the timing and performance of the innovation. In both cases, rather than taking engineers' guesses at face value, we assume that they are over-optimistic.[22] From scientists and managers familiar with the technologies, we have solicited opinions about the "most likely" outcomes, as well as about the full range of possible expected values, based on perceptions of uncertainties and past outcomes. We use the high and low points from this range to formulate the expert's prior cost distribution.[23]

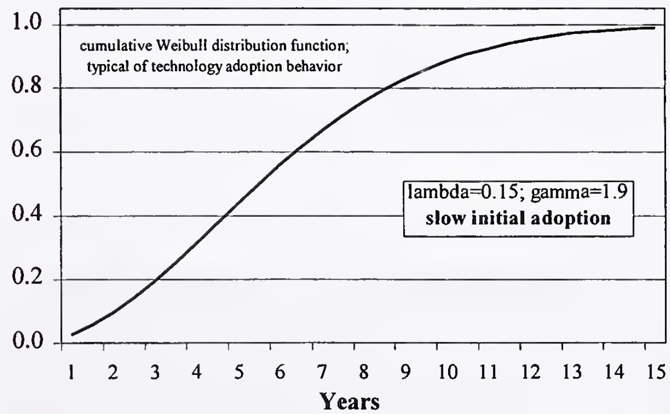
To properly answer questions about uncertainties, the experts must have in mind their own personal subjective probability distribution from which their expectations are drawn. Our interview is structured to elicit this type of information. We operationalize our assumption about optimism by embedding the expert expectations in a probability distribution that is skewed to the left (in other words, having a long right-hand tail). We assume that the actual costs will be distributed asymmetrically about their expected mean value, with a greater than 50% chance that costs will exceed expectations. This assumption is based on a study indicating that *ex ante* cost expectations for "pioneer projects" are biased downwards (Quirk and Terasawa, 1986). In other words, expectations on costs for new technologies tend to be overly optimistic.

Specifically, we take the experts' mean expectation, *plus 50% of the experts' uncertainty parameter,* and locate this at the median of a lognormal distribution function.[24] In practice, this tends to place the expert mean around the 30th percentile of the lognormal, with the actual location depending, by construction, on the amount of expressed uncertainty. The greater the *ex ante* uncertainty, the lower is the percentile which the expert's expectation will occupy in the density function.

This approach identifies only one of the two parameters of the lognormal family of distributions, the median. We select the other parameter, the geometric standard deviation, by assuming a value of 1.5. This value is chosen arbitrarily to achieve the skewed shape we wish to impose. A value close to 1.0 produces a symmetric distribution, while values much larger than 1.5 produce unrealistically high estimates. We subject this parameter to sensitivity analysis.

Figure 2, below, contrasts this type of distribution function with the one we employ for experts' forecasts concerning the defender technology. For the DT, experience and direct observation inform the responses. Since we are asking about expected *future* costs, we still are implicitly seeking information from their subjective prior probability distributions.[25]

Figure 2. Simulated Adoption Rate



The production-cost literature offers little guidance on the form our prior probability density functions should take. We use the lognormal family to model "pioneer" project cost overruns because it is skewed in the desired direction, and because these curves have simple parametric representations.

Figure 2 contrasts sample cost density functions for the DT and for the innovation. The "lognormal" density function for the innovation is asymmetric, reflecting greater uncertainty than what is known about the DT, as modelled with the normal density function. If the experts are less over-optimistic than we assume, so that the lognormal distribution is less skewed than we make it, we will underestimate consumer surplus. Given the prospective

[22] We base this on Quirk and Terasawa (1986) about which more follows.

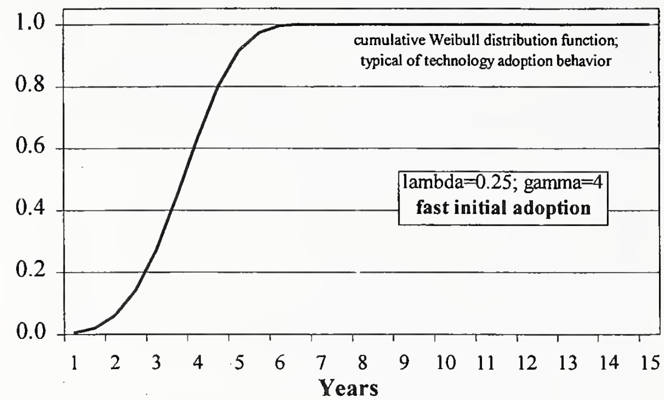
[23] There are better ways to elicit uncertainties, and one must be careful combining expert prior distributions. We address the former concerns with our sensitivity analysis.

[24] The uncertainty parameter is the spread between best and worst expected costs. There is no "best" distribution, and our procedure is *ad hoc.* We also experimented with a less conservative approach which places the experts' means precisely at the 30th percentile of a lognormal, and their "worst case" outcome at the 90th percentile. We find that our estimates of net benefits, and of the uncertainties associated with those benefits, are rather insensitive to our choice of approach, at least among the distributions we have considered.

[25] A technical paraphrase of our approach would be "thinking about the probability distribution of all possible costs for this technology, with your median cost estimate being at the 50th percentile of this distribution, what ("upper bound") cost estimate would be at about the 85th percentile?" In practice, we interpret their upper-bound responses in several ways. We assume normality for DT; for new technologies the interpretation is fundamentally similar—we seek quantiles of the underlying distribution—but we make stronger assumptions about the location and shape of the expectations. We find that our results are reassuringly insensitive to "reasonable" treatment of the responses.

nature of the analysis, though, it is appropriate to make conservative assumptions so as to minimize concerns the findings stem from best-case outcomes.

Figure 3. Simulated Adoption Rate.



Quality Adjustment

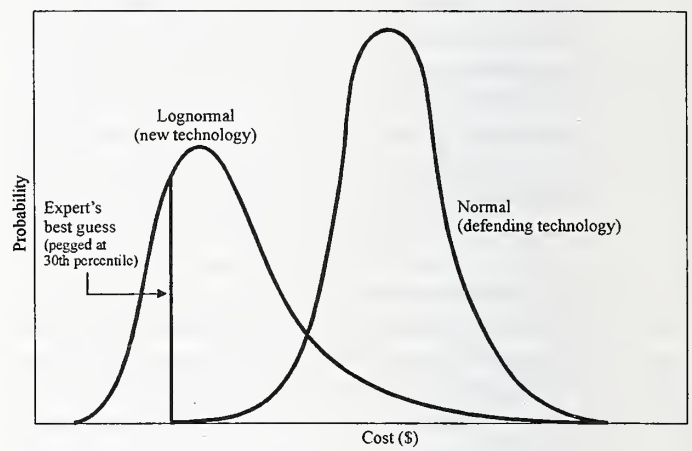
To put expected prices of the DT and new technologies on a strictly comparable footing, we must account for quality differences in the embodying products. For instance, in the case of digital data storage devices, these differences include file access time, data transfer rate, and capacity. These dimensions are not the only potential sources of quality change, but they are widely agreed to be the most important.[26]

Consumers are generally willing to pay more for higher performance, but it is not immediately obvious how *much* more they are willing to pay. To estimate this, we perform a *hedonic* statistical analysis to explain the contribution to market price of each relevant quality characteristic. The outputs of the model, which is fitted to price-performance data on existing technologies, are a set of estimated coefficients—one for each characteristic—that can be interpreted as consumer values. These "shadow prices" represent the average consumer's willingness to pay for incremental increases in the various quality dimensions.

To calculate cost indices, we adjust expected unit prices by netting the estimated values of the expected quality improvements out of the forecast final good price.[27] The result is the quality adjusted W_I (the adjustment of the new technology prices relative to the DT) for the cost index formula. Where the new technologies represent a *substantial* gain over DT, beyond that observed in the data used in the hedonic regression, we subject our estimates to sensitivity analysis.

Finally, new technologies do not necessarily improve in all dimensions. Our model does not preclude a defender technology's having a smaller real unit price W than the real price W_I. Where the new technology is adopted it would, in this case, produce negative consumer surplus relative to that available for the DT. Presumably the market would reject the innovation in this case.

Figure 4. Illustration of Cost Under-Estimation



Summary

By way of summarizing our discussion of the model, we present a series of figures and tables to portray important model elements and outputs. Figure 5 illustrates schematically the relationships between the key model input steps described in this paper. The output of the model, an empirical distribution of estimated consumer surplus over time, is the result of a straightforward calculation carried out in each iteration of the model. It is the product of the cost index times total expenditures, either PCE or in the appropriate sector of the economy. Table 1 displays some of the indices we have estimated for the space technology case studies.[28] Technologies with index values greater than one will increase consumer surplus, while those with index numbers less than one would reduce consumer surplus if adopted. The dollar values for these contributions are given in table 2.

[26] To a person, the technology managers we have interviewed in the digital data storage field agree these are the most important performance dimensions.

[27] These shadow values enter the model as uncertain parameters, using estimated standard errors from the hedonic regressions.

[28] Careful readers may have noted that one must actually exponentiate expression (1) to get cost indices such as given in table 1. The index actually described in the text produces "percent change in surplus" values which are close to zero. One gets virtually the same result by first exponentiating and subtracting 1, which is the correct calculation and is what we actually do. In the body of the paper we focus on "unitary" index numbers for expository reasons.

Figure 5. Model Inputs, Intermediate Calculations

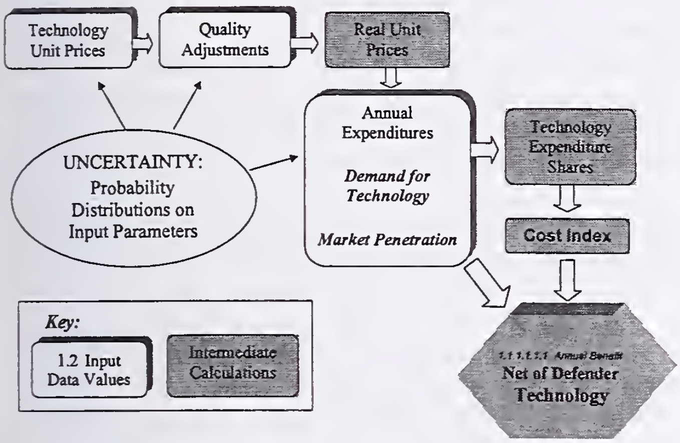
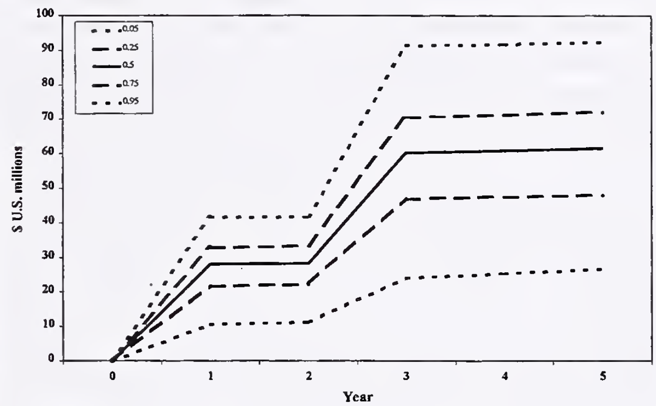


Figure 6. Net Benefit of New Space Technology.



We also estimate a "bottom line", both in that study and for the ATP cases. This is an estimate of total expected surplus over time. In the space study this is expressed as an "effective augmentation" of the public space science budget (since net cost savings on the space technologies can be used elsewhere in the space science program). Figure 8 shows how surplus grows over time. The shape of the curve depends on the rate of "market penetration" (or adoption, for space technologies), and on the budget for space missions requiring either the innovation or the DT. Figure 6 also depicts uncertainty as growing over time, a natural result of the model's parameters. This figure illustrates the way the results for the ATP study will be expressed.

Conclusions and Extensions

Our model provides a sound empirical basis for assessing returns to investment in new technologies. By taking explicit account of alternative technologies and the fact that innovation proceeds apace in *their* development—not just in the new technologies—and by accounting for uncertainties in the timing and quality of innovation, we derive defensible estimates of expected consumer surplus.

Our approach also represents a first formalization of the tendency towards cost-estimation bias in new technologies. We think the explicit treatment of uncertainty and the modelling of defender

Table 1. "Cost-of-Performing-Space-Science-and-of-Producing-New-Technology" Index.

Year	New technology #1	New technology #2
0	1	1
1	1.01335	1
2	1.01271	1
3	1.02638	0.99959
4	1.02674	0.99955
5	1.02709	0.99950

Table 2. Benefit of Using the NMP Technology, Relative to Defending Technology (U.S. dollars)

Year	New technology #1	New technology #2
0	0	0
1	27,040,000	0
2	27,400,000	0
3	58,550,000	-900,500
4	59,360,000	-1,002,000
5	60,140,000	-1,101,000

technologies, together with cost-estimation bias accounting, render our model a very useful tool for government agencies and private firms to use in assessing their funding of new technologies.

We envision several extensions of our model in future research. It can be applied to private sector investments in new technologies, where estimation and valuation of quality improvements can be helpful in predicting the likelihood of a new technology's succeeding in the marketplace. The model can also be adapted to the estimation of *private* returns. With some modification, the model can be used to identify the investment rate and technology selections most likely to yield the highest returns among alternatives. In other words, the model can help designate investment portfolio strategies. Such an extension of the model would include the "drawing board" phase of the innovation process, where agencies and private firms consider optimal investment strategies given competing opportunities for use of the R&D capital.

Another extension we are planning is to consider technologies that generate externalities, such as ones that confer marginal social benefits on top of private benefits (for instance, "environmentally friendly" technologies). For this application, we would include shadow values of social benefits among a technology's "quality" adjustments.

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Socio-economic Effects of Collaborative R&D - European Experiences

by Luke Georghiou[1]

Introduction

Since the early 1980s, governments in Europe, singly or collectively, have been supporting collaborative R&D between firms, also with the participation of universities and other research organizations. The prime rationale for this support has always been to strengthen industrial competitiveness, although other social and policy goals are also cited, notably creation of employment. These collaborative programmes have been subject to intensive scrutiny by a succession of evaluations of all types.

European evaluation practice has been well documented[2] sometimes in a wider context. At a national level there has been considerable diversity driven by differences in the state of scientific development, the organization of science and most importantly from broad practices of governance in the countries concerned.[3] Nonetheless there has also been commonality of experience, driven in part by participation in pan-European evaluations and methodological programmes, and to some degree a calling upon teams from other countries to provide the desired expertise of independence. In this paper the experience of evaluation at a European level is reviewed and in particular the success, or lack of it, in addressing socio-economic effects. After a brief review of the history and composition of Europe's two main instruments for the support of collaborative R&D, the European Commission's Framework Programmes and the inter-governmental EUREKA Initiative, some issues arising from the evaluation of these are considered in turn. After a discussion of the type of outputs and impacts to be expected, the issues of additionality and policy persistence are considered before conclusions are drawn.

Collaborative R&D in Europe and its Evaluation.

Collaborative R&D Programmes

European collaboration in R&D has a long history, originating for the European Communities in the nuclear coal and steel fields and later extending to other areas of science and technology. However, programmes which aimed to promote inter-firm collaboration (as well as the involvement of universities and public research organizations) as an instrument of industrial policy did not emerge until the 1980s. A key development was a 'Round Table' of the then twelve largest European information technology companies which in 1982 produced a proposal for the pilot phase of ESPRIT, the first of a succession of IT support programmes.[4] In parallel there were similar national initiatives such as the United Kingdom's Alvey Programme for Advanced Information Technology. All were justified by the concept of 'pre-competitive research', that is to say shared generic research which would be followed by participants competing in the market. The origins of this rationale were explicitly a response to the perceived success of collaborative projects in Japan, notably the VLSI project.[5] That this perception overestimated the importance of collaboration and underestimated the degree of internal competition in Japan did not matter; pre-competitiveness provided a convenient label to present to the prevailing conservative ideologies in government. Somewhat ironically, one of the most consistent evaluation findings in the ensuing years was that collaboration between direct competitors was relatively rare, except in the field of standards, and that complementarity between the knowledge bases of participants was the driving force for cooperation.

The European Commission proceeded to organize its R&D promotion activities into a more comprehensive multi-annual plan with common objectives, to be called the Framework Programme. This has continued through four iterations with a fifth at an advanced state of preparation. The budget of the Fourth Framework Programme was 13.1 billion ECU. Industrial participants receive up to 50% funding and academic participants 100% of their marginal costs. Framework Programmes have been made up a series of Specific Programmes corresponding to particular objectives or technological areas. They share the overall goal of strengthening the science and technology base of Community industry enabling it to become more competitive at the interna-

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[2] Gibbons M. and Georghiou L., *Evaluation of Research - A Selection of Current Practices*, Paris:OECD, 1987; Meyer-Krahmer F. and Montigny P., Evaluations of innovation programs in selected European countries, *Research Policy 18*(6): pp 313-32, 1989; Ormala E., Nordic experiences of the evaluation of technological research and development, *Research Policy 18* (6) pp.343-59, 1989; CallonM., Larédo P. and Mustar P., *La gestion stratégique de la recherche et de la technologie*, Paris:Economica, 1995, Georghiou L., Issues in the evaluation of innovation and technology policy, *Evaluation Vol.4*, Np.1, January 1998

[3] Georghiou L., Research evaluation in European national science and technology systems, *Research Evaluation Vol.5*, No.1, April 1995

[4] Guzzetti L., *A brief history of European Union research policy*, Commission of the European Communities, October 1995, pp.76-83

[5] Oakley B. and Owen K., *Alvey - Britain's strategic computing initiative*, MIT, 1989

tional level. Since the Treaty on European Union came into force in 1993 the rationale has extended to the promotion of all research actions which further other Community policies. In the Fifth Framework Programme the objectives are evolving further to be expressed in terms of socio-economic problem solving.

The second form of European collaborative R&D addressed in this paper is that supported under the EUREKA Initiative. Though concerned exclusively with civil technologies, this began as a response to the US Strategic Defense Initiative which had prompted fears of a new technology gap opening.[6] EUREKA has been positioned nearer to the market than the Framework Programme and is organized on a bottom-up principle, whereby there are no work plans and industrial participants have wide scope to propose projects. The central mechanisms of EUREKA approve projects for 'labelling' but there is no budget; public funding of participants is left to national governments which may use existing schemes, have a dedicated budget, or if they choose, offer no funding. By 1996 EUREKA has approved over 1200 projects involving 5,600 participating organizations. Public funding in recent years has been of the order of 300-500 million ECU per year, very roughly 20% of project costs. Membership includes several Eastern European countries and Russia.

Evaluation of the Framework Programme

The European Commission's Framework Programmes have provided a focal point of interest for evaluators from their outset, building upon approaches developed in the late 1970s and early 1980s for the evaluation of Community R&D programmes.[7] The Framework Programmes have been evaluated in a variety of different ways, addressing the Framework as a whole, its component programmes (so-called vertical evaluations of Specific Programmes), cross-programme issues (horizontal evaluations) and impacts on individual Member States. Variety has also been experienced in types of evaluator (panels or evaluation experts), client groups (the Commission, Member States or the European Parliament), and in the methods used (principally surveys and interviews with programme managers and participants, but also extending to bibliometrics, network analysis and economic analysis).

In the present era, the system rests principally upon a scheme introduced in 1995 which consists of continuous monitoring, reporting annually, and five-year assessments, carried out midway through programme implementation but including within the frame of analysis the preceding programme. This timing feature has proved the best compromise between the requirement for results in time for decision-making about the successor programme and allowing some time for effects to be manifested. It is self-evident that this is dependent upon continuity from one programme to another and would not work where there are sharp changes of strategy. The system operates for Specific Programmes in parallel and in theory the results are input to an overall evaluation of the Framework Programme. In the first iteration of the five year assessments the Framework Programme level evaluation tended to proceed under its own momentum without close connection to the underpinning exercises. Both monitoring and assessment involve panels of external experts (3-4 in the first case and 6-10 in the second). Monitoring is a relatively light activity aimed at quick course correction, while the assessments take a broader view.

The terms of reference are extensive. For the assessments, criteria cover relevance of objectives, efficiency of operation and effectiveness in terms of objectives achievement, "European added value" and dissemination/exploitation of results. However, in a historical context the present system can be seen as a move away from previous practice of panels taking longer and being supported by a variety of studies designed to cast light on a particular programme, and towards an approach where monitoring and standardised surveys replace much of the data collection previously devolved to panels. The resulting panel reports may contain good ideas but they are based more upon impressions than hard data. Much then depends upon the efficacy of the monitoring system.

Arguments in favour of the current approach rest upon the assumption that the Framework Programme is now a well understood policy instrument from which surprising lessons are unlikely to emerge. In this situation, there could be diminishing returns in the constant repetition of in-depth evaluations. Instead the requirement is for a system which allows consistent measurement and comparison with past performance. There is some evidence that the rise of monitoring approaches is part of a more general trend towards performance indicators as a complement to or even a substitute for in-depth evaluation. The risk is that performance indicators inevitably reflect a particular view of

[6] Peterson J., 'EUREKA: a historical perspective' in Krige J. and Guzzzetti L. (eds) *History of European Scientific and Technological Cooperation*, Firenze 9-11 Novemmber 1995, Commission of the European Communities 1997

[7] For historical analyses of the development of evaluation of the Framework Programme see Georghiou L., Assessing the Framework Programmes - a meta-evaluation, *Evaluation* Vol. 1, No.2, October 1995; Olds B.J., *Technological Eur-phoria? An analysis of European Community science and technology programme evaluation reports*, Rotterdam: Beliedsstudies Technologie Economie, 1992; Guzzetti L., *A Brief History of European Union Research Policy*, Luxembourg: European Commission, October 1995, pp.101-108; and Commission of the European Communities, *Second European Report on Science and Technology Indicators*, Luxembourg: European Commission, pp. 562-585, 1998

the world and may miss developments which do not conform to that perspective. For example publication counts may miss the development of new forms of scientific communication. Developments such as new or extended networks, or tacit knowledge, which are inherently difficult to measure may pass out of the analytical framework. Furthermore, there is the well-known risk that researchers will begin to perform to the indicators rather than to their true objectives, with divergence from the main objectives and a risk of loss of variety in the system.

Looking at both the past and present evaluation arrangements it is clear that success has been mixed. On the positive side the independence of the expert panels has rarely if ever been challenged and their scientific judgements if predictable have not been questionable. Programme management has also been heavily scrutinised, though the main barriers to improvement have often been more fundamental than those responsible for the operation of R&D programmes are able to deal with. The constant lacuna, frequently repeated by the panellists themselves, has been in the ability to engage with the extent of socio-economic effects. There are reasons why a panel-based system is likely to encounter difficulties in this domain. The very seniority of panellists chosen to give a strategic (and legitimated) view prevents them from becoming engaged in extensive contact with projects or the firms in which they are located, particularly on the short time scale of current evaluations (which can be as little as three months). It is also rare for more than two or three members to have an economic, evaluation or even industrial R&D management background. The majority are eminent in the relevant technological field. This creates an expertise gap which was noted in a high level review of the Commission's evaluation practices a few years ago.[8] This affects the ability of panels to absorb information which may be provided to them.

Outside the mandated evaluations discussed above, socio-economic impact has been addressed in studies commissioned through research programmes or by the management of individual programmes.[9] Perhaps the highest profile for such works has been achieved by a series of studies which have calculated an "impact ratio", that is to say an average measure of the economic effects associated with a programme which gives the potential economic gains as a ratio of the investment of public resources in the programme. In the best known of these approaches, from the BETA group at the University of Strasbourg, the calculation of "added value" is based upon both direct effects and four categories of indirect effects (resulting from learning benefits to the participant arising from the project) and attributed to the research project by asking firms to agree on conservative estimates for coefficients which attribute a proportion of commercial effects to the project in question.[10] Over a period of time ratios for the Commission's industrial technologies programme (BRITE-EURAM) from studies by BETA and others were in the range of 4.4 to 7.0.[11] It should be strongly emphasised that these are not rates of return and could in principle represent unprofitable investments if the non-R&D expenditure on innovation were sufficiently high. The need for careful interpretation is clear - treatment of these figures as a sign of spectacular success for the programme would seriously question the rationale for further public funding in the light of such demonstrated benefits. While the scale of effects could be disputed, undoubtedly these methodologies have established the positive role of this type of collaborative R&D.

For the future, as noted above, the Fifth Framework Programme is re-positioning itself away from its predecessors' original self-styled pre-competitive origins to a position where it is 'sold' to its political audience as a means by which European economic and social problems may be solved. This has raised the stakes for evaluation which is now expected to deliver evidence of the degree to which such objectives are being achieved in a more concrete way than before and with the added complication of addressing broadly cast social objectives in addition to the previous core goal of improving the competitiveness of European industry. Currently solutions are being sought but evaluation faces a major challenge to meet these expectations.

Evaluation of EUREKA

The EUREKA Initiative has had a separate tradition of evaluation from the Framework Programme.[12] The management style of this Initiative is very different, with a very small central secretariat co-ordinating decisions taken by representatives of the

[8] Chabbal R., *Organisation of research evaluation in the Commission of the European Communities*, EUR11545, 1988

[9] A further type of evaluation has looked at the impact of EU R&D on individual member states. The best of these studies have identified important issues in terms of the organisational response to the programmes, eg. Larédo P., Callon M. et al *L'impact de programmes communitaires sur le tissu scientifique et technique français*, Paris:La Documentation Française, 1990; Reger G. and Kuhlmann S., *European technology policy in Germany*, Heidelberg:Physica-Verlag, 1995; Luukkonen T. and Niskanen P., *Learning through collaboration*, Helsinki:VTT, 1998

[10] BETA, Economic evaluation of the effects of the BRITE-EURAM Programmes on European Industry, Final Report, BETA, Strasbourg, 1993

[11] *Second European Report on Science and Technology Indicators*, Luxembourg: European Commission, pp. 575, 1998

[12] The exception to this was a transfer of expertise when a senior official from the European Commission's evaluation unit moved to the EUREKA Secretariat. Evaluation culture often depends upon the presence or absence of key individuals, reflecting perhaps a lack of depth in institutionalisation.

Member States who choose whether or not, and by how much, to fund their own nationals' participation in collaborative projects. Each year the Chairmanship of EUREKA rotates among members, and it is traditional for a country to put forward a programme of activities for that year. Evaluation has had its roots in such programmes, in that several countries saw fit to put forward evaluation as a theme for their year. It should also be noted that, given its embedment in national innovation systems, EUREKA has been the subject of numerous national evaluation studies. These are not covered here. The first international exercise took place in 1990-91 under Dutch leadership and was concerned mainly with procedures.[13]

A much larger scale exercise with a specific emphasis on economic effects was undertaken in 1992-93 when France, the country which had been pro-active in the launch of EUREKA, took the chair. Teams from fourteen countries worked together in a commonly defined methodology involving a whole population survey and interviews with multiple participants in a selection of projects.[14,15] Instruments developed for that evaluation, notably the questionnaire, have been replicated in a large number of European evaluations subsequently. Since the great majority of projects were still in progress at that time, the emphasis of the evaluation was on expected benefits. It was already possible to extract several key lessons for successful innovation in this context, for example the relative success of vertical as opposed to horizontal collaborations, the correlation between success and the project being core to the firm's strategy, and the common failure, particularly among smaller firms, to carry out adequate advanced market research.

The next episode in the history of EUREKA evaluation came under the Swiss chair in 1994-95.[16] This was explicitly a follow-up to the French chair exercise, to examine the emerging picture after completion of a significant tranche of projects. The structure in this case was similar to the earlier panel evaluations of EC programmes, though the expertise base was broader in the absence of a single technological domain to be examined. This evaluation confirmed the earlier findings but noted some drift in the Initiative away from large strategic initiatives co-ordinating entire sectors, towards being an instrument principally directed towards small firms. Efforts have since been made to ensure that both functions are maintained. The more longitudinal perspective possible from this exercise also demonstrated that success is not something which can be defined at a single point in time as the fortunes of projects and participants ebb and flow often for reasons beyond the scope of the Initiative or even of R&D.

This finding, together with a realisation that evaluation should not be seen as an ad hoc activity, led the following chair country, Belgium to initiate a new approach, which came to be called Continuous and systematic evaluation. As its name implies, this procedure requires that information is collected systematically every year, by sending a standardised questionnaire to all projects which finish during that year. Continuity comes both from the flow of information about commercial and employment impacts, and because the approach ensures continuity of method from year to year.

The evaluation employs three main instruments:

- *Final Report:* a four page questionnaire sent to participants at the end of the project R&D phase;
- *Market Impact Reports:* a 2-page questionnaire repeating the parts of the Final Report dealing with commercial exploitation of the R&D results and their employment impacts and sent to participants who have previously recorded commercial effects after one, three and five years from the end of the project;
- *Semi-structured interviews:* collecting more detailed and qualitative information, normally on projects which were completed three years previously, and also seeking to validate the questionnaires.

To give an idea of the scale of the exercise, in 1997 the analysis was based upon 434 Final Reports, 265 of which were from firms, the rest from non-industrial partners. This represented response rates of 79% of projects, 77% of main partners and 25% of all participants. In addition, 34 Market Impact reports were received and 30 face-to-face interviews conducted.

The approach is unusual in following up projects some time after completion, an aspect which has proved particularly rewarding. After a pilot year it was decided to convene an Expert Advisory Group to oversee the process, and to recommend an "Annual Impact Report" report to the country holding the chair. This report presents the findings, conclusions and recommendations and is presented formally to the Ministerial Conference that governs EUREKA. The need for the expert group arose for several reasons, including the need to interpret data, to have

[13] Dekker W. et al, Report of the EUREKA Assessment panel, EUREKA Secretariat, 1991

[14] Ormala E. et al, Evaluation of EUREKA Industrial and Economic Effects, EUREKA Secretariat, 1993

[15] Dale A. and Barker K., The evaluation of EUREKA: a pan-European collaborative evaluation of a pan-European collaborative technology programme, Research Evaluation 4(2): 66-74

[16] Airaghi A. et al, EUREKA Evaluation Report, EUREKA Secretariat, 1995

suitably qualified people to perform interviews, and to provide an independent validation of the findings and methodology.

To give some flavour of the results which have emerged, and which for the purposes of this paper have implications for evaluation practice more generally, some findings from the Annual Impact Report of 1997 are discussed in the following paragraphs.[17]

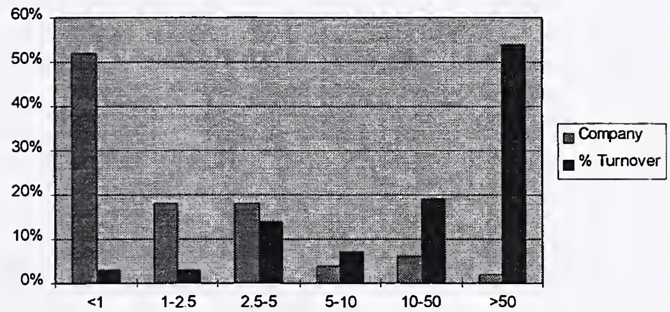
While 78% of participants were expecting commercialization at the end of the project (and 45% had achieved it by that time), one year later one third of these had failed to commercialize. The conclusion is that initial expectations based upon technological success may not be realized in the market and hence findings are sensitive to the timing of evaluation.

There is a skewed distribution of success, defined in terms of impact upon turnover. As Figure 1 shows, just over half of the projects achieved little or no effect (3% of total turnover effects) while conversely 2% of projects accounted for 54% of turnover generated. This is not untypical for an R&D portfolio but it also shows the necessity for large if not comprehensive samples when a handful of "blockbusters" are so important in assessing the overall impact.

Interviews have confirmed that routes to commercial success are often more complex than those which can be captured in a questionnaire. Typical examples include firms that have developed new equipment, improved their knowledge base, acquired new skills, changed concepts or market strategy and entered new networks. Even where the original project objectives have not been achieved some combination of the above has led to significant economic benefits for the firm, causing it to report a high degree of satisfaction with the Initiative. These participants can be taken more seriously than some in public programmes because not all received public funding.

Questions on employment effects were often not answered (a question response rate of c.43%) and interviews showed that participants were uneasy even where they did answer. Answers received showed that the principal effect had been to safeguard jobs in the organisation concerned. Other recorded effects were usually small but positive. Firms were generally even more uncomfortable with the idea of assessing effects outside their organisation. Such effects included jobs created or destroyed as a result of the application of a product or process. None were able to volunteer information on displacement effects in competing firms. The reasons for difficulty were generally that employment decisions involved a wider range of considerations. The only unambiguous cases of employment directly associated with a project came when a new firm, factory or line was established to exploit the output of the project. Negative effects often required qualification; they could be replacing dirty or dangerous jobs where there was difficulty in finding labour. Although the evaluation panel is well aware of the difficulties involved in dealing with the employment issue, there is immense political pressure in Europe for information on this topic and so the attitude has been that an imperfect measure is better than none if it is treated with due caution.

Figure 1. Impact on Participant's Turnover of EUREKA Projects.



Source: EUREKA Annual Impact Report 1997.

The continuous and systematic evaluation is itself a learning process, with minor changes introduced each year, within the constraint of not losing the continuity and comparability which it offers. The database of project effects is cumulative, gaining in analytical power each year. At present the analysis focuses on projects finishing in the year in question but as cohorts are completed, more detailed longitudinal analysis will also become feasible.

It is recognised that from time to time further strategic evaluations will be necessary which look at issues beyond the scope of project impacts. In the meantime this system provides a mechanism which holds the confidence of its principal client community (the national administrations and politicians) and points them towards ways in which the commercialization of results could be improved.

Outputs, Impacts and Effects[18]

Implicit in the discussion above is the existence of a clear view of the menu of outputs and impacts which may arise from a

[17] Georghiou L. et al, *The continuous and systematic evaluation of EUREKA, Annual Impact Report 1997,* EUREKA Secretariat, Brussels, 1997

[18] The discussion in this section draws heavily upon Bach L. and Georghiou L., The nature and scope of RTD impact measurement, discussion paper for International Workshop on Measurement of RTD Results/Impact, Brussels, May 28/29, 1998

Table 1. Outputs and Effects

Outputs		Impacts/effects	
Intermediate	prototypes	Competitiveness	sales
outputs	technological sub-systems		market share
	demonstrations		open up markets
	models/simulators		create new markets
	integration of technologies		lower costs
	tools/techniques/methods		faster time to market
	intellectual property		license income
	decisions on further RTD	Employment	jobs created
	new products		jobs in regions of high unemployment
Products	improved products		jobs secured
	new processes		jobs lost
Processes	improved processes	Organization	formation of new firm
	new services		joint venture to exploit results
Services	improved services		new technological networks/contacts
	processes for delivering new		new market networks/contacts
	services		improved capacity to absorb knowledge
	de facto standard		core competence improvement
Standards	de jure standard		further RTD
	reference		change in strategy
	conformance		reorganization of firm to exploit results
	memoranda of understanding		increased profile
	common functional	Quality of life	healthcare
	specification		safety
	code of practice		social development & services
	identified need for regulatory		improved border protection & policing
	change		support for cultural heritage
	management & organization	Control & care of	reduced pollution
Knowledge	technical	the environment	improved information on pollution & hazards
and skills	training activities		reduced raw material use
	workshops/seminars/		reduced energy consumption
Dissemination	conferences		positive impact upon global climate
	technology transfer activities		decrease in pollutants
	knowledge & skills transfer	Cohesion	employment in LFRs
	publication/documentation		infrastructure of LFRs
			participation of LFRs
			further RTD in LFRs
			regulation and policy in LFRs
		Development of	transport
		infrastructure	telecommunications
			urban development
			rural development
		Production &	energy savings
		rational use of	renewable sources
		energy	nuclear safety
			assurance of future supply
			distribution of energy
			development of internal market
		Industrial	development of SME sector
		development	development of large organizations
			support for trade
			EU regulations or policy
		Regulation &	national regulations or policy
		policy	world-wide regulations or policy
			co-ordination between national &
			Community RTD programmes

programme. This is not necessarily the case. While to some degree it is possible to distinguish between outputs from RTD, (ranging from scientific outputs such as publications, through "intermediate" outputs such as patents and prototypes, to "final" outputs such as new or improved products, processes or services) and impacts or effects which arise from the interaction between the outputs and the economy or society (for example sales, improved competitive position, or policies/regulations which improve quality of life). Several other dimensions also exist for these measures. A fundamental distinction is that between artefacts, knowledge and skills, raising in turn the distinction between tangible and intangible, codified and tacit outputs.

The models of innovation which are explicitly or implicitly used to underpin an evaluation methodology condition the outputs and effects selected for examination. Hence a linear or sequential model of innovation would be represented crudely by a research phase in which scientific knowledge is produced, followed by a transfer to a development environment and then a transfer of a prototype or its equivalent to a context of commercialization. Under these conditions the ultimate monetary benefits associated with the end of the sequence would be used at least conceptually as a base from which the sequence of contributions of the preceding phases would be calculated on an input-output basis.

More recent approaches to innovation, grounded in interactive, evolutionary and systemic contexts, identify the linear model as an extreme special case. It has been demonstrated that by neglecting feedbacks such a model systematically underestimates the benefits of R&D.[19] An interactive approach focuses attention upon learning benefits, structural changes including new networks, and the establishment of standards. Under such conditions it becomes clear that the types of effects and the relations between them differ according to the technology and market involved. Such differences may be founded in the appropriability of knowledge in the sector. It is clear that there is a large difference between the ways in which biotechnology, software and nanotechnology research are likely to manifest themselves in a socio-economic context.

Earlier work by author and a collaborator summarized the range of effects to be addressed.[20] These may be seen in an expanded form in an extract from a taxonomy of outputs and effects developed for a project level management and evaluation system being developed by another part of the European Commission for application to the Framework Programme (see Table 1). It should be emphasised that these are not intended as a checklist but rather as elements from which a logical model of outputs and effects appropriate to a particular project (or programme) can be constructed.

Additionality and Policy Persistence

A final dimension to consider in examining the European experience of evaluating collaborative R&D programmes is that of the effects of these as a policy instrument. Ultimately, however sophisticated an analytical scheme can be created for the identification and measurement of effects, there is the limitation of the degree to which that effect can be attributed to the intervention. The first barrier is one of measurement. Attribution of an effect, as the discussion of EC and EUREKA experiences above indicates, is dependent upon separating the effect due to the programme from any other influences which contribute to or hinder the manifestation of that effect. Such influences may be at the technological level through results being combined with those from other research projects, inside or outside the progremme, or through acquisition of technology by non-R&D means. Beyond technology, a multitute of other factors impinge upon successful innovation including marketing capability, investment capacity and factors outside the firm such as the regulatory environment.

There is a great temptation for the policy-maker to see the contractual entity which he/she funds as a discrete entity, when for the recipients it is a further contribution to a raft of associated work from which the firm's ultimate deliverables are expected. In this situation, it is not surprising that the other evaluation question which inevitably receives a very low response rate is that asking the firm to indicate the rate of return on the project (or on their participation in it). This 'project fallacy' implies assumptions about the way in which support is used by the firm and enters the realm of additionality, another minefield for evaluators. In essence, the additionality issue is based upon the difference made by the intervention. Initially the term was primarily applied to inputs and raised issues about whether the expenditure on was 'additional' to that which would have been incurred by the firm in the absence of the subsidy. This dimension remains of interest because it has emerged as the centre of a dispute between different branches of the European Commission with respect to competition law and restrictions on state aid. In essence, the competition commissioner considers that the funding should demonstrably be spent on the identified project while the research and industry commissioners consider it sufficient to demonstrate that the result of the subsidy is increased spend on R&D.[21]

[19] Swann P., The Economic Benefits of Basic Research, Report to Department of Trade and Industry, PREST, 1997

[20] Georghiou L. and Meyer-Krahmer F., Evaluation of socio-economic effects of European Community R&D programmes in the SPEAR Network, *Research Evaluation* 2(1), pp.5-15, 1992

[21] Research Europe, 1998

Nevertheless, collaborative R&D is a more complex instrument than that implied by such questions. Various surveys have shown a substantial degree of agreement in the response received to questions about additionality.[22] While there is inevitably some "dead weight" in the funding (firms which would have done the research without funding), twice as many claim that they would not have done it at all. However, the most common grouping (and one which to a lesser degree would probably encompass most members of the other two groups) is the response that as a result of the programme they did it differently - faster, with a wider range of options, and above-all collaboratively, thus releasing the specific benefits of collaboration. For small firms, particularly start-ups, it has been shown that participation can provide formative management routines, through the requirements for clear project plans, etc.[23] All of these effects are summarized in the term behavioural additionality.

It is not obvious whether projects with high additionality will produce greater or smaller impacts. On the one hand one would expect firms to cover their highest priority projects with their own resources and hence put forward marginal projects for funding. This rationalistic analysis is not confirmed by the evidence from evaluations - there are ample examples of projects with both high additionality and high subsequent impact. One explanation could be that public funding motivates firms to take undertake projects with a higher risk but potential higher pay-off. The question about whether the RTD [Research Technology Development] would have been done differently raises a further point, that of the *persistence* of effects. If behavioural changes are stimulated by the intervention are these maintained beyond the period of the intervention. Success in the structural objectives of European programmes are dependent upon achieving a lasting shift and all other effects are increased to the extent that the firm has learned from its experience. The issues raised here are an essential component of an evaluation.

Conclusions

In this brief review of European experiences it has been possible only to touch upon some of the issues arising from the collective experience of evaluation. The rich variety of national experiences and the interaction with evaluation of policy measures 'downstream' from support for collaborative research are both important exclusions deserving further consideration. Comparative study with the experiences of the USA and Japan with this instrument are another relatively untapped vein which this conference will help to exploit. However, to summarize and conclude, some important issues emerge. To re-iterate, the development of R&D programme evaluation in Europe has been associated with the rise of collaborative research as an instrument and to some extent their fates are inter-mingled. Of course, other dimensions of research and innovation policy also deserve evaluation but few offer the complexity of challenges that arise when organizations of different types, sizes and competencies seek to combine their skills and resources to achieve mutually beneficial goals.

The durability of the European experience shows that collaboration works - participants keep coming back for more and often maintain their links outside the programme context. It also shows that it is very hard to measure just how well it works in terms that would be comfortable to an investment banker or a finance ministry. In part this is because the language of investment deals with simple inputs and outputs and with what is monetisable. Experience indicates that this restricted view of research risks leading to a serious under-valuation that excludes the large range of options which it opens for those who take the risks.

A tendency for evaluation and monitoring to converge has both positive and negative aspects. A well-managed approach to the systematic collection of information increases the efficiency of evaluations that make use of it, as well as providing a resource for programme managers. It is also best that evaluation resources should be concentrated upon those areas where learning is most likely and away from routine activities. While evaluation may earn its keep through providing the evidence to sceptics that R&D does pay, its prime function should always be one of learning and co-evolution with the policies whose impacts it seeks to measure.

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[22] Buisseret T., Cameron H. and Georghiou L., What difference does it make? Additionality in the public support of R&D in large firms, International Journal of Technology Management, 10(4-6) pp.587-600, 1995

[23] Kastrinos N., The EC Framework Programme and the technology strategies of European firms, Commission of the European Communities, EUR 15784, 1994

Comments on Socio-economic Effects of Collaborative R&D - European Experiences

by Giovanni Abramo[1]

The origins of the discussant date back at the end of the 13th century when the Roman Catholic Church established the Inquisition, a general tribunal aimed at the discovery and suppression of heresy and the punishment of heretics. The role of the discussant, at that time named the inquisitor, was to prosecute anyone professing a religious, philosophical or scientific belief opposed to the orthodox doctrines or official views. Worldwide renown philosophers/scientists, such as Galileo, Giordano Bruno, etc. were condemned for heresy by the Inquisition (the statue of Giordano Bruno was erected in the same place where he was put to stake: "Campo de' Fiori", one of the most beautiful squares in Rome). The obvious effect of Inquisition was the slowdown of the pace of social and technical development. Fortunately times have changed as it is shown in this specific case, although certain subtle, hidden forms of inquisition still persist in certain contexts. Professor Georghiou, one of the protagonists of European R&D programs evaluations for over 15 years, that is one of the most influent representatives of the evaluation "doctrines" in Europe, is now playing the role of the defendant, while myself, a heretic almost by nature, has the unusual role of the "inquisitor".

Because Italy is the country where Inquisition was born and developed, as an Italian and often heretic I need state upfront that my objective is not to send Prof. Georghiou to the stake. My hope is to be able to provide, through my comments, an additional perspective, a managerial one, to the problem of evaluation, which may inspire new insights in those, like Prof. Georghiou, deeply involved in the subject.

I will skip the usual identification of and elaboration on the good points of the paper, which the art of communication would recommend to start with (my heretical nature comes to surface), and pass directly to pose few, hopefully challenging, questions.

The paper cogently traces the evolution of the approaches and methodologies to evaluate European publicly funded R&D programs, in particular the Framework Programme and Eureka. The description is mainly focused on the difficulties generally encountered by the different approaches.

Constraints regarding paper length have probably inhibited the presentation of the results of evaluation studies. In fact, evidence of the socio-economic effects is hardly shown, with the only exception of the evaluation exercise by the BETA Group. Then, the first question which comes to mind is: "After 15 years of evaluation studies in Europe are there figures which provide evidence to skeptics that R&D does pay (citing the author)? If yes, it would be beneficial to include them in the paper. If not, as I suspect, then "why have similar studies in the U.S. (Griliches, Mansfield, Nadiri, etc.) have provided quantitative answers? Is it because the Americans are better, or because we are trying to measure the "unmeasureable" (what does "social" mean to Europeans differently from Americans?)?

Passing from the results of the evaluation studies to the use of such results, if *...the prime function of evaluation should be one of learning and co-evolution with the policies whose impacts it seeks to measure...* (citing the author), "What has been the impact of such evaluation studies on the EU R&D policies? How have the evaluation findings contributed to improve EU R&D policies?"

The paper would have greatly benefited from elaborating on such issue, otherwise the population of skeptics, I am afraid, would grow larger. In fact, most of those who would not need to be convinced that R&D does pay, would start questioning whether investments in the evaluation of EU R&D programmes do pay.

Evaluation studies findings, in addition to facilitating policy makers in orienting their decisions, are an important tool for project management as well. This elicits a further question: "How have evaluation studies contributed to improve the management of the various EU R&D programmes? Within this context the author cites a study by Chabbal of 1988, which points out the significant problem of experts' background in evaluation panels (mainly technical). My own experience, ten years later, as an EU evaluator for the selection of projects, shows that the problem is still there.

This lead to my final comment. My impression is that the EU has placed more emphasis on ex-post evaluation than on ex-ante. Ex-post evaluation tends to see Programme Management as a black box: policy objectives and money are the inputs; socio-economic effects are the outputs to be measured. The correlation between project management and outputs (effectiveness and efficiency) is very strong. Then, if, after all, to obtain evidence of economic returns proves to be so formidable, why not focusing resources in optimizing the processes within the black box (i.e. programme management)? Probably, at the end we would not still know the exact public rate of return to EU R&D investments, but at least, whatever it might be, we would know for sure that it is the highest rate that we could achieve.

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OPENING SESSION

Overview of the Advanced Technology Program and Its Evaluation Program

by Rosalie Ruegg, Director, ATP Economic Assessment Office

ATP is a relatively recent component among United States strategies to foster innovation in the civilian sector. It is unique in having as its main long-term goal that of economic growth. In contrast, the "U.S. mission agencies," such as the Department of Defense and the Department of Energy, often also call out the importance of the economic effects of research they fund, but their first priority is, respectively, defense and energy. Its mission is to foster the rapid development and commercialization of pre-competitive, generic technologies with potential for significant, diffuse impact on the nation's economy. The program shares part of the research costs with industry of technology development projects conceived, proposed, and led by U.S. companies – projects that are selected for award by ATP through a competitive peer-review process that evaluates the technical and business/economic merit of proposals. Each project selected for funding has specific technical and business goals, funding allocations, and completion dates that are established at the outset. The projects are monitored by ATP staff and can be terminated for cause before completion. Funding is on a cost-reimbursable basis. Eligibility extends both to single-company projects, most of which show extensive collaborative activity through subcontracting and informal alliances, and to joint ventures which must include at least two for-profit companies and often include other companies, universities, and non-profit organizations as additional members, as well as subcontracting and informal alliance arrangements. Figure 1 highlights some of ATP's distinctive features. The summary statistics in figure 2 show through 1998, the cumulative number of proposals received from companies, the amount of money offered by industry and requested from the ATP, the number of organizations involved, together with the number of awards made by ATP, the associated funding, and the number of participating organizations.[1]

Figure 1 - Key Features of ATP

- Technology development for national economic benefit
- Industry leadership in planning and implementing projects
- Project selection criteria on technical and economic merit
- Annual rigorous competitions based on peer review
- Positioned after basic science and before product development
- Not "entitlement" funding - all projects have end dates

Figure 2 - Summary Statistics for ATP (1990-1998)

Proposals Received	
Number of proposals	3,585
Total research proposed (U.S. $ millions)	$14,794
Industry share (U.S. $ millions)	$7,103
ATP funding requested (U.S. $millions)	$7,691
Number of proposing organizations	6,104
Awards Made	
Number of awards	431
Total research funded (U.S. $ millions)	$2,783
Industry share (U.S. $ millions)	$1,997
ATP share (U.S. $ millions)	$1,386
Number of participating organizations	1,010

ATP has an integrated set of strategies for accomplishing its mission. It funds projects that are desirable for their social benefits, essentially buying down technical risk that exceeds the level acceptable to private investors. It encourages companies, universities, and other organizations to undertake multi-disciplinary collaboration to solve complex problems of broad importance. It focuses on multi-year partnerships needed to address problems that tend to be neglected when short-term perspectives predominate in investment decisions. Through its selection criteria, it fosters the structuring of partnerships that integrate objectives and approaches across the areas of research, commercial interests of the innovator(s), and the national economy. Short of compromising the incentive to commercialize the technology, ATP encourages companies to share the resulting scientific and technical knowledge with others. In short, ATP aims to induce industry to undertake challenging research needed to develop enabling technologies with potentially high-payoff potential for the nation, research that businesses otherwise would not undertake at all or not with the scale, scope, or timing needed to realize the potentially large societal benefits.

Because ATP's mission is economic in nature, its evaluation emphasizes economic impacts of the program. But there are a number of sub-objectives and constraints to the program that condition the program and its evaluation. For example, in addition to providing economic benefits, projects must entail high-risk research. Hence, one aspect of ATP's evaluation concerns the scientific and technical contributions of funded research. Because the research is high-risk, it is understood that not all projects will be fully successful. Only a fraction will likely ac-

[1] More information about ATP is available on the World Wide Web: http://www.atp.nist.gov; by e-mail: atp@nist.gov; by phone 1-800-ATP-FUND (1-800-287-3863); by written request: Advanced Technology Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 4701, Gaithersburg, MD 20899-4701.

complish **all** the goals — scientific knowledge creation, timely commercialization of products and processes, and widespread diffusion of the technology leading to large spillover benefits. Most will be at least partial successes given that scientific knowledge often is gained even from research failures. Many will likely yield a sufficient return to pay back their costs. A few likely will be "home runs."

Since accelerating the development and commercialization of technology is a program mission, ATP's evaluation tracks the degree of speed up of technology development and the rate of commercial progress of award recipients. It also investigates the economic value of accelerating technology development projects.

Since the program is for national benefit, the evaluation is concerned with generating and measuring spillover effects beyond the direct benefits to innovators — including market spillovers, knowledge spillovers, and network spillovers. It seeks to fund technology development projects for which the spillovers are large, as reflected in gaps between the resulting social rates of return and the private rates of return to the innovators.

Because ATP is charged with promoting the formation of research joint ventures, collaborative research is another topic of particular interest for ATP's evaluation. The objectives and progress of the individual joint-venture members are tracked, as well as those of the overall entity. Efficiency issues, the internalization of spillover effects, and technology diffusion effects are examples of research topics of interest to ATP that concern collaborations.

Because it is critically important to the realization of benefits from the program that ATP make a net contribution to the nation's economy — leveraging rather than displacing private sources of capital — ATP's evaluation seeks to measure the differential impacts attributable to ATP, in addition to the overall impact of projects and groups of projects. With- and without-ATP scenarios are posed to help get at the effects attributable to ATP. This entails the use of counterfactuals and the attendant uncertainties thereof.

The ATP initiated evaluation at the outset of the program, first, to develop a management tool to make the program better meet its mission and operate more efficiently; and, second, to meet the many external requirements and requests for ATP program results. Demands for performance measures for ATP are intense. Requests for evaluation results come frequently from individual members of Congress and their staff, from Congressional subcommittees, the General Accounting Office, the Executive Office of the President, the Office of Management and Budget, the Office of the Inspector General, the Press, think tanks, industry groups, and others.

Title II of the American Technology Preeminence Act of 1991 (P.L. 102-245), enacted in 1992, directed that a comprehensive report on the results of the ATP be submitted to each House of the Congress and the President not later than 1996. This report was delivered in April 1996 (the Advanced Technology Program 1996).

In addition, ATP, like other federal programs, is subject to the evaluation requirements of the 1993 Government Performance and Results Act (GPRA). The GPRA resulted from a bipartisan effort to improve accountability, productivity, and effectiveness of federal programs through strategic planning, goal setting, and performance assessment. ATP/NIST is developing assessment plans and techniques, and carrying out evaluation studies in compliance with the GPRA. ATP receives many inquires about its evaluation tools and methodologies from other agencies, as well as from similar programs in other countries.

To square the often urgent demands in the short run for evaluation results with the reality that patience is required to realize and validate empirically long-run program outcomes, ATP has adopted a multicomponent evaluation strategy. Its main components include (1) descriptive (statistical) profiling of applicants, projects, participants, technologies, and target applications; (2) progress measures derived principally from surveys and ATP's "Business Reporting System;" (3) real-time monitoring of project developments by ATP's staff; (4) "status reports" on completed projects; (5) microeconomic and macroeconomic case studies of project impacts; (6) methodological research to improve the tools of longer term evaluation; (7) special-issues studies to inform program structure and evaluation; and (8) econometric and statistical analyses of the impacts of projects and focused programs.

Early evaluation studies carried out by ATP economists and contractors suggest that ATP is on track, meeting its objectives, and delivering results for the U.S. economy. But at this time only rough quantitative and qualitative projections of project impacts are possible due to limited information and uncertainties about the ultimate outcomes. These measures will become better informed as commercialization and diffusion activities progress. By tracking developments as they unfold, we expect over time to be able to reduce the estimating errors, extend the scope of analysis, and provide better measures. Over the coming years, the ATP expects to contribute significantly to the body of work on technology impact assessment and to build towards a more comprehensive view of the impacts of ATP.

R&D and Productivity: Some Historical Reflections

by Zvi Griliches[1]
(Keynote Address)

Dedicated to the memory of Edwin Mansfield, one of the great pioneers of this subject.

I want to note first that studies of technology and patenting have a long history and predate the more recent interest in aggregate productivity and the residual. For example, the 1960 Minnesota Conference on *The Rate and Direction of Inventive Activity*, organized under the auspices of Simon Kuznets, with the participation of most of the next generation of scholars who would matter in this field: Mansfield, Nelson, Scherer, Schmookler, and myself among others, did not really relate to aggregate productivity measures, though Nelson in his introduction to the 1962 published volume tries to make a connection. The conference and the book were focussed primarily on the micro-economics and econometrics of invention and innovation.

But as the evidence on large residuals in the accounting for output growth percolated through the consciousness of the economic community (as the result of the work of Schmookler, Abramovitz, Kendrick, and the synthesis by Solow), it became common to interpret this residual as reflecting largely technical change and think of it as being caused primarily by public and private R&D efforts. Already earlier, in 1953 and 1958 respectively, Theodore Schultz (recently deceased) and I made calculations relating the two in the agricultural sector and implying rather high rates of return to the publicly supported R&D there.

Very early on researchers turned to regression analysis using various constructs of R&D capital as their independent variable. The pioneers here were Terleckyj, Minasian, Mansfield, myself, and others. We quickly established that R&D seemed to be an important "statistically significant" variable in explaining productivity differences, but the estimated coefficients were not large enough to provide a major explanation of the large growth in TFP observed in those years.

It was obvious that what was missing was some accounting for spillovers of R&D results and other sources of new knowledge across firms, industries, and countries. So a number of studies, starting with the work of Evenson and Kislev (1973) and Terleckyj (1974), looked for some ways of capturing them in the data. The most influential of the more recent studies are Jaffe (1986) and Coe and Helpman (1995). Many more have been done since. Though each one is subject to some reservations, the overall conclusion was that spillovers seem to be there and are important. The eventual justification for the activities of our host, the ATP program, is ultimately based on the perceived importance of such spillovers and the need to support them explicitly.

So while one can say that this line of research was very successful, both substantively and in its impact on policy, the world was changing while we were collecting our laurels. The unexplained growth of productivity, which we were attributing to science and industrial R&D, came close to disappearing! (See Figure 1.)

Two questions arose: If R&D is so important "where is the meat"? Where is the promised productivity growth? If one pointed to a decline in the aggregate rate of growth of R&D, the answer was that most of that decline was in federally supported R&D which earlier studies had found less productive (Figure 2). But then why was there no spurt in productivity growth as the result of the spurt in private R&D investment in the mid-eighties?

Either R&D didn't matter as much as we had claimed, or it's impact had declined, or it was running into sharply diminishing returns. One example of such an argument was based on patent data which were largely stagnant in spite of the growth in R&D. (See Figure 3.) But the decline in patenting per R&D dollar was happening also in the good old days!

A second piece of disquieting evidence is the decline in the apparent valuation of R&D by the stock market. (See Figure 4, from B.H. Hall (1996).)

I want to admit the possibility that the rate of TFP growth that was achieved during the 1950's and 1960's may not be sustainable in the long run, but I am not as pessimistic about our future (at least from this direction). The future impact of our (and the world's) political leaders on the lives of our children is rather scary to contemplate. First, there is a large reservoir of still undiffused technical and organization knowledge that could and should improve productivity for years to come. Also, there is much technology "in the making" that has not yet hit the markets significantly. Biotech is a fine example.

But the main point that I want to make in closing, a point that was clear to the participants of the 1960 Minnesota Conference, is that aggregate productivity numbers are only dimly and possibly misleadingly related both to the measurement of true technical change and the impact of R&D on it, especially federally supported R&D. This is due, in part, to difficulties in productivity measurement per se, and second to the particular location of most of R&D in the industrial spectrum. There are two questions here: (a) is the productivity slowdown real? (b) can we see the effects of R&D on it?

[1] Dr. Griliches is a Professor of Economics at Harvard University and a member of the National Bureau of Economic Research.

The answer to the first question is clouded by the fact that much of this slowdown occurred in what I call the "unmeasurable" sectors, such as services and construction, and that these sectors also grew greatly in importance in the total economy. This is documented in Figure 5 and Table 1. Looking at Table 1 and the numbers for the non-farm, non-manufacturing sectors, do we really believe that two-thirds of the economy has been retrogressing for the last 20 years?

Table 1. Multifactor Productivity Growth

	1949-73	1973-79	1979-90	1990-96
Non-farm business	1.87	0.40	0.00	0.20
Excluding labor quality adjustment	2.07	0.40	0.30	0.60
Manufacturing	1.74	-0.40	1.00	1.90
Implied non-farm non-manufacturing	1.77	0.82	-0.17	-0.29

Source: USDL 95-518m95187, and Lysko (1995)

A. Based on gross sectoral output measure rather tan GDP.

B. The first number is computed as 2.07-.32 x 1.74/.65) 1-.32), where .32 is the approximate share of manufacturing in total non-farm business during the first period and .65 is the ratio of value-added to sectoral output in manufacturing. These two numbers are approximately .23 and .53 respectively, for the last two periods.

It is also the case that most of the R&D in the economy has been directed to the "unmeasurable" sectors: space, defense, health, and IT, and in none of these sectors will a major technological breakthrough show up easily in the productivity numbers as they are currently computed. This is not entirely true of computers and communication advances, but they too, as you are likely to hear from Tripplett tomorrow, are largely consumed in the "unmeasurable" sectors: primarily finance, health, education, and other services. And much of the direct R&D has also moved into these sectors. NSF estimates that a *quarter* of all industrial R&D is now performed in non-manufacturing industries, up from only 3 percent in 1995, where its output is again unlikely to be measured.

So I want to conclude by saying that I am cautiously optimistic about the immediate future, especially as I observe the recent rise in patenting and the up-tic in manufacturing productivity. (See Figure 6.) But we, as a research community, must develop better tools for measuring the contribution of R&D. Aggregate productivity statistics just won't do it. That's what you are here for, and I am encouraged by the quality of the new work by a new generation of researchers that is reflected at this meeting.

I am worried, however, by the continued decline, both relative to GDP and in absolute terms, in federal support to the national R&D effort. It has fallen from more than a half of the total R&D in the 1970's to just 30 percent in 1997. Some of the cuts may have been warranted, but I doubt that this is the investment in the future that we should be cutting, on the margin. And Francis Narin's evidence presented today only strengthens my worries. While I do not think that these declines have had or will have noticeable effects in the near future, they may come back to haunt us later on, especially if we figure out better ways of measuring their impact and realize what has happened. But it may be too late then. The sooner we can have a better quantitative understanding of these processes the better. The future of our children may be at stake here.

Figure 1: Growth Output per Hour

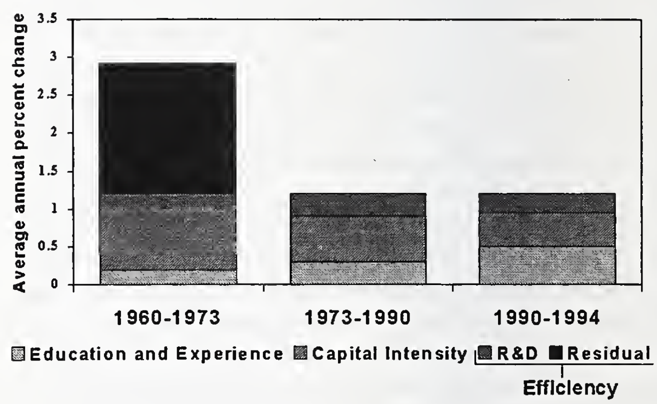


Figure 2: Expenditures as a Percentage of GDP By Funding Source, 1960-1995

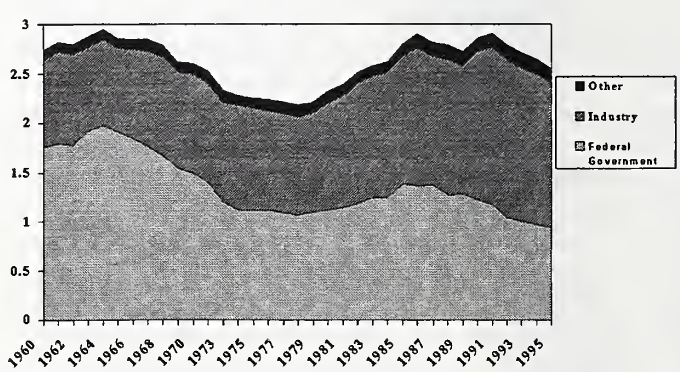


Figure 3: Domestic Patent Applicatins per Company Financed R&D in Industry (1972 $'s) an per Scientist and Engineer

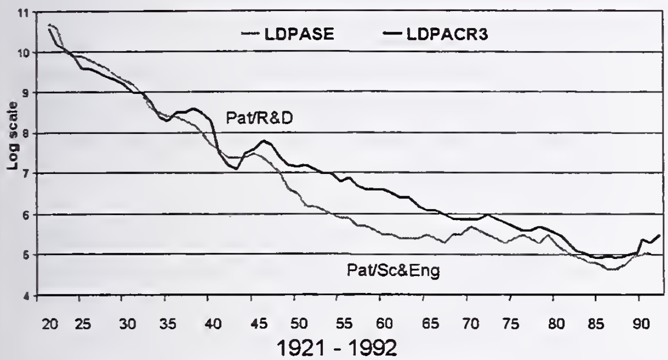


Figure 4: Implied Valuatins of Physical and R&D Capital in the Stock Market. Co-efficients from log Q equations, unbalanced annual cross-sections, 1976, 1995.

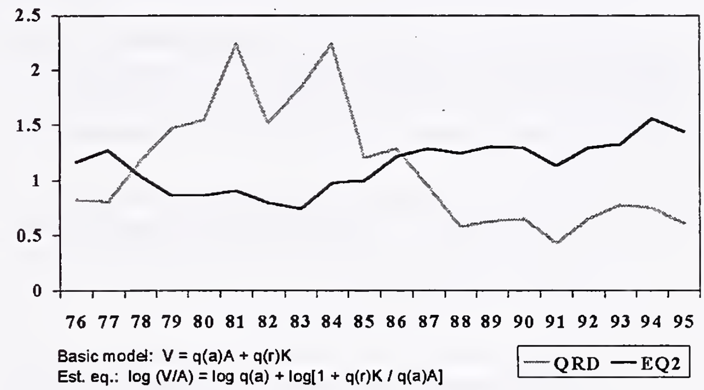


Figure 5: Log of GDP per hour: 1948-1996

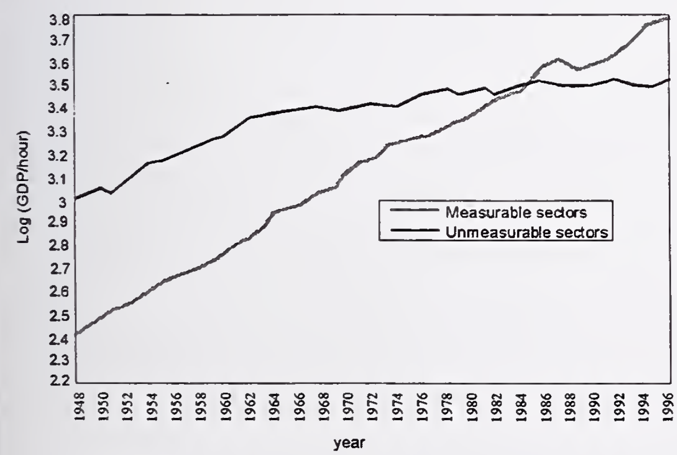
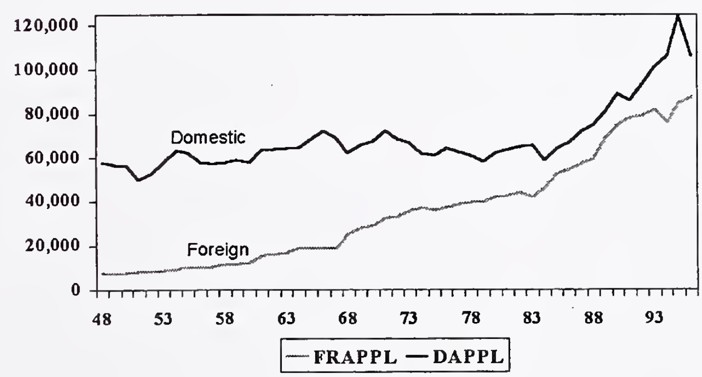


Figure 6: Patent Applications in the U.S. numbers, 1948-1996



The Solow Productivity Paradox: What Do Computers Do to Productivity?

Jack E. Triplett[1]

"You can see the computer age everywhere but in the productivity statistics."

Robert Solow, New York Review of Books, July 12, 1987

Dr. Triplett referred to Solow's often repeated aphorism, now more than ten years old, in his discussion of the impact of computers on worker productivity. The presentation reviewed and assessed the most common "explanations" for this paradox:

You don't see computers "everywhere," in a meaningful economic sense. Computers and information processing equipment are a relatively small share of GDP and of the capital stock.

You only think you see computers everywhere. Government hedonic price indexes for computers fall "too fast," according to this position, and therefore real computer output growth is also "too fast."

You may not see computers everywhere, but in the industrial sectors where you most see them, output is poorly measured. Examples are finance and insurance, which are heavy users of information technology and where even the concept of output is poorly specified.

Even if you do see computers everywhere, some of what they do is not counted in economic statistics. Examples are consumption on the job, convenience, better user-interface, and so forth.

You don't see computers in the productivity statistics yet, but wait a bit and you will. This is the analogy with the diffusion of electricity, the idea that the productivity implications of a new technology are only visible with a long lag.

You see computers everywhere but in the productivity statistics because computers are not as productive as you think. Here, there are many anecdotes. The technological demands of networking are also a factor.

There is no paradox: Some economists are counting innovations and new products on an arithmetic scale when they should count on a logarithmic scale.

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[1] Dr. Triplett is a Fellow at the Brookings Institution in Washington, D.C.

The Evaluation of Private Sector Research

Rebecca Henderson[4]

Dr. Henderson discussed the often complex issues faced by private sector managers seeking to evaluate the productivity of their research programs. She reviewed a variety of techniques used within the private sector, focusing particularly on the tensions between ex ante and ex post evaluation, between individual versus team or group evaluation, between long and short range outcomes and between qualitative and quantitative metrics. She concluded with a discussion of the possible implications of private sector experience for public sector work.

[4] Dr. Henderson is a Professor in the Sloan School of Business at M.I.T and a member of the National Bureau of Economic Research.

PANEL SESSIONS

International Conference on the Economic Evaluation of Technical Change

Panel Sessions

Two panel sessions were held consisting of both academics and government representatives from several countries who have had years of experience in either researching government technology programs or in administering them. The panel titled "**Publicly Financed Research Consortia**" was chaired by Rosalie Ruegg, Director of ATP/EAO, and included: Dr. Luke Georghiou of PREST, UK; Dr. Francois Sand of the EUREKA Secretariat, Belgium; Dr. Giovanni Abramo of the Consiglio Nazionale delle Recerche, Italy; and, Dr. Mariko Sakakibara formerly of the Ministry of International Trade and Industry (MITI), Japan. Each member of the panel received a list of questions in advance of the conference in an effort to focus the discussion.

The panel that addressed the topic of "**Public-Private Partnerships in R&D: Lessons Learned**" was chaired by Maryellen Kelley, Senior Economist at ATP/EAO, and consisted of: Liam O'Sullivan of the European Commission, Belgium; Dr. Phillipe Laredo of the Centre de Sociologies de l'Innovation, France; Ralph Lattimore of the Productivity Commission, Australia; and, Dr. Adam Jaffe of Brandeis University.

PANEL SESSION: Publicly Financed Research Consortia

Professor Luke Georghiou
Director, PREST
University of Manchester, UK

1) What sorts of technologies, e.g., infra structural, should be targeted in research consortia?

The first question is whether any technologies should be targeted - if the benefits are intended to be manifested in the improved competitive performance of individual firms then it should be up to those firms to come forward with proposals for areas of advanced technology which they wish to pursue. This case is reinforced by the convergence and inter-dependence of many advanced technologies, for example the importance of bioinformatics in progressing biotechnology and conversely the prospect of the use of biological processes in advanced computing.

However, I would also concede that there are arguments for targeting in certain circumstances. These include those areas where co-ordination at the R&D phase improves the speed and scope of the market phase. A good example here would be vehicle information systems, which require coordinated R&D across a variety of firms in the electronic, automobile and service sectors, together with an input from regulators and standard-setting bodies. Effects in these circumstances are greater than in stand-alone project assistance. A similar argument could apply in a very new area where a focus of activity could create a critical mass of researchers and again amplify the benefits.

2) *What is the appropriate mix of participating firms in research consortia in terms of size, technological strength, etc?*

A first point is that the European experience has shown that the appropriate mix includes not only firms but also a significant contribution from universities and public research bodies. The "golden triangle" project features a producer who takes the output to market, a user who gives early feedback and benefits from early access, and an academic partner who raises the technological level of the activity as a whole. European experiences encompass firms of all sizes but their needs are different. Small firms (unless they are specialized research performers for whom the program is a type of business) normally have a much shorter time horizon and seek to go straight to the market after the project (though many find that the ensuing "productization" phase is costly and time-consuming to the point where they need external help). Large firms, on the other hand tend to see the programs as a window on the world where they can monitor academic developments and the activities of other firms while building their competence base.

In terms of the direct mix the key point is to structure projects around technological and market complementarity - few projects succeed containing direct competitors (other than for standards or non-competitive areas). It is the differences between participants which lead to success.

3) *To what extent should the funding government agency attempt to actively participate in the project?*

A well run selection process increases confidence in the initiative. Passing on knowledge gleaned from previous work is also useful for participants, for example, that concerning intellectual property rights agreements. During the project the aim should be to interfere as little as possible except to ensure that resources spent are matched by work done. Help should be on hand if things go wrong. At the end, small firms may need further help in securing access to private venture capital or to find a partner able to offer a better route to the market.

Dr. Francois Sand
Eureka Secretariat
Brussels, Belgium

Introduction

I would like to start with a short introduction of myself: my name is François Sand and I am from the EUREKA Secretariat based in Brussels (Belgium). I was a nuclear physicist (I still am I suppose!). Eleven years ago I joined the Evaluation service at the European Commission (DG XII, Science, Research & Development) where I had the opportunity to coordinate many evaluation exercises for specific Community R&D programs like BRITE, STD, EURAM, etc. Five years ago, I was seconded to the EUREKA Secretariat. One of my main tasks was to set up the CSE (Continuous and Systematic Evaluation process) which assesses the impact that EUREKA projects have had on the market in the years after completion. For three years now, an Annual Impact Report has been presented to the yearly Ministerial Conference.

I have attended all the presentations that have been given so far today. They gave me the impression of being on my bicycle on the ground and looking at you in the blue sky flying the ultimate jet model: it was very impressive! At my ordinary level, however, I consider that one of the roles of evaluation is to start correcting a somewhat too simplistic view that some of our politicians sometimes have in mind regarding outputs of R&D public funding.

Being the last speaker this evening, I shall not repeat many of the views that the previous panelists expressed and which I share with many of them. Furthermore, relying on EUREKA's experience for my contribution, I shall point out several difficulties specifically connected to the international cooperation framework.

Let's now address the first question:

1) *What sorts of technologies, e.g., infra structural, should be targeted in research consortia?*

In the EUREKA initiative, due to the basic principles in its definition, especially flexibility and bottom-up initiative, this problem of targeting doesn't occur directly at the central level (international). The national support process, however, which is part of the labeling procedure introduces de facto a type of hidden selection amongst the project proposals which nevertheless asserts that clear targets are useful for national operators of the initiative.

Supporting collaborative research to produce structural results is, for itself, meaningless. Indeed the target must not merely be in R&D but in longer term perspectives for which R&D is to be considered as a tool, i.e., supporting vector. But if it should help in improving societal structures, it becomes worthwhile to address it.

In a case like PROMETHEUS, for example, a project which aims at a global approach of road traffic problems, it will be based on complementary expertise of the industrial consortium set up by the main European car industries as well as on related development. The adaptation of the infra-structural technologies needed for the project will be at the core of the development. We can pick as examples the communication tools with global systems (IR, VHF, GPS/GSM etc), communication between cars (including information on the status of the surface etc.), autonomous detection systems (radar, vision, detectors, etc). Each of these examples have been developed in view of the specific application and simultaneously extend the basic know-how available for other fields of application.

Another example of a project having a strong component of infra-structural technologies is HDTV (High Definition Television). It could be considered in principle as a failure regarding the official target (the system involved the use of analog signals) but it was actually a success regarding all the infra-structural development (standards) and fall out (digital development). Furthermore, it later permitted the partners to relaunch quickly another project, ADTT (Advanced Digital Television Technologies) for a broader prospect in the use of digital TV signals. We noticed however that in this case an advisory board at the political/administrative level could possibly have helped to refocus the project much earlier as underlined in the Airaghi evaluation report.

The experience proves that all the technologies are not similarly successful in the framework of collaborative projects and does not appeal in the same way to different types of participants.

2) *What is the appropriate mix of participating firms in research consortia in terms of size, technological strength, etc?*

The past and current evaluation exercises put in light the following findings regarding consortium structures:

- The best structures involve a chain of qualification with partnership extending from the producers to the final clients.
- This supposes a clear distribution of tasks from the very beginning and an agreement on the future exploitation: i.e., how to share the results.
- The projects with several competitors are only very seldom successful. This is, however, not a rule and depends very much on the type of target considered by the project. Common definition for new standards (HDTV) or improvement of safety on the road (Prometheus) or organization of a worldwide market (Gallileo & Amadeus) are examples of positive collaboration between competitors. In most of these positive examples, it is to be noticed that a global reorganization of the corresponding market was at stake. Consequently, the participating organizations were well aware of the importance for them to be part of the effort, in order to preserve their future share of the market.
- As a rule the leaders of a consortium play a crucial role. In most cases, it must be an industrialist, even if there are some few examples of success with non-industrial leadership. When such a situation occurs however, it is advisable to attach to the consortium a type of advisory board, mainly constituted with industrialists, to help the leader when strategic decisions regarding the products and/or processes are to be taken.
- Expectations from participants are very much dependant upon size:
  * SME's are aiming at short term market applications
  * Large companies are more attentive to the evolution of know-how and in controlling market evolution;
  * Service companies, which are increasingly more active in such projects, are interested in gaining good adaptation (and accurate information) vis-à-vis market needs and networking (for new clients).
- No general rules can be derived from EUREKA's experience regarding the technological strength. One of the possible results from analysis on a number of case studies is that, when large numbers of participants are collaborating together despite their competitive status, the possibility of success can be better if the organization of the project is more "à la carte", i.e. when the development of the project reaches a stage where more precise and applied outputs are concerned, some clustering between participants occurs which permits a better control of information fluxes and preserves the IPR. Another interesting trend, in the results so far, indicates that success often occurs in projects where a dominant partner works with potential subcontractors or operators.

3) *To what extent should the funding government agency attempt to actively participate in the project?*

When interviewing the participants, the following argument came regularly:

There is a clear basic idea: if the industrialists knew from the beginning that the chances of success are great and the potential market large, they would never look for (international) cooperation framework with the related problems. The main goal of public support is consequently to permit the participants to take a risk that they would not have taken alone. The level should be adjusted accordingly. This should take into account the distance to the market as presented in figure 2. Regarding public funding, the figure indicates that the agencies should not intervene in Domain A where industries can take over on their own because the risk is acceptable. On the other hand, public funding can help industries to start projects in Domain B where the risk is too large for individual initiative until the moment when the risk decreases sufficiently to be accepted by the firms.

In this framework, an active participation of the funding agency could also be encouraged at the following levels to:

- Force the participants to properly prepare the files of the project (especially market analysis and forecast). However, the services involved in this matter must keep in mind to limit as much as possible their bureaucracy.
- Push the participants to follow-up project development by an accurate monitoring system and a sound analysis of these developments. The agency has also to put the participants in a position to adapt in real time to the evolution of the project (results obtained versus evolution of the market) and to recommend a preliminary feasibility phase when the project is ambitious.

- Encourage the set up of an industrial advisory board, especially, as previously said, if the leader is a non-industrialist.
- Ensure a more active role in mediating and facilitating collaboration (as requested by participants - Annual Impact Report '97[1]). It should never take over the participants responsibilities and should keep the level of control a reasonable one (i.e. taking the opportunity to help when needed but avoiding any form of dirigisme).
- Help to identify and solve the problems linked to commer cialization not for but with the participants.
- Ensure the required supportive measures (norms and standards).

[1] The successive Annual Impact Reports are available from the EUREKA Secretariat on request by e-mail to : hilde.iemants@es.eureka.be.

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Premise

As soon as I began elaborating on the intellectually challenging questions to be raised in this panel, I immediately realized that no answer, however generic it may be, would be appropriate to every environment. Being Italian (Italy is a relatively small economic entity among major industrialized countries) and a European Union citizen at the same time, unavoidably induces me to take an international perspective any time I face problems of the kind discussed here (especially if I have to do it in English - the good side of being "small" and not English mother-tongue!).

Every time I tried to figure out the sorts of technologies to be targeted or the appropriate mix of participating firms in research consortia in Italy, I realized that the answer would have not necessarily been the same at the European Union level. As a consequence, in order to avoid potential subsequent misunderstanding I find it useful to make from the very beginning a few considerations which may elicit the intrinsic limitations of and needed assumptions for the problem at hand.

First of all, the answers to the above questions are strongly dependent on the context where research consortia operate. The economic, industrial and research policies of a country, its industrial structure and technology infrastructure, its level of technology specialization, its business culture, as well as its geopolitical role will all, more or less, affect the decision on the appropriate mix of participating firms or the sorts of technology to be targeted.

Second, at a more micro level, the answers to the above questions may be different depending on the specific publicly financed R&D program we are referring to. Also, they will depend on the content and objectives of other co-existing programs. A consortium engaging in basic research, for example, may entail a different set of partners than a consortium engaging in technology development. So the answers will very likely depend on the scope and objectives of the program, unless we assume that a research consortium is an end per se rather than a mean.

Third, in case we are able to achieve commonly agreed upon more or less definitive answers, it is important to ask ourselves from the very start how we are going to use such answers: Simply to enhance awareness of people involved in the matter? Or, possibly to revise and improve current publicly supported R&D programs? If the latter is the case, as I presume, it is important to keep in mind that implementation issues should be considered from the very early stage of the program formulation/revision process in order to reduce the likelihood of subsequent operations problems. The adoption of this "concurrent engineering" perspective will affect for sure the process of elaboration on the issues at hand, and very likely its outcome as well.

The foregoing considerations elicit the need to define more precisely our field of investigation, in order to try to provide answers not too generic in kind. Then, an assumption needs to be made, regarding the reference publicly financed R&D programs. We may frame the questions in the context of ATP-like programs (at European Community level one of the programs which more closely resembles ATP, in terms of broadness of technology fields covered and market orientation, seems to be the INNOVATION Program of DGXIII, as far as the Technology Validation Projects and the Technology Transfer Projects are considered). Furthermore, the approach I take is to consider, in my elaboration, whenever deemed appropriate, also the implications for implementation of possible solutions to the above questions. As for the geographical context, I will avoid focusing on Italy, which would be as less difficult to me as of little interest to the audience, but I will try to leave it open, although with an unavoidable emphasis on Europe, which may synergistically complement the U.S. focus of local participants in the panel.

Given the above assumptions and limitations it is important then, that the following discussion and conclusions be treated with proper caution and that the potential bias of the European perspective of the panelist be borne in mind, especially by the non-European audience.

Following on the above preliminary considerations common to all the questions raised, I now turn to elaborate on each single question separately.

1) *What is the appropriate mix of participating firms in terms of size, technological strength, etc.?*

Needless to repeat that the answer to such a question is strongly linked to the context and underlying philosophy of the program at hand and the policies it is aimed to realize.

With reference to size, the attitude towards fostering the participation of small- and medium-sized enterprises (SME's) in publicly financed R&D consortia varies among nations, depending on the context and priorities deriving from it. The European Community, for example, has emphasized special attention on SME's, since the very beginning of its R&D programs. The United States ATP, instead, only recently, I understand, has set the explicit goal to increase participation in ATP by SME's. This is probably due to the different needs arising from the very different industrial structures of the two economies. 92.4% of the 11.6 million European enterprises employ below 100 employees, and only 0.1% above 500 employees. SME's in Europe represent 70% of total revenue and contribute to 75% of total employment. When you deal with such proportions, probably there is little need of referring to economic or organizational theories to justify interventions in favor of SME's. If, on the one hand, SME's, with their high specialization, flexibility and dynamism may be considered one of the main potential strengths of the EC, on the other hand their small size may penalize them and make them vulnerable when it comes to face the complex challenge of technology-based global competition. Then, *ad hoc* policies may be deemed necessary to favor SME's growth and networking and to foster the diffusion of technological innovations among SME's competing in traditional sectors.

Anyway, there are a number of reasons, more or less directly based on economic theory, why the participation in R&D consortia by SME's should be fostered. Many of these reasons may apply also to those nations, such as the U.S. and Japan, whose industrial structures may not make the attention to SME's so vital.

With reference to one of the objectives common to all ATP-like programs, i.e. the maximization of the gap between social returns and private returns to R&D investment, a direct consequence follows with regard to SME's. As compared to large companies, SME's in general tend to be less able to capture the same number of and to the same extent the potential externalities arising from R&D investments. In fact, the likelihood that SME's have market power in the relevant markets, the needed complementary assets, the ability to protect the innovation and to create and sustain long-lasting first-mover's advantages is comparatively lower than large companies. This would have a positive impact on public returns, making SME's participation in publicly financed R&D consortia, all others equal, more appealing than large companies.

With reference to another objective common to all ATP-like programs, which is minimizing displacement or, in other words, selecting those projects that would be "under funded," delayed, or, otherwise inadequately pursued, the likelihood that the latter would happen with SME's is comparatively higher than with large companies. This is due to the increasingly high costs of R&D, the comparatively higher financing barriers to SME's (especially where financial markets are not so developed as in the U.S.), and the comparatively more negative impact of potential project failure on SME's.

It seems also that SME's tend to benefit more from R&D consortia to establish their competitive position. A possible explanation for this is that smaller firms have more potential to grow than larger firms which have already established competitive positions. Furthermore, as organizational literature explains, through R&D consortia firms internalize the externalities created through spillovers (this statement would open an interesting question on the preference between single-company's R&D project proposals vs R&D consortia's, from the financing agency standpoint). Since SME's are less capable than large firms in general to appropriate externalities, it is likely that they may benefit more, all things equal, from participating in R&D consortia. If one also considers the learning process involved in joint-R&D activities, in addition to the economic potential of their output, SME's tend to have more to learn than (from) large companies, which makes SME/large company partnerships more appealing.

The factors presented above belong on the good side of the coin. A comprehensive analysis though, should also investigate potentially less favorable aspects connected with SME's participation in R&D consortia. The latter regard mainly the implications for R&D project execution and program implementation.

Among the former, the relatively lower bargaining power of SME's participating in R&D consortia together with large companies, raises the likelihood of moral hazard especially with regard to intellectual property rights issues and exploitation of project results. As a consequence organization costs, such as those associated with monitoring opportunistic behavior of participants and aligning interests among participants, increase. Risk of project failure should increase as well.

Among the latter, less sophisticated information processing systems and weaker capabilities by SME's to provide project proposal assessors with all data and information needed to adequately carry out ex-ante project evaluation and selection, are to be expected and counteracted (in my own experience with the EC as evaluator of around twenty R&D project proposals, I have never come across a financial or economic cost-benefit analysis correctly carried out, nor was I able to carry out one myself with the information provided. This would open an interesting question about the interface losses between scientific-level debate, of the kind we are having here, program formulation and program implementation).

The positive reasons identified above which justify the presence of SME's in publicly financed R&D consortia are based essentially on economic potential issues. The ATP-like financing agency, though, is interested above all in the realization of such economic potential. More particularly though, in those projects where the gap between the expected social and private rates of returns to the nation is particularly high.

From this perspective, we may rephrase the original question in this way: "What is the appropriate mix of partners in a consortium that assure the realization of the economic potential of a project?" Excluding not-for-profit organizations as lead proponents, ATP in a sense, has already given a partial answer to the question (although there may be other reasons unknown to me underlying such constraints).

A well balanced partnership in ATP-like R&D projects is probably one involving all or most, according to the specific project, of the following: technology providers; technology users/intermediaries; end-users; and venture capitalists. Equally important is the convergence of the interest of all partners and a congruent resources/commitment participation of each partner.

In Europe in particular, where the ratio of public R&D to private R&D investments is higher and the integration of Universities/public research institutions with industry is less strong than in the United States, consortia composed of entities from both sides may be worth promoting.

Partnerships which involve trans-sectoral dimensions should be highly regarded as well, for the high potential of trans-sectoral knowledge spillovers. Trans-regional dimension, instead, appreciated as a positive factor in the above mentioned EC program (fostering cohesion), may be open to objections. While from a social point of view, it may be regarded as positive to reward the participation of less industrialized regions, the merit-based selection process would be unavoidably distorted. It is a matter of the underlying philosophy. Someone would say: "Teach them how to fish rather than giving them a fish". Others would reply: "Give them some fish while teaching them how to fish".

2. *What sort of technologies, e.g. infra structural, should be targeted in publicly financed research consortia?*

The most direct answer to such a question would be: those technologies which are more likely to contribute to the achievement of the ends of the publicly financed program in question. Then, for ATP-like programs, technologies which entail high market and knowledge spillovers, such as:

- infra technologies, i.e. those technologies that leverage industry's ability to conduct every stage of technology-based activity;
- "systemic" technologies, i.e. those technologies whose commercial value is strongly dependent on the development of other related technologies.
- "generic" technologies, i.e. those technologies with a wide range of potential market applications, which go beyond the scope of corporate strategies of firms participating in the consortium.
- "bandwagon effect" technologies, i.e. those technologies whose development may elicit significant developments of other technologies/applications.
- "breakthrough" technologies, i.e. those technologies which may open up new fields of activity, whose embedded benefits are unlikely to be wholly appropriated by the inventor.
- "gap filling" technologies, i.e. those technologies whose development induces significant advances in the underlying knowledge.
- technologies whose appropriability regime is weak, because of the inefficacy of the legal mechanisms of protection or the intrinsic nature of the technology (i.e. technologies whose embedded knowledge is codified rather than tacit);
- technologies requiring certain complementary capabilities or assets, other than those possessed by the inventor.

If the public financed R&D programs explicitly pursue social returns which go beyond the purely economic component of social returns, such as the above said EC programs, additional considerations need to be made. Probably, the most urgent problem that Europe faces, and indeed has proclaimed it will immediately deal with, is unemployment (it is sufficient to compare EU unemployment rate: 12%, with the U.S. rate: 5%, and Japan's rate: below 3% to realize the relevance of the problem). In this context EU publicly financed R&D programs in the future will most likely stress even more the importance of "employment generation" technology development.

Another aspect which may be considered from a social perspective is the distribution of economic benefits arising from publicly financed R&D projects. Two opposite positions confront themselves in the current debate: whether and to what extent one should rely on market forces alone for a fair distribution of economic benefits. The answer may depend on the particular environment. In fact, another element of differentiation between Europe and the U.S. and Japan is that regional development is less homogeneous in the EU. Probably, market forces alone would not be sufficient in Europe to reduce the gap among regions, or at least to do it at an adequate pace. In the absence of the EC programs specifically targeted to such problems, R&D programs would favor the development of those technologies oriented towards the needs of the industrial base of less developed regions.

The sort of technologies to be targeted in the R&D programs we are discussing here may depend also on the level of industrial specialization of and the industrial policy pursued by nations. If we compare international specialization indexes of high- and low-tech industries (in 1992, high-tech: U.S., 151; Japan, 144; Europe, 82. Low tech: U.S., 74; Japan, 46; Europe, 113) and their evolution along time, Europe competitive position in high-tech industries results relatively weak and deteriorating. This awareness may well lead to specific industrial and technology policies, which will determine the sorts of technologies to be pursued in R&D programs. Furthermore, such targeted technologies may vary across industrial sectors and along time. While in the past EC R&D policies seemed to emphasize the shifting of the best practice production possibility frontier, more and more diffusion concerns (moving industrial production units closer to the frontier) are being considered and affecting the formulation and implementation of R&D programs (see the up coming EC Fifth R&D framework program). Japan is another case in point. R&D programs' ends and technology pursued therein, have changed along time parallel to the shifting of Japanese industry form a simple follower stage to one of leadership in an increasingly number of sectors.

3. *To what extent should the funding government agency attempt to actively participate in the project?*

In order to answer this question it should be defined what "actively participate" means. In the world, it is possible to find examples of institutions whose mission is both to carry out research and act as funding agency as well. The National Research Council of Italy, to which I belong, is a case in point. In these contexts potential synergies between research and funding activities may be realized. At the same time the risk of opportunistic behavior gets higher, whereby projects evaluators may have more or less direct vested interests in the projects under examination.

For those government funding agencies which do not carry out research themselves, their more appropriate role is probably that of "sponsor". As far as it falls within their power domain, they should act as facilitators, smoothing obstacles, in order to improve the likelihood of success of the project. They should also try to streamline the bureaucratic burden of project monitoring and make it functional also to better management of the project itself. If necessary, they should try to protect the project from unnecessary distractions, such as the overlapping and redundancy of bureaucratic requirements by different administrations.

The most fruitful participation in a project would be, in my view, making the external environment as suitable as possible to allow for project success. This would entail to identify the critical factors of success of a project and the external variables which mostly affect them, in order to intervene on them, if within the agency's capabilities.

The search for complementarities and synergies with other similar programs is to be searched for, in order to avoid inefficiencies or duplication of efforts.

Finally, a way to transfer the learning curve of participating to such programs to new participants should also be devised, to enhance cost efficiency (it must be kept in mind that the larger the number of firms participating in a consortium, the more complex its management, therefore management costs increase. Furthermore, SMEs may have more problems than large companies in adequately fulfilling all program's requirements).

Concluding Remarks

The main conclusion that we may draw from the foregoing discussion is that there are no standard answers to the problem. Answers need to be nation-specific, reflecting context, policy, and culture of the country at stake. Differences can be identified even at the very basic level of objective formulation of programs. Is there a publicly financed R&D program in the US, EC, Japan, or anywhere else which does not pursue high social returns? Still, what does "social" mean to an American, a European and a Japanese? As can be extrapolated from the content, ends and eligibility/selection criteria of different nations' programs, the concept social is open to a quite broad range of interpretations. Employment generation, geographical distribution of benefits, etc. seem to be more highly valued by Europeans than by Americans or Japanese. Here, it is not a matter of somebody being right and somebody else being wrong. Each one is right, in his/her own context/culture.

I do not know if the results of this workshop are going to contribute to affect in any way future formulation of publicly financed R&D programs. If this is the case, it should be born in mind that considering at a very early stage the implications of program changes on implementation is of utmost importance. The implementation of a publicly financed R&D program is nothing else than an optimization problem. Changes to a program may affect either the eligibility criteria or the selection criteria or both. Eligibility criteria turn our optimization problem into a constrained optimization problem. The field of possible solutions to the problem may be more or less large depending on the number of constraints embedded in the eligibility criteria. We must be aware then, that any time we add eligibility criteria we restrict the field of possible solutions. Eligibility criteria should be consistent with a prioritization of objectives. For example, the EC R&D programs' eligibility criterion of transnational consortia can be translated into "select those projects with the highest expected public returns for the EC, as long as they are proposed by transnational consortia". Contrary to what most people would expect, an inevitable interpretation of the underlying message is that the main objective is not strengthening European industry competitiveness, especially SMEs, as it is often emphasized. Rather, it is fostering European member states integration (or, at least it is a prerequisite to the former). Nor can be thought that the objective is to encourage setting up R&D consortia, as this could be done as well with a national scope.

Changes may affect also selection criteria. The larger the number of selection criteria, the more complex the selection process. The relative weight of each criterion and of their correlation should be defined with respect to the objectives of the program. Also, it must be borne in mind that the task of an evaluator is extraordinary difficult. In addition to assessing the public potential (think of all the factors which determine it) of a project, he has to assess then the likelihood of success (think again of all the factors which may determine it), and finally the proportion of benefits which are likely to be appropriated by domestic industry vis-à-vis foreign competitors. Moreover, he has to do it under time pressure and relying on data provided by parties with vested interests and sometimes inadequate. At EC level these difficulties are further amplified (I just remember evaluating a project few months ago where, in addition to myself from Italy, there were two other evaluators from Germany and France, the EC officer in charge of the project from Belgium or, rather, Flemish (never confuse a Flemish with a Valloon), and two partners of the consortium, one from Denmark and one from Greece. You may wonder: "was Britain missing?". Do not worry, we all spoke and read documents in English. Probably, British English.

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I would like to discuss some issues regarding the design of publicly-funded research consortia based on my research on government-sponsored R&D consortia in Japan. When the government is involved in the formation of research consortia, government planners or coordinators can determine the design of consortia to achieve desired goals. The design of consortia includes the types of companies that participate, characteristics of target technology, and the degree of government involvement. The goal the government wants to achieve through consortia formation partly depends on the national development stage, and partly on the national innovation systems countries possess. I want to discuss the issue of the design of consortia in a broader context surrounding R&D in general, including some review of the historical development of R&D consortia in Japan.

Research consortia can change or enhance three major determinants of private R&D intensity, namely: technological opportunities; expected market size; and appropriability conditions. First, research consortia can contribute to or increase the technological opportunities companies face. For example, if the outcomes of research consortia efforts diffuse among and beyond participants, they will stimulate a new round of innovative activities. Also, within research consortia, firms can bring different expertise together in order to create new technology. The provision of government subsidies might contribute to the enhancement of technological opportunities firms face because subsidies can reduce the effective cost of conducting R&D, which might encourage firms to undertake more R&D.

Second, expected market size can be increased if uncertainty regarding buyer preferences are resolved. Also, when several standards exist and it is unclear which standard will become dominant, firms cannot focus their research direction on one standard; this uncertainty can discourage firms' efforts toward innovation. If research consortia involve vertical cooperation, suppliers would have a better idea about the characteristics of the expected market because buyers can communicate with potential suppliers about the specifications of products they might want.

Third, appropriability conditions can be improved through the formation of research consortia because firms can set clear cost-sharing rules before R&D is executed and outcomes are shared. Thus, the incentive to conduct R&D, which could be hindered by potential spillovers of R&D outcomes, can be restored through the occurrence of R&D consortia.

Different countries face different degrees of problems on these three determinants of R&D intensity, and so the design of research consortia should be set to address major problems a country wants to solve. When a country is in a developing stage, for example, or behind in a certain technology area, a major problem that type of country faces is the lack of R&D capability by domestic firms to produce original R&D results. Research consortia will be used to transfer and digest technology developed by advanced countries. In such a case, participating firms in a consortium will come from a narrow set of industries, because the goal of the project is clear, almost set by other countries, and the major task is to take the most efficient research path by dividing tasks and avoiding wasteful duplications. I call this the VLSI project model. For these countries, large government subsidies will be warranted against other countries.

There will be a limited moral hazard problem in research consortia in this case, because there will be no significant difference in R&D capabilities among firms. This implies that cooperation among companies with different technological levels will be possible because no one firm will feel that it suffers from the opportunistic behavior of other companies to absorb as much as possible while keeping their own technology secret. Even if a firm feels that some proprietary knowledge may be threatened, the benefit to participating in research consortia, namely the government subsidies and access to advanced technology, will outweigh such a potential loss.

When a country is one of the technology leaders, the desired goal has to be changed from the model I just described. The major problem for a country will now be to generate original technology which will be a core of next-generation technologies. The goal to be achieved through research consortia formation should be to increase technological opportunities available to companies, and to facilitate spillovers among companies. To achieve this goal, governments should promote the formation of consortia which consist of firms from diverse industries. In this case, the participants will face learning opportunities from firms with different backgrounds, and so it might be the case that firms will have an incentive to increase their R&D efforts in order to absorb from other members. Knowledge or skill sharing, rather than cost sharing, should be the main purpose of such consortia, and government subsidies should play a less critical role compared with the previous model. In my analysis, I found evidence that the knowledge sharing opportunity brought by diverse participants has a positive effect on participants' R&D efforts.

Once a country achieves technological progress and firms accumulate technological capabilities, it will be more difficult to ask technology leaders to participate in research consortia, because potentially they can lose more than they can gain from other participants. The target technology should be basic, because when near-commercial technology is targeted, the conflict of interest will be greater among participants, which will exacerbate moral hazard problems.

Japanese consortia confirm the propositions above. I collected data on government-sponsored R&D consortia in Japan. In my data set, I identified 237 R&D consortia occurring between 1959 and 1992. 1171 companies participated in these consortia during this period. I conducted a questionnaire to participants of these R&D consortia in 1993. There were 398 useable responses from 67 companies concerning 86 projects.

Questionnaire results showed that the breadth of participation in a consortium has increased over the years of the study. It is also shown that the target R&D outcome has gone from near-commercial in the 1960s to more basic by the late 1980s. In my sample, government-sponsored R&D consortia represent only a small fraction of the total Japanese R&D expenditure, and the per project budget peaked in the 1970s.

In the 1960s and 1970s, Japanese firms were desperate to catch up with Western technology leaders, facing direct competition from them after the trade and foreign direct investment liberalization in the early 1970s. Japanese firms at that time did not possess enough R&D capability to produce original R&D results, and there was no significant difference in R&D capability among firms. Their financial resources were also limited. Government funding for R&D consortia did matter for participants, and the subsidy provided to a typical consortium in the 1970s was eight times larger than the subsidy provided in the 1980s.

As for the composition and the goal of research consortia, participants tended to come from a narrow set of industries, and the target technology was relatively near-commercial. Participation was a signal of a firm's recognized R&D capability to outsiders such as buyer industries and banks, which encouraged the participation of technology leaders.

This model no longer holds in the 1990s. Differences in capability among firms has grown larger, and in interviews some government officials noted that there are signs that technology leaders are now hesitant to participate in R&D consortia. The size of government funding per project has become smaller, firms have become less capital constrained, and so government funding is not a primary inducement of participation. Questionnaire results suggest that firms can only agree on projects which are distant from commercialization, and which are associated with less conflict of interest. They can only agree on the projects which require complementary knowledge, and ones which are impossible to conduct by themselves.

What is the role of publicly-funded research consortia in the 1990s? The 1970s model of horizontal cooperation which was driven by the motive of sharing fixed costs with heavy government involvement, as seen in the VLSI project or SEMATECH, is not an answer. A general recommendation for government policy to developed countries is that government should set criteria to promote cooperative R&D which achieves its social goals and minimizes risks to competition: encourage participation from different industries; promote cooperation in basic research; promote cooperation in emerging industries; and give partial funding to make government funding complementary. My analysis suggests that though government-sponsored R&D consortia will allow firms to conduct research projects which firms would have done on a much smaller scale without government subsidies, government subsidies could work as a substitute to a firm's total R&D spending.

Governments should note that cooperative R&D cannot substitute for other policy tools to stimulate private R&D. For example, cooperative R&D might have only a limited role in increasing technological opportunities and technological diffusion; funding of basic research, especially funding of research in universities might be a more effective means for this purpose. For countries with high researcher mobility, researchers contribute to the dissemination of technological information, and so such a role by R&D consortia might be limited. Also, cooperative R&D does not solve demand uncertainty unless user industries are also participating; public procurement is a more direct means for this purpose, though it should be used only in the cases in which the government can be a sophisticated and cost conscious buyer.

In conclusion, the design of research consortia, and technology policy in general, should be considered in the context of national innovation systems. Research consortia should be treated as one of many tools governments can use to promote R&D.

PANEL SESSION: Public-private Partnerships In R&D: Lessons Learned

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1. Why are we having this conference and how can one benefit from it?

I think the importance of this conference derives from a number of factors. First, I think it reflects the increased standing of R&D in economic policy formation. From a European Union perspective, this is reflected in the design of the evaluation criteria for the Fifth Framework Program, which has put specific emphasis on economic factors, particularly economic growth and employment performance. These are largely macroeconomic considerations and are a measure of the concern felt by policy makers over poor economic growth performance in Europe and the need to cast the net wider than the traditional instruments to find the means of solving the problem. The US, for its part, is enjoying a period of strong growth, which has depended in no small way on the contribution of high-tech industries. Thus across the world economy, there is an increasing appreciation and expectation of the economic role of R&D investment. However, the specifics of this role have never been satisfactorily identified and events such as this help to clarify how the task can best be addressed.

Second, this new emphasis on economic objectives implies that we now have to measure research performance in economic terms. We can no longer adopt the 'research is good' attitude which underpinned earlier approaches to evaluation. We are asked to choose between alternative research programs and are thereby confronted with the classic economic problem of resource allocation and therefore need a way of measuring impact. However, we are also confronted with a serious measurement problem. This was more or less the conclusion of the Workshop we organized on measuring RTD results/impact in Brussels last month and the discussion here helps us in addressing the problem of developing appropriate methodologies for measuring economic impact.

Third, the classic benefit of conferences and the reason those of us in the knowledge generation business encourage them is to facilitate dissemination. Much of the material presented here in the last two days opens up promising avenues of exploration which can potentially be applied in Europe to our own problems of impact measurement. Perhaps my presence here will be justified by the generation of a sort of transatlantic spillover effect.

Fourth, there is no doubt a more skeptical political climate underpinning the support for public research programs. Part of the need to demonstrate results, and particularly economic results, is to fulfil a defensive purpose. The political motivation for intervention to support research is increasingly based on the premise that it boosts economic performance - this is no doubt part of the motivation for the increased reliance on partnerships between public and private sector. However, as we have seen, this support for public RTD is fragile and anything which can be done, therefore, to demonstrate the positive impact of our efforts can only be helpful to those of us who believe that there is a role for the government to play in the economic domain. Compared to the political hostility recently experienced in the US, the political climate in Europe is in some respects more supportive of government support for R&D. However, the atmosphere is certainly more skeptical than heretofore and this is reflected in the adoption of the stricter new selection criteria and although European political attitudes remain solidly in favor of intervention, there is nonetheless evidence of a hardening of attitudes which means a more uncertain future for public research, particularly research in areas where the results are less tangible.

2. Which methodologies appear most promising for current usage and which ones need further development?

Measurement of economic impact is, as we have discovered at European level, an area which poses serious methodological problems. Part of the problem can be attributed to a mismatch between the political objectives set for R&D performance which are largely macroeconomic in character (improving economic growth or alleviating the unemployment problem) and the means available to tackle the measurement problem (at this stage, the only scientifically reliable methodologies available are microeconomic in character. Of these, the one most successfully employed at European Framework Program level is that of the BETA institute at the University of Strasbourg which has resulted in the calculation of impact ratios for given levels of RTD investment in various European research programs. Perhaps the best publicized BETA finding was in relation to the 1993 study of the BRITE-EURAM program which indicated a 7:1 ratio of economic benefits accruing from the initial EU investment. The appeal of this methodology derives from its theoretical rigor and empirical validity. However, the difficulty with such microeconomic methodologies is their limited applicability to the macroeconomic objectives outlined above. Using such microeconomic results in a political context can only give rise to serious problems of interpretation regarding the economic prowess of technology policy.

Of other approaches, the one which I found most striking (even if its findings were not what supporters of intervention one would have wished for) was that used by Scott Wallsten and documented in his testimony before Congress on the impact of the SBIR program. Apart from its theoretical plausibility, the attractiveness of this methodology I think derives from its direct focus on the additionality issue and is therefore deserving of wider application into areas where the results are likely to be more favorable to proponents of R&D support.

Other methodologies which are promising but are in need of further refinement include some of those which have been presented at this conference. From the viewpoint of designing policy, I was particularly interested in approaches which sought to establish a clear link between policy and subsequent performance. - of particular note in this regard were those adopted by Klette and Arvanitis because of their focus on measuring national policy effects directly. Another particularly interesting presentation for me was that made by Francis Narin linking the effects of basic research in subsequent patenting behavior because this could represent a promising technique for assessing the impact of many of the more basic-research-oriented activities (within the Framework Program there are many such activities). Overall, however, it is difficult not to agree with the opinion expressed here and also at our own May workshop in Brussels that there are a number of dimensions to the measurement problem and a need particularly to establish links between the micro and other more aggregate levels.

3. What are the multiple purposes and rationales for such partnerships from a public policy perspective and from the perspective of private industry?

As regards the rationale for intervention, perhaps I can put my contribution to the market failure argument as follows. Under traditional economic growth theory, because of the assumption of diminishing returns, the actions of investors are assumed to only have *private* significance and there is no role for the public authorities in the capital formation process. However, in the absence of diminishing returns, the actions of the private investor lead to under investment. This problem of under investment does not imply any inadequacy on the part of the private investor - indeed, at the level of his private decision, the assumption of diminishing returns may well hold. Another way of putting the argument is by considering that the development of ideas or know-how is a costly process, but once something is known, it can be repeated ad infinitum at no extra cost. The existence of development costs, however, implies that ideas or know-how are not in free supply and therefore, need to be recompensated. Thus the new insight offered by endogenous growth theorists is that there is a spillover from the actions of private investors *taken in aggregate* in terms of new knowledge which generates additional returns.

This insight applies particularly to R&D investment activity because of its public goods character but also to any activity which results in increased dissemination of knowledge (it is for this reason that new growth theorists additionally emphasize the importance of training and research networks). The dichotomy between the private return to investors and the actual return imply market failure and the case for intervention to boost RTD activity rests on correcting this failure. From a policy standpoint, the inference is that RTD policy, which has traditionally been viewed mainly as an instrument of microeconomic policy is now viewed as an economic policy tool which also has macroeconomic significance with a clear role to play in addressing problems of economic growth.

The notion of partnerships also corresponds to the needs of both parties involved. From the viewpoint of the public sector, the rationale is that it is a means of improving the economic efficiency of its research activities via explicit links to the commercial sector. In addition, it is a means of guaranteeing the necessary dissemination of the spillovers arising from the investment. From the perspective of the private sector, it appears that there are a number of advantages to the arrangement. First, it is a means of access to technologies via the other partners in the consortium. Second, there is evidence to show that European firms consider that this means of research funding is an important mechanism for reducing the risk involved in undertaking an R&D project. However, I think the most interesting aspect of this question however, relates to the question of capital market imperfections. The advantage of public funding is that it enables the firm to undertake research which it would otherwise not undertake, research of a more risky character but therefore likely to generate the sort of high returns that we have seen in some studies of R&D impact in Europe. This type of investment, which is not only of benefit to the firm (even under diminishing returns) is critical to the achievement of societal goals.

Lastly, it is probably worth emphasizing that among the most important economic effects of research investment is the learning effect generated via the process of participation (network effects could be seen as a typical example of this). Several European studies have emphasized the importance of this factor in improving long-term economic growth potential. One of the difficulties, however, with such long-term effects is that their measurement can be extremely problematical.

4. Consider how these rationales and the foci of technology policy initiatives vary among countries: related to economic development, policy priorities, strengths/weaknesses of the private sector.

This question is a particularly interesting one from a European perspective and offers me the opportunity to make the case for having a technology policy based at the European level. I think the question is perhaps best addressed in any case by comparing technology policy in the US and the EU taken as a whole because there is a market size dimension to this issue. Although the larger member states of the EU still wield a significant degree of independence in economic policy setting, the increasing globalization of economic activity means that the scope for independent action is diminishing. For the smaller member states, this scope for autonomy has never really been a consideration. Perhaps this is the reason why it is so difficult to demonstrate the effects of R&D policy at individual country level (although Norway is not a member-state, the results of Tor Klette's study seem instructive in this regard). That this interdependence is no bad thing is recognized by the countries themselves through the introduction of important institutional changes, the establishment of the Single Market being the most important of these. The European focus of different aspects of economic policy, notably monetary policy, follows on logically from the Single Market project.

The research position and its increasing economic focus could also be taken to reflect this reality. Science being international in character, there was already a strong rationale for a European effort and the achievement of the Internal Market has underpinned the establishment of stronger links between economics and RTD objectives and in particular, to strengthen the economic focus of the Framework Program. In this sense, a correspondence can be traced between the theoretical emphasis on the importance of technology transfer and spillovers and the creation of the appropriate institutions at international level to foster these objectives.

In summary, the economic rationale for a European research program could be said to be that it underpins the single market and by encouraging maximum co-operation eliminate duplicative effort at national level is the most efficient response to underlying economic realities. This market size aspect of technology policy design has never been an issue to the same extent for the US and the relative success of its policy could be a reflection of the importance of this structural feature.

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1) Why are we having this conference and how can one benefit from it?

The title of the conference deals with 'economic evaluation' and 'technological change.' At the same time, a session dealing with patents is labeled 'private innovation' and public research'. These terminological variations are revealers of the uncertain space in which policy evaluation develops. What is at stake, what is put forward when promoting such policy initiatives deals with innovative capabilities of firms in a given country.

Both economics and sociology join to underline a set of lessons about innovation - and it is so rare a case that policy analysts should really look carefully at them! Let me mention some very briefly since, to my point of view, they represent the core of arguments developed in cases evaluated (at least those I know of).

* A first set of lessons underlines the role of 'lead' users and the importance of going from 'sub-contracting' to 'co-development' with suppliers. Both push towards industry alliances (which de facto have witnessed and are witnessing an exponential growth), but these are 'vertical' alliances (i.e., excluding any direct competitors)... and should not concern governments attentive to competition rules. The rationale for intervening in such fields has to be found elsewhere: in the public benefits that could derive from the new products, in answering a public good need. New drugs for orphan diseases, new tissues for cardiovascular therapies, new energy options are some examples which do not only belong to the sphere of defense industries. They should not be underestimated... and I must say, this is an issue which has not been addressed yet in satisfactory terms.

* A second set of lessons deals with 'radical innovations' (which following Apple and Microsoft are very fashionable ones today). It highlights the decisive role of early choices (the so-called 'small events') in their trajectory; it shows the very long cycles of most to go from their first niche market to generalized use (which makes them recognized as radical innovations that have transformed the world). Thus all the fashionable and politically very attractive about enlarging the number of those 'inventors' who get a chance for a first test : we have gone here to the simple notion of access to funds to this of helping them build their very first 'niche', their first network of interested partners, ATP being clearly positioned along this line. And as time (as well as criteria) are not there to assess 'generalization', the core of the effort goes along the definition of what enters in this category of 'potential radical innovations': ATP seems to have been quite innovative in this respect.

* A third set of lessons, following Polanyi's work on tacit dimensions on knowledge, insists, especially in so-called 'frontier science' or 'science in the making' on the need for direct connections for firms to be able to master internally the new knowledge under production, to turn in into specific assets. Thus the need for public-private relations and the boom in industry-university relations (at least in Europe where more and more companies pay for PHD students, enter into lasting contracts with public research units...).

To better grasp the frame under which such partnerships develop, this phenomenon needs to be linked with two other ones.

a) Many authors have highlighted the role of 'non technological' dimensions of innovations processes, locating the ability of successful firms less in their technology portfolio than in their organization of the innovation process and in their so-called 'design capabilities' (I have used the terminology 'block building model of innovation' to highlight the difference between the 'internal mastering of a technology' and the ability to mobilize the relevant technological option in a given development). Thus sharing a given technology with others might not be so frightful since the core of the competitive advantage lies in the ways it is mobilized. The danger is then not to share it with others, but to be barred from its access in due time.

b) At the same time innovation analysts have highlighted the multiplication of technologies any product integrates and for each technology the explosion of potential new options. These two simultaneous changes (in 'reality' or, may be more, in our understanding of innovation processes) explain why companies enter more and more into partnerships while being competitors and why in such partnership the 'public research' type component is often central. This promotes a different analysis of innovation dynamics where the notion of 'reservoir of knowledge' remains central provided one accepts a small change: each economic actor has to build and shape its own reservoir. The idea of doing this alone, however large the firm might be, has now gone, less for financial reasons than for competence ones. Thus partnerships have become or are becoming central to the shaping of the firms' reservoirs of knowledge, (To my point of view the risk and cost dimensions are not central at this stage of 'internal mastering of technologies' ; they play a major role at later development stages .. with both the increases in mergers and in alliances specific to one product line)

May they be termed 'indirect' effects (Cohendet), 'socio-economic' effects (see Georghiou, this conference), 'structural' effects (see Laredo, 1995) or spillovers (as overwhelmingly used in the US), these situations have been at the core of assessments, audits or evaluations. Still, there is a long way to go from the micro level of case studies (now quite well documented) to the 'meso' level of the policy initiative or to the 'macro' level of a country / 'national system of innovation' (this latter dimension pushing the issue of comparisons between policy initiatives and of the national frame or 'system' for evaluation).

This long development was necessary for my own understanding of what the conference aims at, and of the differences that can be witnessed between the American and European evaluation scenes. The former focuses more on producing figures (what return for the public investment) while the latter insists more on images (what changes in the innovation landscape). They might well be two corners of the same story, but they still remain to articulate...

2) Which methodologies appear most promising for current usage and which ones need further development?

It is very difficult to answer beforehand to this second question. Personally I would rephrase the question : there is no case I know of which is satisfactorily described by only one method. Thus the issue is the mix of methods which enable to have both the 'figures' and the 'image', the numbers and the landscape. Thus a central issue: which evaluation process for choosing the relevant methods of investigation, those adapted to the initiative under review or, as is more often the case, to each part of a given policy initiative.

3) What are the multiple purposes and rationales for such partnerships?

From a public policy perspective and from perspective of private industry?

I needed to answer this question to address the first question posed. So may be it should be useful to start with this question. I have addressed the rationale from the 'innovation promoter' standpoint (which is not always equivalent to a private firm, see Etzkowitz and his notion of research groups as quasi-firms.

From a public policy perspective, two elements are central a) 'Public goods' or 'collective issues' such as environment or health drive a large part of our economies. The choices are most of the times built through a triangular relation between public promoters (government but also states, counties and cities), private operators which will eventually be delegated operations ('utilities') and public sources of knowledge built by public authorities to advise them, to anticipate new problems, to open new options for choice (new energy options being a typical case of such approaches) b) fostering the adequate research infrastructure as government intervene for transport infrastructures, for organizing telecoms, etc: there is now a new challenge for 'generalizing' the capacity of economic actors to access new technologies in the making (cf my third 'lesson')

The third element - high risk ventures - is the US way to the old fashioned French 'grands programs': in France we believed in military type organized efforts along major industrial issues (with it must be said afterwards quite significant successes besides few exemplary failures); in the US there seems to be a belief in the genius inventors - and that not enough make their way ahead, so that public action should help giving a chance to 'claiming to be radical innovators'. One can easily understand that it faces difficulties for justification.

I leave aside all the 'market failure' type arguments - for those 'poor' small SME's which we must socially assist, for those lost public researchers who want to create their own companies, etc. We all face these politically fashionable and sensitive problems. They are out of the present debate.

Five Concluding Remarks from the Presentations and Discussions

Philippe Laredo

It is a difficult but challenging task to draw some conclusions from ten presentations, two panel sessions and two days of extensive discussions. Being external to the field of econometric studies which were the main focus of this conference, I shall focus on the conditions for development and limits of such methods, as put forward by the different speakers and the audience.

My comments will be organized around five points: semantic issues, the importance of context, the take-up of policy choices and implementation within models, the balance between model development and data quest, and finally, the focus of research on evaluation (methods vs process).

Semantic issues as revealers of different frames of analysis. The keyword in this conference for justifying public intervention in innovation was without doubt "spillovers". It is symbolic to see its overwhelming presence in all but one titles of presentations by U.S. speakers while it was completely absent from European ones where the main wording referred to socio-economic, indirect or structural effects. Internalizing "externalities" (an expression rarely used by both "sides") takes thus complementary routes on both sides of the Atlantic Ocean. Spillovers account for an approach where overflows are both barriers to private investment and reasons for public involvement. Public intervention is traditionally there to design more effective frames (e.g. fostering appropriability) and/or to compensate for leakages. But if overflowing is taken as an intrinsic dimension of market dynamics (Callon, 1998), organizing public intervention to foster "socio-economic" effects is to be considered as an objective for public intervention and a "win win" situation where both given private actors (e.g. a company dedicated to gene therapy) and wider subsets of the society (e.g. patients with cystic fibrosis) will benefit from public support to the former. How to identify such areas? Which criteria and support mechanisms to design? These questions have been central both to ATP and EU programs. ATP has developed extensive sets of criteria for qualifying these situations while European Programs have insisted on consortia and private-public collaborations as a marker of such situations. This joins the point made by Jaffe, Singh, and Fogarty in their presentation: spillovers are localized, they do not constitute "pools" but are linked to existing "networks" (see our own approach for EU programs, Laredo 1998). Semantic differences, as well as attempts to bridge them, act thus as revealers of different focuses in policy making.

Context Matters:

A striking second result dealt with the context in which technological change and innovation happen. Analyzing patents, and citations of scientific papers, Narin insisted upon local effects, showing that this phenomenon does not only apply between nations but within nations, highlighting in patents the strong geographical correspondence (similar states) between inventors and the scientific references made. Also using patents, Jaffe, Fogarty et al, went one step further, developing a model linking the potential for spillovers to firms' system position. But "innovation networks" do not only encompass those actors dedicated to technological change may they be from university, national labs or companies. Involvement is far more heterogeneous. Gompers and Lerner, for instance, told us that without taking into account the 1979 change by the Department of Labor in the way pension funds account for risk assessment (from project to portfolio risk assessment), Venture Capital would not have developed the way it has, hampering the explosion of new high tech companies which build up the core of the transformations observed this last decade. How to take context into consideration in econometric studies is therefore a central challenge.

Policy Matters:

However central, this is not enough a challenge, were we told by other speakers. The choices and forms of public intervention are also to be accounted for. To explain the positive effect of public support on firms efficiency in Israel as opposed to results obtained in Norway or in the U.S., Griliches and Regev arguments revolved around the framing and implementation of policies: "government has been more lucky in selecting firms", "the policy was less planned (than in Norway), more bottom-up, with more opened windows", "they were able to give the grants to good people". Such explanations, as well as arguments developed by Klette about "institutional inertia" and "complexity of coordination", raised a new set of issues. What difference does it make in the long run for public intervention when support is focused on "potential Microsoft in their early stages" or when it is used for "raising the technological capability of a given set of actors"? when "picking up winners" is opposed to "caring more for those which have difficulty to absorb new technologies (generally SMEs)? Or when different forms of support are used (tax incentive vs direct support, grants vs reimbursable loans in case of success, etc)? Can such issues be left out from the models?

The balance between model development and data quest. Such a question was directly related to the following one: What is the adequate balance between further model refinement and the access to relevant data? How much can evaluation studies rely upon available datasets? The impressive collecting effort made by ATP (as presented by Ruegg) is to be related to the investment made by CHI for being in a position to follow the relations between patenting and scientific activities or by Carnegie Mellon for Cohen to study industry appropriability strategies. The quest for ad-hoc tailored data "at project level (funded or not)" or "through direct surveys of firms" was voiced more than once in these two days. The conference ended with the very strong plea by Jaffe advocating for controlled experiments as in clinical research and as witnessed for social policies: would firms be the sole entities to escape this well established evaluation approach?

Return to semantics: evaluation methods vs evaluation process. Such a question resonated with previous presentations by European speakers- Georghiou on socio-economic effects and additionality, Dreher on lessons to be drawn from the German evaluation experience. The focus was there less on methods and more on the embedment of evaluation in a larger policy frame. Evaluations are not seen as one-off events but as periodic, feeding into "strategic management". What is then at stake is the evaluation process through which present-day issues are identified, relevant approaches selected and interaction with policymakers and stakeholders at large organized (for a description of such articulations in Europe, see the book edited by Callon & al, 1997). Dreher advocated for giving to evaluations a "moderating task creating transparency in a multi-actor network" and thus "serving as support for enlarged debates in wider arenas than solely administration and directly interested parties". Henderson spoke of evaluations as a means for "structuring conversations". These positions underline the fact that evaluations do not exist in a vacuum, that they are part of the policy-making process and widely differ from control exercises. It is not their primary objective to distribute good and bad marks. Looking into past action serves to learn about future action. As highlighted for innovations, this learning process is central for policy development. Policy making can no longer be seen as a sequential or linear but as an interactive, whirling process where evaluations' role is to help in the closure of each loop, feeding into the debate for defining the next loop. Following Leeuw & al (1994) using Argyris approach, this learning process covers the whole of the policy frame and simultaneously addresses objectives pursued and implementations structures (Rip, 1987). Evaluation methods require thus to be related to the stage of development of the policy under consideration, to the frame in which evaluation takes place and the nature of questions presently raised. It was not then surprising to witness within the audience a plea for enlarging the "toolbox of robust methods" and for a greater mix of qualitative and quantitative methods in evaluation processes.

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About the Advanced Technology Program

The Advanced Technology Program (ATP) is a partnership between government and private industry to conduct high-risk research to develop enabling technologies that promise significant commercial payoffs and widespread benefits for the economy. ATP provides a mechanism for industry to extend its technological reach and push the envelope beyond what it otherwise would attempt. Promising future technologies are the domain of ATP:

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- Technologies for which there are challenging technical issues standing in the way of success;
- Technologies whose development often involves complex "systems" problems requiring a collaborative effort by multiple organizations;
- Technologies which will go undeveloped and/or proceed too slowly to be competitive in global markets without ATP.

ATP funds technical research, but it does not fund product development. That is the domain of the company partners. ATP is industry driven, and that keeps it grounded in real-world needs. For-profit companies conceive, propose, co-fund, and execute all of the projects cost-shared by ATP. Smaller companies working on single-firm projects pay a minimum of all the indirect costs associated with the project. Large, "Fortune-500" companies participating as a single firm pay at least 60 percent of total project costs. Joint ventures pay at least half of total project costs. Single-firm projects can last up to three years; joint ventures can last as long as five years. Companies of all sizes participate in ATP-funded projects. To date, more than half of ATP awards have gone to individual small businesses or to joint ventures led by a small business. Each project has specific goals, funding allocations, and completion dates established at the outet. Projects are monitored and can be terminated for cause before completion. All projects are selected in rigorous competitions which use peer-review to identify those that score highest against technical and economic criteria.

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