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ABSTRACT

This document contains the proceedings from the National Science Foundation (NSF) Workshop on Strategic Research Partnerships. Papers include: (1) "Strategic Research Partnerships: Results of the Workshop" (Albert N. Link and Nicholas S. Vonortas); (2) "Strategic Research Partnerships: Evidence and Analysis" (Stephen Martin); (3) "Strategic Research Partnerships and Economic Performance: Data Consideration" (Donald Siegel); (4) "Inter-Firm Partnerships--An Overview of Major Trends and Patterns Since 1960" (John Hagedoorn); (5) "Using Cooperative R&D Agreements as S&T Indicators: What Do We Have and What Would We Like?" (David C. Mowery); (6) "Strategic Research Linkages and Small Firms" (David B. Audretsch); (7) "Strategic Research Alliances and 360 Degree Bibliometric Indicators" (Diana Hicks and Francis Narin); (8) "Strategic Research Partnerships in Biotechnology" (Maryann P. Feldman); (9) "Strategic Research Partnerships: Their Role, and Some Issues of Measuring Their Extent and Outcomes--Experiences from Europe and Asia" (Mark Dodgson); (10) "Strategic Research Partnerships in Japan: Empirical Evidence" (Mariko Sakakibara); (11) "Strategic Research Partnerships: What We Have Learned?" (John T. Scott); (12) "Constructing Indicators of Strategic Research Partnerships" (Barry Bozeman and James S. Dietz); and (13) "Technology Innovation Indicators Surveys" (John A. Hansen). (YDS)

# Strategic Research Partnerships:

## Proceedings from an NSF Workshop



Special Report

Division of Science Resources Studies
Directorate for Social, Behavioral, and Economic Sciences
National Science Foundation
July 2001

# Strategic Research Partnerships:

# Proceedings from an NSF Workshop

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Special Report

Division of Science Resources Studies
Directorate for Social, Behavioral, and Economic Sciences

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The Division of Science Resources Studies (SRS) fulfills the legislative mandate of the National Science Foundation Act to ...

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To carry out this mandate, SRS designs, supports, and directs periodic surveys as well as a variety of other data collections and research projects. These surveys yield the materials for SRS staff to compile, analyze, and disseminate quantitative information about domestic and international resources devoted to science, engineering, and technology.

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Any opinions, findings, conclusions, or recommendations expressed in this report are those of the participants, and do not necessarily represent the official views, opinions, or policy of the National Science Foundation.

# Contents

## Part II: What are the Policy Needs for SRP Indicators?

## Foreword

The Division of Science Resources Studies (SRS) of the National Science Foundation (NSF) supported the workshop on "Strategic Research Partnerships," that was convened at SRI, International, Washington D.C., on October 13, 2000. The objective of this workshop was to identify for NSF, SRS, and the National Science Board the policy needs for, and available data on, indicators related to the formation, activities, and economic consequences of alliances and strategic research partnerships (SRP). An SRP was broadly defined as an innovation-based relationship that involves, at least partly, a significant effort in research and development.

Patterns of the Nation's R&D investments have changed considerably during the past twenty years, including an apparent increase in the web of partnerships among firms, universities, and federal agencies in conducting R&D and sharing the resultant knowledge. The information generated by this workshop is intended to assist NSF in its continuing effort to track and measure these structural and process changes, and to advance the possibility of developing indicators related to SRPs. An understanding of the nature and magnitude of these changes is needed to inform program and policy deliberations and assist in planning various science and technology initiatives.

The information presented here complements and augments the coverage on R&D partnerships and technology alliances in the *Science and Engineering Indicators* report (Chapter on U.S. and International Research and Development Funds and Alliances) of the National Science Board.

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July 2001

## Workshop Agenda

### Workshop on Strategic Research Partnerships

Sponsored by the National Science Foundation

Convened at:
SRI International, Washington, DC
October 13, 2000

*The purpose of this policy workshop on strategic research partnerships (SRPs) is to evaluate:*

- *What are the policy needs for indicators related to the formation, activities, and economic consequences of alliances and SRPs? What data and indicators are currently available about alliances and SRPs? What are their strengths and weaknesses?*
- *How should the Science Resources Studies Division of NSF proceed to develop SRP indicators?*

### Agenda

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| **8:30** | **Assemble and Coffee** | at SRI |
| **8:45** | **Welcome**<br>Purpose of the Workshop<br>Overview of the Day | Lynda Carlson<br>John Jankowski<br>Al Link |
| **9:00** | **PANEL 1:**<br>**SRPs and Economic Performance** | Greg Tassey, Moderator |
| | "Strategic Research Partnerships: Evidence and Analysis" | Stephen Martin |
| | "Strategic Research Partnerships and Economic Performance: Data Considerations" | Don Siegel |
| | "Inter-Firm Partnerships–An Overview of Major Trends and Patterns Since 1960" | John Hagedoorn |
| | "Using Cooperative R&D Agreements as S&T Indicators: What Do We Have and What Would We Like?" | David Mowery |
| | "Strategic Research Relationships and Small Firms" | David Audretsch |

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| **10:30** | **Break** | |
| **10:45** | **PANEL 1: continued** | |
| | "Strategic Research Alliances and 360 Degree Bibliometric Indicators" | Fran Narin |
| | "Strategic Research Partnerships in Biotechnology" | Maryann Feldman |
| | "Strategic Research Partnerships: Their Role, and Some Issues of Measuring Their Extent and Outcomes–Experiences from Europe and Asia" | Mark Dodgson |
| | "Strategic Research Partnerships in Japan: Empirical Evidence" | Mari Sakakibara |
| **11:45** | **General Discussion on Panel 1** | Nick Vonortas, Moderator |
| **12:30** | **Lunch** | at SRI |
| **1:30** | **PANEL 2:**<br>**What are the Policy Needs for SRP Indicators?** | Chuck Wessner, Moderator |
| | "What We Have Learned" | John Scott |
| | "Constructing Indicators of Strategic Research Partnerships" | Barry Bozeman |
| | Comments on Panel 2 | Franco Malerba<br>Greg Tassey<br>Andrew Wyckoff<br>Kathy Combs<br>John Hansen |
| | **General Discussion on Panel 2** | |
| **3:15** | **Break** | |
| **3:30** | **PANEL 3:**<br>**How Should NSF Proceed to Develop SRP Indicators?** | Lynda Carlson, Moderator |
| | Specific Recommendations to NSF | |
| **4:45** | **Closing Remarks** | Al Link |
| **5:00** | **Informal Discussion and Refreshments** | at SRI |

## Strategic Research Partnerships: Results of the Workshop

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The George Washington University

### I. Introduction

A strategic research partnership (SRP) can be broadly defined as an innovation-based relationship that involves, at least partly, a significant effort in research and development. The objectives of this workshop on strategic research partnerships were to evaluate:

- What are the policy needs for indicators related to the formation, activities, and economic consequences of alliances and SRPs? What data and indicators are currently available about alliances and SRPs? What are their strengths and weaknesses?
- How should the Science Resources Studies (SRS) Division of NSF proceed to develop SRP indicators?

This paper summarizes the salient points of the background papers that follow in this report, as well as the general discussion during the workshop. To advance NSF's interest in the possibility of developing indicators related to SRPs, the papers and the discussion appraised the potential use and the nature of such indicators. The approach was essentially based on two questions:

- Are SRP's important to the economic system? More specifically, do SRPs deserve policy attention? Are SRPs important from an economic or policy perspective?
- What data initiatives are needed with regard to understanding the economic importance or policy relevance of SRPs?

There is little doubt as to the answer to the first question. Prior research has shown that SRPs constitute an important–and probably increasing–component of the innovation system, and the papers presented and discussed at the workshop confirm this. There is a long list of reasons why this is so. In a few words, it can be argued that SRPs are socially useful because they expand the effective R&D resources applied to innovative investment.

Second, the background papers and the discussion during the workshop clearly indicated that existing data on SRPs suffer from various shortcomings. There is a need to develop systematic tracking of the incidence of the inputs and outputs associated with various types of SRPs.

Analytical and policy needs have traditionally driven the construction of new statistical indicators. Specific broad policy questions apply pressure and "pull" such indicators. The literature and, more generally, the understanding of a phenomenon is mature enough to be able to support methodologically the construction of efficient indicators. It was the consensus of opinion at the workshop that this is exactly where we now are with respect to SRPs; SRS should begin a systematic collection of statistical information related to various dimensions of SRP activity.

Section II of this paper summarizes the chronology of innovation-related indicators that NSF has developed. Section III presents our interpretative summary of the salient points from the background papers presented at the workshop and the discussion that followed as related to the first of the two objectives of this workshop: *What are the policy needs for indicators related to the formation, activities, and economic consequences of alliances and SRPs? What data and indicators are currently available about alliances and SRPs? What are their strengths and weaknesses?* Section IV summarizes the workshop discussion that was related to the second of the two objectives: *How should the Science Resources Studies (SRS) Division of NSF proceed to develop SRP indicators?*

## II. Chronology of Related Indicators by NSF

NSF has had significant experience with indicators related to strategic research partnerships, R&D collaboration, and technology transfer. The chronology of the introduction of these indicators is:

- R&D expenditure flows across sectors (1972)
- Bibliometric co-authorship indicators (1980)
- University patents (1982)
- Federal technology transfer indicators (1991)
  (CRADAs, patents, licenses and invention disclosures)
- Industrial joint research ventures (1991)
- R&D expenditure flows across countries (1991)
- International strategic alliances (1993)
- University-industry research centers (1993)
- Foreign location of R&D facilities (1993)
- Federal cooperative technology program dollar support (1996)
- University technology transfer indicators (1996)
  (AUTM licenses, startups, revenue)
- Patent/article citation indicators (1996)
- Defense dual use programs (1996, 1998)
- Advanced Technology Program data (1998)

## III. Overview of Background Papers

Nine background papers were commissioned and presented at the workshop. The salient points from these papers are:

- The mainstream theoretical economic literature may not be very useful in isolation in indicating the best approach to constructing SRP indicators. While industrial organization economists were pioneers in the early 1980s in getting a better understanding of the spreading phenomenon of inter-organizational cooperation, they have paid less attention to formally modeling the important understandings about the variety of forms of SRPs and the variety of incentives to join that have been gained since. Even though transaction costs theory and contract theory have made significant steps to explain the formation of inter-firm collaboration, it cannot be argued that formal mainstream economic theory has been able to approach the richness of concepts arising in the fields of strategic management and evolutionary economics. A combinatorial approach that would reach across narrow disciplinary approaches is considered more appropriate for the methodological approach to SRP indicators.

- A number of definitions, taxonomies, and analytical approaches to SRPs have been posited in the literature. Although academically interesting, such diversity also introduces difficulties in comparing analytical results across studies.
- The broadest possible differentiation of SRPs is between formal and informal relationships. They are both very valuable to supporting innovation. Informal relationships seem to be the larger but also the most amorphous of these two sets, presenting great difficulty in data collection. All existing systematic databases exclude informal SRPs.
- Extant databases (CATI, CORE, NCRA-RJV) are as diverse as the definition of an SRP. Even though the basic intellectual interests that motivated their construction were fairly similar, there is a significant difference between the first and the other two due to the difference in sources of original material and data collection approach.
- A major limitation of all existing databases on partnerships is the lack of information concerning the termination of partnerships.
- Another major limitation of existing databases is the lack of performance measures for partnerships. This seems to be primarily the result of continuing uncertainty among experts concerning the level at which performance is judged (e.g., at the level of the partnership or the individual member) and the yardsticks that can be used.
- Yet another major limitation may be that small firms may be underrepresented in most existing SRP databases. Possible reasons for that may be that small firms often do not formalize their R&D and probably their partnerships too. One implication is that an inference that SRPs are relatively less important for small firms than they are for large firms could well be mistaken. Another implication is that we may need to take a more serious look at informal partnerships than has been done in the past. There is thus some ground for arguing the necessity of a survey that would carefully reach small as well as larger firms. Some experts do, however, doubt the reliability of survey answers by a significant cohort of small firms, particularly those in non-R&D intensive activities.
- Formal SRPs are just one of the ways firms may use to link to each other and to other organizations. Consequently, it is argued that SRP indicators will underestimate the extent of collaboration. To get a more complete picture, it may be useful to combine SRP indicators to others such as bibliometric and patent indicators.
- CRADAs is an important form of SRPs with potentially a lot of information, which has yet to be collected extensively and systematically. SRS has been reporting aggregate data on CRADAs, but there is a sense that much broader coverage is warranted. Output indicators are also needed.
- A second important differentiation of SRPs is between public-private and private-private. Which one of these is of interest crucially depends on the question. The presumption that public-private SRPs may be more important for public policy makes the implicit strong assumption that public policy is limited to contributing resources to SRPs. Policy decision-makers are clearly interested in other policies as well that affect the economic and regulatory environment in which SRPs operate. Knowledge about both sets of SRPs is useful for policy.
- It would be useful to researchers and policy analysts if existing and to-be-created SRP indicators could be linked to other data related to economic and technological performance of individual organizations that other government agencies collect (e.g., market performance of individual firms and patent portfolios). Such bridging of data is expected to produce direct benefits to SRP analysis, not least because it will allow creating control groups of non-SRP participants.

- One often meets in the literature efforts to approximate the performance of SRPs with patents. A suggestion has been that collaboration in R&D should result in co-inventing and co-patenting. Unfortunately, co-patenting is much too little to be relied upon as such an indicator. It appears that firms have traditionally avoided co-patenting, probably due to expectations of increased legal problems. Although co-patenting numbers are increasing, they are still too low relative to the overall level of patents issued annually in the United States.
- One other set of indicators that may be naturally linked to SRP indicators is the so-called innovation indicators. Such indicators are being constructed in the European Union and a few individual country members. NSF is also considering them and currently fielding a pilot survey in the information technology area. For example, one possibility could be to use the same survey instrument for both general innovation indicators and SRP indicators. There is some skepticism among experts concerning the feasibility and reliability of innovation indicators – having to do particularly with the definition of an innovation and the willingness of respondents to identify failed innovations. Still, in the lack of better alternatives, many consider this worth the try; it is expected that there is a learning curve in raising the quality of collected statistics.
- NSF is clearly not the only agency considering SRP indicators. The Organization for Economic Cooperation and Development has also developed a strong interest in the subject, in relation to several other concurrent activities. The latter include: the revision of the Frascati manual to better define R&D, partnerships, outsourcing, etc.; the creation of a Globalization manual; the revision of the Oslo manual on innovation surveys. There is a strong sense at the OECD that this is the right time in the life cycle of the phenomenon for public agencies to get involved in defining and building statistical information on SRP indicators.
- One of the more interesting international phenomena in SRPs during the past couple of decades has been the relative increase in the proportion of contractual agreements vis-a-vis traditional, equity-based joint ventures that create new organizational entities. This is an important development from both the business strategy and public policy points of view. It is also a major complicating factor in collecting data for SRP indicators. Many of these contractual agreements are synthetic. That is, these agreements include various activities, thus introducing a problem of classification, and apparently are of more informal nature than required for accurate reporting.
- It is now clear that activity in three technological areas has been responsible for the vast majority of observed SRPs during the past couple of decades. The largest by far is information technology. Biotechnology comes next. Advanced materials follow.
- SRP intensity and characteristics may vary with the field and the technological life cycle. A possible consideration is to link SRP data to some kind of a life cycle model.
- Specifically to biotech, SRPs are extremely useful in the research, production, and delivery stages of products. Biotechnology is, of course, an area with particular characteristics, including greater than average reliance on academic research, proliferation of small firms, rapid turnover of firms, a strong effort by the big pharmaceuticals to avoid falling behind, extensive patentability of research outcomes, significant availability of venture capital. There are already four proprietary databases relating to biotechnology SRPs, with reported limitations in terms of scope of data, cost, and quality.
- Biotechnology SRPs frequently emerge among people with prior working relationships. If the observation is accurate, as it seems to be, human (scientist) mobility and SRP formation indicators should correlate strongly. It would be interesting to investigate the relationship between human mobility and partnerships in other technology areas as well.
- The proliferation of SRPs and the observation of a large failure rate of SRPs have naturally raised the question of performance. Early attempts to approximate SRP success by the longevity and

stability of the relationship were more appropriate for equity-based partnerships than for most cases of contractual agreements. It is also clear that different partners have different objectives in the same partnership, making the definition of partnership performance problematic. This has obvious implications for data and indicators of performance. It is quite possible that there are no widely applicable objective indicators of success at the level of the partnership. SRS may have to make do with indicators of success at the level of the individual partner.

- A major complication in constructing partnership performance indicators reflects a selection problem. That is to say, if SRP participants tend to perform better than non-participants, is the difference the result of SRP participation or the result of SRP participants performing better irrespective of membership?
- Two important features of SRPs that have received a lot of attention by business analysts and much less so by all others is the multi-dimensionality of relationships and their organizational structure. As far as NSF's effort is concerned, the danger is with expanding the scope of the indicators very much to make them intractable and with crossing the borders between formal and informal SRPs, which increases the degree of fuzziness.
- The construction of SRP indicators must take into account the strong current interest in innovation environments and in the increasing role of networks as the reference point for individual innovations. Significant effort must be devoted to argue over the appropriate unit of analysis which could be the individual, the group, the business unit, or the firm. Ideally, one would like to have information at different levels.

## IV. Developing SRP Indicators by SRS

It emerged from the background papers and the expert discussion during the workshop that:

- SRPs have important effects on innovative investment behavior and performance;
- Public policy can affect the performance of SRPs, both directly in certain circumstances and indirectly by changing the rules of the game;
- Currently available data on SRPs are limited in several respects, not systematically gathered or coordinated, and uneven in quality and degree of coverage.

Experts believe that there is a need for ongoing, systematic, and coordinated documentation and reporting of:

- Incidence of SRPs
- Types of SRPs
- Inputs into the formation of SRPs
- Output of SRPs
- Role of SRPs as inputs into the innovation process

There is a clear sense that multiple measures of inputs and outputs, each reflecting the particular circumstances of a type of SRP, are useful and appropriate. Appropriate data could and should be integrated from a variety of sources in order to be useful in answering various, and quite different, policy- and strategy-oriented questions that analysts ask in relation to SRPs.

It would certainly prove useful to have information on:

- number, industrial affiliation, and size of participating firms in SRPs
- organization structure of SRPs and types of members
- overall budget and individual contributions to SRPs, including government cost-share

- reasons for the termination of SRPs
- SRPs outputs, such as new products, patents, publications, licensing agreements, launching of startups, new jobs
- Impact of the SRP experience on the performance of individual participants

Such lists are limited only by the imagination of the analyst, however, and are often beyond the means of responsible agencies to collect.

Four important considerations for SRS were discussed:

- Is this the right time for direct SRS involvement in building SRP indicators?
- What would these indicators be?
- What indicators are also applicable in the international context?
- What are the policy issues we are trying to inform?

The discussion covered a wide range – it was meant to be brainstorming, after all. This was the first time that such a gathering took place in the United States. Nonetheless, several important indications were signaled to SRS representatives. They included:

- On the question of whether coverage should be limited to public/private SRPs, or to private-private SRPs, or be extended to both kinds, the outcome was balanced towards the latter.
- Public agency support of public/private SRPs should be collected.
- Questions could be added to existing NSF surveys to elicit information on the extent of private organizations' resources devoted to SRP activity.
- Additional survey questions should address the formal versus informal nature of SRPs.
- While the utility of a broad question asking respondents to estimate the share of formal and informal partnerships was felt to be significant, the difficulties in definitions and estimation seem to make it difficult to operationalize.
- The human mobility aspect of SRPs have not been addressed by any of the existing SRP databases.
- Data on international collaboration are important in spite of complicated definitional problems.
- An argument was made over the distinction between and value of understanding the extent of collaboration and understanding the factors driving it. Budget limitations may oblige SRS to follow a stepwise approach, however, limiting the coverage to the first leg as a start.
- Proceeding in parallel with survey data collection and with case studies of SRPs may reveal unanticipated trouble spots regarding definition, inputs, outputs, budgets, and so forth.
- Additional information should be collected on the experience of international agencies in developing SRP indicators and building appropriate survey instruments.

Although the workshop produced a useful dialogue, it was by no means conclusive. It clearly underlined the importance of a continuing, proactive discussion between experts and the SRS regarding the most appropriate procedure for developing SRP indicators.

# Strategic Research Partnerships: Evidence and Analysis

Stephen Martin
University of Amsterdam

> Results? Why, man, I have gotten a lot of results. I know several thousand things that won't work.
>
> —Edison

## I. Introduction

A strategic alliance (Chan et al., 1997, pp. 199–200) "enables a firm to focus resources on its core skills and competencies while acquiring other components or capabilities it lacks from the marketplace." Such alliances extend beyond research, the focus of this paper, and take a variety of forms.[1]

It is sometimes said that theoretical research in economics is a largely self-contained activity, firmly insulated from the vagaries of evidence about the subjects it analyzes.[2] The extent to which this might be true in general is beyond the scope of this paper, but it does seem to be an accurate description of a good deal of the recent theoretical literature on R&D cooperation.

What is even more discouraging, however, is that much of the policy literature on R&D cooperation seems disconnected from both mainstream theoretical[3] and empirical work on the phenomenon.

Much of the theoretical work on R&D cooperation in the 1990s took off from d'Aspremont and Jacquemin, AJ, (1988). The impact of this linear demand, quadratic cost of own-cost reduction, deterministic R&D model may well have surprised even the authors, who referred to it as "an example." In its basic form, it considers a duopoly market. Since there are only two firms, R&D cooperation, if it occurs at all, includes all firms in the industry. This is in sharp contrast to the kind of R&D cooperation described by, for example, Hagedoorn and Schakenraad (1993), who document that major players in innovation-intensive industries simultaneously undertake a great many cooperative R&D projects, often with narrowly defined targets.

In the AJ model, innovation is deterministic: firms select a certain cost reduction that they will pay for, and they obtain that cost reduction with certainty. Since innovation is deterministic, if a firm undertakes R&D at all, it performs only one R&D project. A deterministic formulation abstracts from

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[1] My own preference is for the "operating entity JV" and "secretariat JV" classification of Ouchi (1989) and Vonortas (1994), which at least has the merit of being based on functional differences.

[2] Leontief's (1982) comments are well known: "Page after page of professional economic journals are filled with mathematical formulas leading the reader from sets of more or less plausible but entirely arbitrary assumptions to precisely stated but irrelevant theoretical conclusions."

[3] In some cases, at least, deliberately so (Teece, 1996, p. 194).

the uncertainty that is inherent in innovation. It is not obvious why the deterministic formulation is preferred in the literature, since racing models allow for uncertainty and are not technically more difficult than deterministic models.[4]

In the AJ model, if a firm performs R&D, it is R&D output—a cost reduction—that spills over to the other firm. This spillover just happens: if firm 1 pays for (and therefore obtains, given the deterministic nature of the model) a unit cost reduction $x_1$, firm 2's unit cost falls by $\sigma x_1$, where the spillover parameter $\sigma$ lies between zero and one.[5]

The d'Aspremont and Jacquemin model is unstable for large spillover levels (exactly when the impact of cooperative R&D on dynamic market performance is of greatest interest). Instability does not arise in the model of Kamien, Mueller and Zang (1992), who consider R&D input spillovers rather than R&D output spillovers. The two models are compared by Amir (2000), who shows that

- the two models are not equivalent,
- that the AJ systematically predicts higher levels of R&D than the KMZ model, and
- that the KMZ model predicts that industry R&D levels decline as (input) spillovers rise, while the AJ model makes the same prediction only for lower values of the (output) spillover rate.

Amir argues that the KMZ model is better suited for the analysis of independent and cooperative R&D. Amir (2000) distinguishes 7 R&D cooperation scenarios from the theoretical literature:[6]

- Case N: firms behave noncooperatively in both R&D and the product market;
- Case C: firms select equal R&D levels for their individual R&D projects to maximize joint profit, behaving noncooperatively on the product market;
- Case CJ: as in case C, setting the R&D spillover equal to 1;
- Case NJ: case N, with the spillover parameter set equal to 1 (this seems to be the case of a secretariat joint venture);
- Case J: the firms set up one laboratory, share the cost, and both enjoy the same cost reduction (this is an operating entity joint venture);
- Case CC: firms collude at both levels, carrying out independent R&D with the natural level of spillovers;
- Monopoly.

The final category is a benchmark for comparison.

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[4] Most of the small literature that uses racing models assumes that if a firm undertakes R&D at all, it undertakes one R&D project (my own work falls in this category); much evidence is to the contrary. Scott (1993, Chapter 8) is an exception.

[5] The possibility that firm 1 might license full use of the technology that allows the cost reduction x1 to firm 2 for a royalty payment $(1 - \sigma)x_1$ per unit of output must surely have been considered in one of the many generalizations of the basic model. Such licensing does occur in the real world, and must be an element affecting the decision to carry out stand-alone or cooperative R&D.

[6] The literature abounds with taxonomies of R&D cooperation, with definitions depending on the number of R&D operations, on whether or not formation of an R&D joint venture means in increase in the spillover parameter, on whether or not firms cooperate in production as well as R&D. For alternative classifications, see d'Aspremont and Jacquemin (1988), Hagedoorn (1990), Kamien et al. (1992), and Hagedoorn et al. (2000, p. 569).

Specifications in which cooperating firms set the spillover parameter equal to 1 are considered by KMZ. While it may be that firms can increase[7] their knowledge spillover rate, it is by no means certain that they choose to do so, and there is case study evidence that firms do not behave in this way.[8] At least, it would seem preferable to model the choice of spillover rate, rather than simply assume that it becomes 1 for some cases of R&D cooperation.

Much of the theoretical (and policy) literature takes off from the idea that imperfect appropriability is a source of innovation failure in market economies,[9] often appealing to Arrow's (1962, p. 615) frequently quoted observation that:

> no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information. The very use of the information in any productive way is bound to reveal it, at least in part. Mobility of personnel among firms provides a way of spreading information. Legally imposed property rights can provide only a partial barrier, since there are obviously enormous difficulties in defining in any sharp way an item of information and differentiating it from similar sounding items.

Even on a theoretical level, this view has been challenged. Cohen and Levinthal (1989, pp. 569-70) emphasize that information often does not flow freely from innovator to other users:[10]

> we argue that while R&D obviously generates innovations, it also develops the firm's ability to identify, assimilate, and exploit knowledge from the environment—what we call a firm's 'learning' or 'absorptive' capacity. While encompassing a firm's ability to imitate new process or product innovations, absorptive capacity also includes the firm's ability to exploit outside knowledge of a more intermediate sort, such as basic research findings that provide the basis for subsequent applied research and development.

On an empirical level, Levin et al. (1988) present survey evidence suggesting that innovating firms have many strategies available to exploit their innovations, if not uniquely over all time, at least in advance of follows, allowing realization of first-mover advantages.

A frequent justification for promoting R&D cooperation is that it eliminates "wasteful duplication." This justification should by now be thoroughly discredited. It fails both theoretically (Dasgupta and Maskin, 1987) and empirically (Nelson, 1982b, pp. 455, reviewing case studies).[11]

From a social point of view, effective pursuit of technological advance seems to call for the exploration of a wide variety of alternatives and the selective screening of these after their

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[7] Much of the policy literature seems to take it for granted that firms cannot reduce the spillover rate, at least, not to zero. This is why appropriability of the revenue that flows from successful innovation is thought to be incomplete. There is also the possibility that if firms could reduce spillover rates to zero, they would not find it value-maximizing to do so; Martin (2000).

[8] See Sigurdson's (1986) account of Japan's VLSI project. See also the discussion, below, of Joly and Mangematin (1996).

[9] I resist use of the common term "innovation market failure." My own view is that if there are such things as markets for innovation, they tend to be narrowly defined: the efforts of pharmaceutical firms seeking to develop an aids vaccine have not much to do with efforts to develop commercially applicable materials that will act as superconductors at room temperature.

[10] See also Kamien and Zang (2000) and Martin (2000).

[11] See also the discussion, below, of Tapon and Cadsby (1996).

characteristics have been better revealed—a process that seems wasteful with the wonderful vision of hindsight.

When the outcome of R&D projects is uncertain, as it always is, it is socially beneficial and frequently privately beneficial as well, to pursue multiple research paths toward a common target.

In the policy literature Teece (for example, 1996) and others have emphasized the tacit nature of some kinds of knowledge—in sectors where technology transfer is difficult without the transfer of particular individuals—as a justification for R&D cooperation. It may be so in some sectors: but if knowledge does not flow freely because of its tacit nature, then it cannot also be that firms cannot realize the commercial benefits that flow from their innovations because the underlying knowledge spills freely over outside the firm.

One of the motivations often cited for the U.S. National Cooperative Research Act of 1984 is that it served to reduce business-sector anxiety about possible antitrust liabilities incurred because of participation in R&D joint ventures. It is difficult to know upon what such anxiety might have been based.[12] The European Union has always had a positive attitude toward R&D cooperation.[13] U.S. antitrust, to the best of my knowledge, records one antitrust case involving an R&D joint venture.[14] The government's theory in that case was that automakers had used an R&D joint venture to delay the development of environmentally motivated emission control equipment. The case was settled by a consent decree.

Keeping these characteristics of the theoretical and policy literatures in mind, I have preferred to examine selected portions of the empirical literature for regularities that might appear and offer some insight into possibilities for measuring the impact of public support on technological performance. I have focused in particular on studies of the pharmaceutical sector and of government support for or collaboration with private sector innovation.

## II. Pharmaceuticals

### A. Size advantages, absorptive capacity

The pharmaceutical industry was early on and remains (now along with the more broadly defined biotechnology sector) a proving ground for the study of innovation. In part, the pharmaceutical sector attracts attention simply because of its high policy profile. In part, it attracts attention because it seems apparent that static and dynamic performance in the industry is directly affected by government policy (although opinions differ about the nature of the effects). More recently, the industry has attracted academic attention because it seems to offer a close real-world counterpart to widely used racing models of innovation.

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[12] Scott (1989, p. 68) notes that in its policy proposals "the Reagan administration—surely at least in part because of its concern with declining competitiveness of U.S. firms in global markets and in part because of its desire to deregulate markets—justified these policies by extraordinarily selective reference to theory and facts."

[13] In the EU, this policy stance is constitutional in its foundation: Article 81(3) of the EU Treaty makes the promotion of technological advance one basis upon which the European Commission may permit cooperation that would otherwise be prohibited under Article 81(3) (which sets out EU policy on cooperation among firms).

[14] United States v. Automobile Manufacturers Association 1969 Trade Cases (CCH) Para 72,907 (C.D. Cal. 1969) (consent decree), modified 1982–3 Trade Cases (CCH) Para 65,088 (C.D. Cal. 1982).

The evolution of the U.S. pharmaceutical industry was shaped by two early policy developments. The 1939 U.S. Food, Drug, and Cosmetic Act separated the purchase decision from consumption for prescription drugs (Temin, 1979, p. 34). Consumption could take place only by prescription; the physicians who issued prescriptions did not pay for the drugs they prescribed. The result was to make the demand for prescription drugs price inelastic. Further, pharmaceutical industry researchers in the 1940s developed systematic techniques for identifying antibiotics in soil samples. U.S. patent law was interpreted so that such antibiotics were patentable. This interpretation was by no means inevitable; antibiotics might have been found to be natural substances and not patentable (Nelson, 1982b, p. 456).

As a consequence economic profits were diverted into rent-seeking activities (Temin, 1979, pp. 443):

> New technological opportunities led to patent monopolies. FDA regulations reduced the elasticity of demand. Maximization of monopoly profits with very inelastic demand led to monopoly production rather than to patent licensing. The presence of shared patents and competing patents on similar drugs led to vertical integration, larger firms, and increased advertising in the pursuit of larger market shares in the markets for similar drugs. The increased advertising and R&D stimulated by this competition reduced the profits of the newly integrated firms, albeit not to the competitive level.

It has long been recognized that the pharmaceutical sector is one where patents are relatively effective in securing property rights in innovations. Temin's analysis suggests that effective patent protection did not result in good overall market performance in the U.S. pharmaceutical industry of the 1950s and early 1960s. Drug companies had the option of licensing products in which they had effective property rights, but opted instead to restrict output and dissipate the accompanying economic profits on marketing efforts aimed at physician-prescribers.

Temin finds no evidence of economies of scale in production: leading pharmaceutical firms grew by increasing the number of establishments they managed, but the size of the typical establishment did not increase. On the same point, Comanor (1986, pp. 1191-3) finds empirical studies inconclusive, some suggesting the presence of economies of scale, others not. One explanation suggested by Comanor is (1986, p. 1193) "that larger firms are relatively more important when all new drugs are included but not so in regard to the most important innovations."

Graves and Langowitz analyze the probability of introducing a new chemical entity for a sample of 16 large pharmaceutical firms over the period 1969-87. They find the elasticity of the expected number of patents with respect to R&D spending to be less than one and to fall as R&D spending rises, evidence for diseconomies of scale in innovation.

Caves et al. (1991) document that patent protection is not the only device that allows innovating drug firms to collect economic rents. They study 30 drugs that lost patent protection in the decade 1976-87 and find that after patent protection expires generic substitutes sell at substantially lower prices than the formerly protected version, but that the first variety suffers only modest reductions in market share.[15] Advertising to prescribing physicians—an activity that is cut back in advance of the

[15] Scherer (1993, p. 101) suggests that the prices of first varieties may actually rise after the expiration of patent protection, with much of the retail market supplied by the first variety at a high price and institutional demand supplied by generic substitutes at a lower price.

expiration of patent protection—apparently creates product differentiation that survives well after the introduction of generic substitutes.

Scherer (1993, p. 99) discusses the U.S. Orphan Drug Act of 1983, which gives exclusive marketing rights and tax benefits for firms developing drugs targeting diseases that affect relatively small numbers of people, which Scherer describes as having had "a marked impact." This is noteworthy because it suggests the ability of narrowly targeted measures to promote particular policy goals.[16]

Debackere and Clarysse (1997) study a sample of 118 U.S. biotechnology firms over the period 1982 to 1994. They find that patent probability rises with the number of years a firm has been involved in collaborative research, suggesting that collaborative R&D enhances R&D productivity.

Cockburn and Henderson (1994) study research programs of 10 pharmaceutical firms in 38 research areas. They find substantial evidence of knowledge flows across firms (1994, pp. 507–8):

> Some firms pursue different goals within the same general therapeutic area, while others compete more directly. In either case publication and the norms of professional disclosure appear to ensure the rapid exchange of knowledge across the industry. ...Competing projects are better described as complements rather than substitutes, and there are significant spillovers of knowledge across firms.

Henderson and Cockburn (1996, p. 33) identify three possible sources of large size in research and development, that:

- larger firms are able to spread fixed cost of research over a larger sales base;
- large firms may have advantages in financial markets
- larger firms may be better able to exploit economies of scale and scope in the research itself.

A fourth benefit of large size, widely noted in the literature, might be termed the serendipity effect, and is associated with diversification as much as with large size alone: a large, diversified firm is more likely to be able to be able to exploit an unexpected discovery.

Henderson and Cockburn find some evidence that economies of scale in pharmaceutical research increased in importance in the period after that covered by Temin (1979), but also that such economies of scale may have disappeared after 1978. They do find that larger firms enjoy greater R&D productivity than smaller firms, and attribute this to economies of scope—knowledge spillovers across research programs within a firm and the accompanying ability to make productive use of knowledge spillovers across firms (1996, p. 55):

> the benefits of spillover can be realized only be incurring the costs of maintaining absorptive capacity, which take the form here of large numbers of small and apparently unproductive programs. We believe that these effects are what account for the presence of very large research oriented firms, despite sharply decreasing marginal returns to research spending at the level of the individual research program.

Cockburn and Henderson (1998, p. 159) highlight even more strongly the importance of absorptive capacity for dynamic market performance:[17]

[16] Similarly, Scott (1996) finds that the U.S. Clean Air Act Amendments of 1990 were able to promote private investment to control specific targeted pollutants.
[17] See also Mowery (1982, p. 352):

> Our results are consistent with the hypothesis that the ability to take advantage of knowledge generated in the public sector requires investment in a complex set of activities that taken together change the nature of private sector research. In the second place, they raise the possibility that the *ways* in which public research is conducted may be as important as the *level* of public funding. To the extent that efforts to realize a direct return on public investment in research lead to a weakening of the culture and incentives of 'open science,' our results are consistent with the hypothesis that the productivity of the whole system of biomedical research may suffer.

To the extent that strategic alliances add to or maintain absorptive capacity, they have a positive social benefit that is unlikely to be recognized by conventional evaluation methods.

**B. Organizational factors**

Pisano (1989) studies the organizational form of 195 biotechnology sector collaborations involving private firms. His analysis suggests that firms favored equity holdings over contracts as an organizational framework for R&D collaboration. He interprets these findings from a transaction cost perspective: equity holdings raise the cost of opportunistic behavior (which would reduce the value of the equity holding), and representation on the board of directors of the collaborative entity is a vehicle for continuous monitoring of performance.

Pisano (1989, p. 124) suggests that antitrust treatment of R&D collaboration organized by means of equity holdings should balance these efficiency advantages against the possibility that an R&D joint venture might facilitate tacit collusion and worsen static market performance.[18] Pisano (1991) notes that much (at least, much early) collaborative biotechnology R&D has been vertical in nature, involving on the one hand small specialized firms in a position to offer specific expertise and skills and on the other large established firms able to offer financial backing and access to distribution channels.

Taking these two contributions together, to the extent that R&D collaboration is vertical in nature, the potential for worsening static market performance is lower[19] than would be the case for R&D (horizontal) R&D collaboration among firms operating in the same product market.

Pisano (1991) also notes a more recent tendency for established firms to integrate backward into R&D activity and for specialized biotechnology firms to integrate forward into production and distribution. Such integration, increasing the number of actual and potential competitors, improves static market performance. On the one hand, this finding suggests that public support for biotechnology sector innovation should be structured in a way that does not raise the cost of entering the market. More generally, it suggests that the way public support for biotechnology innovation is

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> the importance ascribed by many economic theorists to the appropriability of results from research may be misplaced. In understanding the organization and evolution of industrial research, the requirements for knowledge transmission and utilization, as well as the difficulties encountered in the negotiation and enforcement of contracts, acquire an importance equal or greater than that of the appropriability of the returns from research.

[18] See Martin (1996) for a formal model.

[19] The potential to worsen static market performance is present: if established firms systematically seal relations with small knowledge-intensive firms, costs of entry to the biotechnology sector might increase.

structured should not take for granted that observed private-sector relationships are fated to continue: the kinds of contracts and market structures that are privately optimal in one phase of an industry's life cycle may change over time.

Lerner and Merges (1998) analyze the allocation of control in vertical biotechnology alliances. They find that the greater the financial resources of the specialized biotechnology firm, the less the degree of control allocated to the larger (typically a pharmaceutical) firm.[20]

Public policy affects equilibrium market structure and therefore equilibrium market performance. *Any* program of public support will alter the balance of bargaining power between biotechnology firms and larger partners. Programs of public support that increase the financial resources of specialized biotechnology firms are likely to increase the bargaining power of those specialized firms with respect to established pharmaceutical firms, reduce entry costs, and improve static as well as dynamic market performance.

Tapon and Cadsby (1996) analyze private sector–university pharmaceutical collaboration. Their discussion, like the work of Cockburn and Henderson, suggests the positive impact of knowledge spillovers on innovation. Tapon and Cadsby argue that private pharmaceutical firms link up with university laboratories to promote basic research and as a way of taping into specialized stores of knowledge in areas that developments in the field reveal to be important.

Quoting a biotechnology researcher, they document the inherently uncertain nature of biotechnology innovation (1996, pp. 389-90):

> I think that rational drug design is obviously very admirable. It's more than a great idea, it's a move in the right direction. It applies as much rationality to your programs as possible. But, you're not going to be able to predict 100% ... of the outcome. You're always going to have things that happen that nobody really foresaw and you look back in hindsight and say that there is no way that we could have predicted that outcome ... There is a certain amount of good luck involved ... you have to have the breaks; if you don't have the breaks in drug development you may have great difficulty in getting any compound.

Tapon and Cadsby also find that physical proximity of research facilities has a positive impact on research productivity.[21]

### C. Implications for evaluation

The importance of knowledge spillovers in the pharmaceutical sector means that the benefits of obtaining innovative results extend beyond the particular program that produces those results. Even a very precise measurement of the output of a particular pharmaceutical research program will provide only a lower bound measurement of the welfare impact of that output from a social point of view.

More generally, these results suggest that—certainly in the pharmaceutical sector, and perhaps elsewhere in the economy as well—that public support for private innovation should be carried out in a way the promotes the free flow of knowledge among R&D-active firms. A performance-enhancing

[20] See also Pollak (2000).

[21] See Jaffe (1989) and Adams and Jaffe (1996) for similar findings.

*quid pro quo* for public support of private R&D is that patents obtained with such support should be openly licensed on reasonable terms by the private-sector firm that holds the patent.[22,23]

The inherent uncertainty of R&D outcomes in this area also signals difficulties for evaluation. Results must be assessed *ex post*, but any cost-benefit analysis must include the cost of programs that were reasonable *ex ante* but happened, by the luck of the draw, not to mature as rapidly or in the directions expected. Evaluation should not be carried out at too disaggregated a level.

## III. Government R&D, Government-private R&D Cooperation

Joly and Mangematin (1996) study 20 French public laboratories associated with the National Institute for Agronomic Research (INRA). They confine their analysis to two research departments, but even working with this limited sample they distinguish three types of public laboratories:

- *research centres for the profession*: laboratories with close ties to small and medium sized firms and industry associations, concentrating on the development of improved strains of plants;
- *designers of generic tools and methods*: laboratories concentrating on basic research;
- *basic and specialised laboratories*: provide expertise to industry to solve specific problems.

While some of their conclusions may be specific to agronomics and to the French institutional setting, the point that public laboratories are heterogeneous in terms of assets, expertise, and activities seems likely to be quite general. Further, the finding that some public laboratories apply specialized expertise to some specific, long-term problems for industry may well be a leading indicator of the role that will be played by (former) US defense laboratories.

This conclusion is consistent with Nelson (1982b, p. 453), who emphasizes the importance of the presence or absence of a government procurement interest in designing a program of public support for private innovation.

In the same vein, Ham and Mowery (1998), who present five cases studies of Cooperative Research and Development Contracts (CRADAs) between private firms and the Lawrence Livermore National Laboratory, conclude that the most successful joint efforts are those that "draw on the historic missions and capabilities of the laboratories" and that "defense laboratories are poorly suited to that task of civilian technology development in areas not directly linked to their historic missions."[24] They also highlight the importance of the "generic" benefits derived by private firms from Cooperative R&D Agreements with Lawrence Livermore National Laboratory (Ham and Mowery, 1998, p. 663): "design principles, engineering techniques, testing methods" (surely, a kind of spillover contributing to absorptive capacity). What private firms pay under such contracts, and the value of the inputs they

[22] Despite the fact, as noted by David et al. (2000, p. 506), that to the extent that public policy that promotes information dissemination, it may lower the expected profitability of later innovators discouraging follow-on innovation.

[23] R&D cooperation agreements that restrict the access of one party to the agreement to the results of the cooperation do not normally qualify for the EC block exemption permitting R&D cooperation "because they do not, as a general rule, promote technical and economic progress by increasing the dissemination of technical knowledge between the parties" (EC Commission, 2000, Para. 64).

[24] See Cicotello and Hornyak (2000) for an analysis of the terms of CRDA contracts. They do not assess the impact of contract form on CRDA performance.

commit, may be one measure of what they expect the output to be worth. But to the extent that the benefits are generic, it will be a lower bound of the social benefit.

Another noteworthy result of the Joly and Mangematin study appears in their account (1996, pp. 917–8) of interviews with the director of research at INRA, who expressed disappointment with his experience that the information flows in public-private contracts were all one way, from the public to the private sector. They comment that this "shows that co-operative research is not synonymous with a process of combined learning." It is common in theoretical models to assume the innovation spillovers are complete within R&D joint ventures, and this interview evidence suggests that other specifications may be appropriate.

Jaffe et al. (1998) examine patenting practices of US Federal laboratories, and patenting and citation practices of the NASA-Lewis Research Center. Although they interpret their findings as confirming that patent citations are a valid index of the importance of the innovation covered by the cited patent, they also find that (1998, p. 196) "approximately one-fifth … of citations are cases where neither the technology nor the application is clearly related to the cited patent...apparently spurious citations" and that (p. 198) "citations are clearly a noisy indicator of spillovers." The conclusion that counts of patent citations are a valid but noisy indicator—whether of importance of the innovation cited or of spillovers—is not necessarily comforting from the point of view of using patent citations to evaluate the impact of an innovation or of a program to support innovation.

Leyden and Link (1999) discuss the empirical regularity that cooperative R&D projects that include public laboratories tend to be larger, all else equal, than those that do not. They point out that public laboratory participation in a joint R&D project most likely reduces the ability of private participants to appropriate profits flowing from successful innovation[25] but may also reduce the cost (to private participants) of monitoring the R&D efforts of participating firms. If a joint R&D effort includes a large number of partners, any incremental reduction in appropriability is likely to be small, while the reduction monitoring costs remains as a private benefit to the participating firms. To the extent that such a reduction in monitoring cost enables joint R&D that would not otherwise take place, or makes such joint R&D as does take place more effective, there is a public benefit as well. The social benefit due to this type of reduction in transaction cost is unlikely to be caught by traditional measures of innovative output.

## IV. Government Support for Private R&D

Lichtenberg (1987) criticizes econometric studies of the impact of direct Federal funding of R&D on private R&D spending that ignore differences in the composition of demand across industries. Since much private-sector R&D spending is aimed at satisfying government demand, industries that benefit from substantial government demand will conduct substantial R&D to satisfy that demand and also tend to receive greater-than-average government support for R&D. Ignoring demand variations (and simultaneous causality) tends to bias upward the estimated impact of private on public spending.

This point is correct in principle. It is not clear how important it is in practice. Using a sample of Federal Trade Commission line-of-business data, Lunn and Martin (1986) find that a greater share of

[25] This reduced appropriability may be a private bad, but it is likely to be a social good. Furthermore, to the extent that the knowledge embodied in the innovation is tacit, public laboratory participation may not reduce appropriability to any significant extent.

industry sales to the Federal government lowers privately financed R&D spending per dollar of sales, while a greater share of industry sales to state and local governments increases it. Both effects are especially pronounced for a subsample of high-technology industries.

Cohen (1994, p. 162) makes a point about the impact of government demand on government-supported R&D that is perhaps more relevant to the question of program evaluation. In sectors where the public sector is a significant consumer, it can virtually guarantee the commercial success of sponsored projects by its purchasing decisions. In such sectors, commercial success is a weak indicator of program effectiveness.

Wallstein (2000) looks at another manifestation of simultaneous relationships in this area. He examines the impact of R&D grants made under the U.S. Small Business Innovation Research and emphasizes the importance of taking into account the incentives of funding agencies (2000, p. 83):

> If government agencies face incentives to fund the most commercially promising proposals they receive, they will be inclined to support projects that would be privately profitable—and thus would be undertaken anyway—rather than projects that would benefit society but are privately unprofitable.

In the event, his results suggest that SBIR grants to publicly owned recipients crowd out private R&D spending on a one-for-one basis, so that public grants replace private R&D spending but do not increase total R&D spending.[26] The implied risk for evaluation programs that adopt commercial indices of success is that they would create just such an incentive to fund R&D activity that would have been funded in any event.[27]

Fölster (1995) analyzes a sample of 540 R&D projects of Swedish firms and their research competitors. His results indicate that R&D subsidy programs that allow firms to choose the form of cooperation do not increase the probability of cooperation, but increase the incentive to invest in R&D. Subsidies that require firms to cooperate and to share results increase the probability that firms will cooperate, but decrease the incentive to invest in R&D.[28]

Rosenfeld (1996) reports two case studies of evaluations of U.S. state programs to promote network cooperation among small- and medium-sized enterprises. The evaluation methodology included surveys of participants, interviews, and some analysis of data describing the activities of the firms involved. One of the evaluations included an assessment of cooperation on the local economy. Evaluations of this kind have an unavoidable subjective element.

Luria and Wiarda (1996) report on objective evaluation of programs of the Midwest Manufacturing Technology Center. Their description will evoke admiration and give pause to those contemplating

[26] Robson (1993) finds that Federal support *increases* private spending on basic R&D one-for one. However, he works with aggregate data.

[27] Martin and Scott (2000, pp. 440–2) suggest a scheme of indirect public support for private innovation, with funding going in the first instance to venture capitalists, in effect reducing their cost of capital and allowing them to identify and fund R&D projects that would not otherwise receive funding.

[28] Fölster (1995) distinguishes between information trading (of intermediate research results) among firms carrying out their own R&D projects and result-sharing within the context of a cooperative agreement. "Result sharing" seems to be a secretariat R&D joint venture with complete information spillovers among cooperating firms.

similar efforts. It is clear that objective evaluation is time consuming, costly, requires considerable effort, and is likely to be sector-specific, in that indicators of success developed for one industry often will not carry over to another. (Examples that they mention include manufacturing lead-time, inventory-sales ratios, and the on-time delivery percentage). They used the offer of benchmarking reports to entice firms that were not recipients of MMTC funding to contribute comparative data to the evaluation process.

Westerback (2000) studies the impact of Strategic Information Technology Management practices imposed on Federal agencies by the Clinger-Cohen Act of 1996. As one conclusion of the study, she finds that (2000, p. 38) "Use performance measures as a proxy for return on investment" is a useful information technology management practice for Federal agencies. But she also writes:

> This is an expedient approach to get around the difficulty or, and lack of consistency in, measuring return on investment in the federal government. Many assumptions and judgments are factored into return on investment figures. The requirement that a project show a positive return on investment may lead to strained use of the numbers.

If this is true for measuring the return on government practices that are reasonably close parallels to functions performed and evaluated in the private sector, how much more serious will the problem of evaluation be for the federal contribution to strategic alliances, when the assets the federal agency brings to bear are fundamentally different from the kinds of assets found in the private sector, this very difference is what makes the alliance worthwhile for the private partner, and in any case the private return to investment in innovation can be measured in only the most approximate way?

### V. Private Returns

Boulding and Staelin (1995) use the PIMS database to examine the impact of private R&D spending on the private rate return. There are many studies of this kind, and they generally find that the impact of private R&D spending on the private rate of return is positive, as do Boulding and Staelin.[29] Such techniques might be applied to study the impact of public funding for or cooperative R&D on private returns (seeking to avoid the critique of Lichtenberg (1987)). The result would be a lower-bound indication of the social return.

Zahra and Bogner (2000) examine the impact of technology strategy on the performance of new firms in the computer software industry. Their measures of performance are the rate of return on stockholders' equity and the growth rates of sales and of market share. All three variables seem to have been afflicted by measurement difficulties.

It might be possible to measure the impact of strategic alliance participation on the rate of return on equity for relatively undiversified firms that participate in at most one strategic alliance at a time. If all private-sector firms allying with a government agency fell in this category, a summary of the effects might serve as an indicator of the value of such collaboration to the private business sector.

Externalities limit the use of the rate of growth of sales or of market share as an indication of the social return to innovation: against the benefit received by a cooperating firm the market share of

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[29] Martin (1983) finds that greater line-of-business spending on R&D lowers line-of-business profitability, all else equal, while greater firm-level R&D spending increases line-of-business profitability.

which grows more rapidly than would otherwise have been the case must be offset the losses of rival firms the market shares of which grow less rapidly than would otherwise have been the case.

Chan et al. (1997) examine the impact of the formation of strategic alliances on movements in share prices of 460 firms involved in 345 alliances. They do not limit their attention to innovation alliances. They find that strategic alliances increase the combined market value of the firms involved, and that for horizontal alliances the increase is larger, all else equal, if it involves knowledge transfers.

While the event study methodology might be applied to evaluate the private returns to specific companies and for specific innovation alliances, it seems unlikely that it could be used to evaluate results of a support program aimed at a wide range of firms, not all of which would be listed on financial markets. The diversified nature of many firms and the large number of strategic alliances in which some are involved might also mute the impact of a particular alliance on firm value.

Yang et al. (1999) analyze factors determining the performance of NCRA-registered joint ventures. They find that performance is enhanced by alliance stability and if the alliance combines complementary assets. Their performance measure, however, is based on subjective evaluation of the extent to which a joint venture achieved its objectives. They specifically suggest (1999, p. 116) that "[a]chievement of objectives is an appropriate measure of intermediate performance for R&D strategic alliances in cross-sectional studies." But there will be many circumstances in which such a measure could not be constructed even with respect to the private rate of return.

## VI. Perspectives from Industrial Economics

Industrial economics as a field overwhelmingly employs partial equilibrium analysis. Strategic research alliances surely have some general equilibrium consequences, although it may well be that their primary impacts are confined to particular segments of the economy.

Keeping the existence of such general equilibrium effects in mind, it seems nonetheless to be the case that just as Nelson (1982a, p. 2) wrote "if they are to be successful, public policies to stimulate technical progress need to be nicely tuned to the particulars of the different economic sectors," so today we can write that if the evaluation of strategic research alliances is to be effective, so evaluation methods need to be tuned to the particulars of different sectors and of the types of alliances.[30]

This observation is consistent with the evolution of empirical research on static market performance in industrial economics, which has passed from reliance on industry cross-section data in the 1960s and 1970s to analysis of time series and panel data at and below the firm level.[31]

The data requirements to carry out such a study would be severe.[32] Results would, of course, depend on the specifications used for estimation. That is true for all empirical work. Analysis taking product

[30] On this point, see Luria and Wiarda (1996).

[31] For examples, see Feenstra and Levinsohn (1995) or Roberts and Supina (1996, 1997). The purist approach to measuring the impact of strategic alliances on sectorial performance would be to specify and estimate a complete (demand-side and supply-side) structural model, allowing for firm-specific rates of technical progress and allowing those rates to depend on explanatory variables measuring both the firm's own participation in strategic alliances and on the sector-average frequency of strategic alliances.

[32] Not obviously more severe, however, than that confronted by Luria and Wiarda (1996).

varieties as given would for the most part apply techniques that have appeared in the literature. Analysis that allowed for new product development—an essential aspect of strategic alliance output in some sectors—would probably require use of techniques only recently developed and not yet widely applied (Bresnahan and Gordon, 1997). The results of such a study would give some indication of consumer and net producer benefits from strategic alliances in the sector under investigation. The results would not give an indication of spillovers outside the target sector.

## VII. Conclusion

There are valid questions about any evaluation scheme.

One relates to interpretation of whatever "grade" is generated. Low values of a particular performance index may simply reflect the highly skewed distribution of "big ticket" innovations. Scherer and Harhoff (2000, p. 563):

> researchers who seek to assess the success of government technology programs should focus most of their effort on measuring returns from the relatively few projects with clearly superior payoffs, not on projects in the heavily populated low-value distribution tail.

If major innovations come along only once in a great while, failure to achieve stunning results is not failure.[33]

In such a world, the question the evaluator should seek to answer is not "Were the results good?" but rather "*Ex ante*, was it reasonable to think that there was a high enough probability that the results would be good to devote resources to the project?" For basic research, at least, *ex post* peer review might answer that question.[34] Link and Scott (2000) present estimates of just such expected rates of return, based on survey and interview evidence, for a sample of projects subsidized under the U.S. Advanced Technology Program.[35]

There is also the "spillover problem" of Klette et al. (2000, pp. 482):

> if an evaluation study finds little difference between the supported firms and the non-supported firms it could either be because the R&D program was unsuccessful and generated little innovation, or because the R&D program was highly successful in generating new innovations which created large positive spillovers to the non-supported firms.

Such spillovers might not be such a problem in sectors for which knowledge has a high tacit component. Firms in such sectors might, however, invest more-or-less adequate amounts in

[33] It should also be kept in mind that it may take some time before the value of an innovation is evident. Cournot did not even receive his first review, a harshly critical one, until after his death. The full import of his work did not begin to be appreciated until more than 100 years after it appear. The fundamental innovation embodied in the ubiquitous post-it sticker was developed in 1968, the product first introduced in 1980 (http://www.3m.com/about3M/pioneers/fry.html).

[34] Of course, if one is going to conduct peer review, one might as well do it *ex ante*, when it might have some effect on the allocation of resources.

[35] Their estimates are a lower bound, as expected returns to consumers are not taken into account.

innovation without strategic alliances or other support mechanisms, since the tacit nature of knowledge would offer them the prospect of appropriating most of the returns from an innovation.

Nor should one lose sight of the impact of evaluation schemes on incentives.[36] It should not be necessary to belabor this point to an audience the members of which have had to answer the question "What do we need to know for the exam?" If students need good SAT scores to get into college, and if high schools are evaluated based on how many of their students get into college, then it should not surprise if high school courses end up being organized not so much to educate, but rather to educate along the lines examined in SAT tests.[37]

Keeping these caveats in mind,[38] Table 1 lists targets that might be associated with particular strategic research alliances. Innovative activity proceeds along many dimensions, strategic research alliances have many targets (and, most likely, any one strategic research alliance will have multiple targets). How one measures depends on what it is that one wishes to measure, and for each target, Table 1 lists possible evaluation methods (column 2) and possible shortcomings of the suggested evaluation method (column 3). This litany of shortcomings is not a plea to abandon evaluation. Rather, the point I wish to make is that any and all evaluation will be highly imperfect, and that the results of project evaluation should be treated with appropriate caution.

[36] One might call this the Heisenberg evaluation principle.

[37] If public universities emphasize both teaching and research in evaluating faculty performance, but the availability of external funding is related to research performance only, then it should not surprise if greater weight is given to research performance in evaluating … but I digress.

[38] And recalling once again the motto of the Christopher Society: "It is better to light one candle than curse the darkness."

**Table 1: Strategic Research Alliance Performance Indicators**

| Target | Index | Comment |
|---|---|---|
| Increase knowledge | Peer review; publications, citations | Subjective; Edison problem: knowing that one line of research does not work is a result. |
| Transfer knowledge in public laboratories to the private sector | Count number of cooperative agreements signed; survey private sector partners | Not all strategic alliances are created equal. |
| Increase diffusion of (commercially applicable?) knowledge | Count patent licenses; count commercial applications; survey users; (event studies?) | Either requires subjective evaluation of patent, citation quality, or treats as equal things that are not |
| Augment absorptive capacity of commercial partners | *Ex post* survey, interview | Subjective; natural tendency to view one's own part of the world through rose-colored lenses |
| Increase level, effectiveness of innovation | Econometric studies of R&D inputs or outputs | Inputs are not the same as outputs; output studies: not all patents are created equal; superfluous citations; may be an index of benefit to private partners; does not take impact on rivals, consumers, into account; does not give indication whether benefits would have been obtained without strategic alliance |
| Correct insufficient innovation in a market system | Full-fledged structural estimation | Stringent information requirements |

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# Strategic Research Partnerships and Economic Performance: Data Considerations

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## I. Introduction

The number of strategic research partnerships (SRPs) involving firms, universities, non-profit organizations, and public agencies has increased markedly in recent years. Some of this growth can be attributed to three policy initiatives and a key economic trend:

- Expansion of public-private partnerships
- Relaxation of antitrust enforcement to promote collaborative research
- Policies promoting more rapid diffusion of technologies from universities to firms
- Growth in venture capital investment in high technology start-ups.

Despite the ubiquity of SRPs and their potential importance as a mechanism for generating technological spillovers, it is difficult to evaluate the impact of these partnerships on economic performance, given the limitations of existing data. That is unfortunate because an assessment of the desirability of these policy initiatives ultimately depends on our ability to derive accurate estimates of the private and social returns to SRPs.

In this paper, I identify these data limitations and also outline the salient measurement issues, based on a comprehensive review of the burgeoning empirical literature on SRPs. I offer some suggestions for the collection of additional data that might ultimately enable researchers to determine which policy initiatives are effectively addressing market failures and stimulating improvements in economic performance.

Although some of this discussion constitutes a "wish list" for information that would be useful in policy analysis, I focus on suggestions that are <u>feasible</u>, given the federal government's limited resources for data collection. My review of the literature reveals that there is good news, in terms of feasibility, because much of this additional data has already been collected by private and non-profit organizations. Thus, it is conceivable that some of these institutions might be willing to engage in an SRP with NSF to exchange data and pool resources. This would reduce the cost of a data expansion initiative, as well as obviate the need to significantly add to the considerable response burden currently placed on high technology firms. At minimum, NSF should facilitate the process of linking existing data to these new, richer sources of information.

The remainder of this paper is organized as follows. Section II provides a brief review of recent empirical studies of the relationship between SRPs and economic performance. Much of this discussion focuses on the characteristics and shortcomings of the data analyzed in these papers. Section III outlines the salient measurement issues. The final section presents suggestions for the formulation of new indicators of SRPs and a specific data collection strategy. The objectives of this strategy are to target data collection efforts to the "most important" SRPs (those that are most likely to enhance economic growth) and to place a stronger emphasis on measuring SRP (and R&D) outputs.

## II. Review of Empirical Research on SRPs

Before discussing recent empirical studies of SRPs, it is useful to define some terms and characterize the wide variety of collaborative relationships that have emerged in recent years. SRPs are defined as any co-operative relationship involving organizations that conduct or sponsor R&D.[1] Many of these partnerships are potential sources of R&D spillovers and economic growth. The following are examples of SRPs:

- Research Joint Ventures (RJVs)
- Strategic Alliances
- Strategic Networks
- Industry Consortia (e.g., SEMATECH)
- Co-operative Research and Development Agreements (CRADAs)
- Engineering Research Centers (ERCs)
- Industry-University Co-operative Research Centers (IUCRCs)[2]
- Federally Funded Research and Development Centers (FFRDCs)
- Science Parks
- High-Technology Firms Receiving Financial Support from Venture Capital Funds
- Licensing Agreements Involving Universities, Government Laboratories, and Firms
- Sponsored Research Agreements Involving Universities, Government Laboratories, and Firms
- University-Based Entrepreneurial Start-ups
- Co-authoring Between Academics and Industry Scientists
- Faculty Consulting
- Educational Partnerships Involving Universities and Firms.

Note that this definition is quite broad and includes SRPs that have gained in prominence in the "new" economy, with its greater emphasis on intellectual property, venture capital, entrepreneurial start-ups, and university-industry technology transfer (UITT). As described in Siegel, Waldman, and Link (1999), the recent increase in UITT, through a technology transfer office (TTO) and other formal means, has led to a concomitant rise in the incidence and complexity of research partnerships involving universities and firms. The authors also report that in recent years, universities have become more receptive to the idea of accepting an equity position in an entrepreneurial startup, in lieu of up-front licensing revenue.

The last two categories of SRPs (faculty consulting and educational partnerships involving universities and firms) constitute informal means of transferring technologies from universities to firms. According to a recent National Academy of Engineering (NAE) study, summarized in a forthcoming paper by Grossman, Morgan, and Reid (2001), these SRPs may also be important

[1] An even broader definition might include any individual or organization that has an interest or stake in this relationship.

[2] ERCs and IUCRCs are NSF-sponsored public-private partnerships designed to promote technological diffusion, commercialization, and integration of research and education.

determinants of technological spillovers. The NAE study examined the contributions of academic research to industrial performance in five major industries and concluded that in some sectors, faculty consulting and educational partnerships between universities and firms played a critical role in the introduction of new production processes.

In characterizing SRPs, it is also important to distinguish between private-private partnerships and public-private partnerships.[3] Most SRPs fall into the latter category. Public-private partnerships receive some level of support from a public institution. Such support can assume various forms, such as government subsidies for projects funded by private firms (e.g., ATP), shared use of expertise and laboratory facilities (e.g., ERC or IUCRC), university technology incubators, science parks, licensing agreements between universities and firms, and university-based startups. Private-private partnerships are defined as relationships involving firms only. Examples of such partnerships include research joint ventures, strategic alliances, and networks involving two or more companies.

This distinction serves to underscore the "strategic" aspect of SRPs. For private-private partnerships, it is assumed that the key strategic objective is profit maximization. Hence, scholars who examine such relationships (see the burgeoning literature on SRPs in the field of strategic management) tend to focus on the impact of SRPs on stock prices or accounting profits. In the case of public-private partnerships, a government agency also has a "strategic" goal in establishing such an initiative. Typically, their objective is to address an innovation market failure (see Martin and Scott (2000)), and ultimately, enhance economic growth.

Thus, from a public policy perspective, once appropriate antitrust and intellectual property laws have been designed, public-private partnerships are likely to be of greater interest than collaborations involving firms only.[4] In theory, they should generate technological spillovers and ultimately, high social returns. If SRPs are achieving their goals, one would expect to see a reduction over time in the magnitudes of the market failures they address.

On the other hand, an assessment of the performance impact of private-private SRPs is more likely to reflect a private return to this activity. Although it is certainly relevant to calculate private returns, it is primarily the divergence between the private and social return that provides the fundamental rationale for government intervention in high technology industries. This is especially true when the private return is not sufficient to justify private investment. Note that private-private partnerships may also generate spillovers, although presumably of a smaller magnitude than public-private partnerships. The key difference is that for the private-private partnership, the private return is sufficient to warrant private investment, even if it falls short of the social return. I will return to this point later on, as I believe that much of the data collection effort should be focused on tracking the performance impact of public-private partnerships, so as to allow researchers to generate a better estimate of these social returns.

Another interesting policy issue involving public-private partnerships is the trend towards greater scrutiny of public investments in R&D. As described in Link (1996) and (1998), this stems, in part,

[3] Hagedoorn, Link, and Vonortas (2000) distinguish between research partnerships that are formal and informal. While that may be also be an important distinction, the analysis presented in this section presumes that all SRPs are formal relationships.
[4] Of course, the choice of appropriate antitrust and intellectual property laws requires an accurate assessment of the performance of collaborations involving firms only.

from recent initiatives to hold public technology-based institutions more accountable for documenting the economic impact of the R&D projects they have supported. Universities may face similar pressures from legislative bodies that provide funding. In contrast, for private-private partnerships, shareholder accountability has always been a powerful force in constraining self-serving behavior on the part of corporate managers, ensuring that they will closely monitor the financial return on investment in SRPs.

Table 1, included at the end of the paper, summarizes the key features of 47 recent studies of SRPs. For each study, I denote the type of SRP, nature of the institutions involved in the SRP, unit of observation, data sets used in the empirical analysis, methodology, and proxies for performance. Note that scholars in a wide variety of disciplines, such as economics, finance, sociology, public policy, and strategic management have examined SRPs. Interdisciplinary interest in this topic offers several advantages:

- An increase in the number of datasets available to researchers
- Consideration of SRPs in specific industries and nations
- A broader understanding of the antecedents and consequences of these relationships
- Alternative indicators of "performance," since notions of performance vary substantially across fields.

I now consider each of these in turn.

Three major datasets analyzed in these studies are the MERIT-CATI (Maastricht Economic Research Institute on Innovation and Technology-Cooperative Agreements & Technology Indicators) file, NSF's CORE (CO-operative REsearch) database, and the NCRA-RJV (National Co-operative Research Act-Research Joint Venture) database.[5] Many authors have examined special datasets consisting of firms that have received funds from government programs that support technology-based SRPs, such as the ATP and SBIR programs. Typically, these authors then link this information to firm-level surveys of production, R&D, accounting profitability, and stock prices (e.g., COMPUSTAT and CRSP), in order to assess the impact of the SRP on economic or financial performance.

It is interesting to note that the papers constitute a mix of quantitative and qualitative research. In fact, some researchers have designed their own surveys of firms involved in SRPs, typically with government or foundation support. More importantly, numerous authors have made liberal use of proprietary databases, such as files created by the Securities Data Company, Science Citation Index, Recombinant Capital, Corporate Technology Directory, and Venture Economics. Studies examining SRPs resulting from university-industry technology transfer (UITT) have been based on the comprehensive survey conducted by the Association of University Technology Managers (AUTM), as well as archival data on patents, licenses, and startups at several major universities (Stanford, Columbia, MIT, and the University of California system). Several authors, especially in the field of strategic management, have collected data on specific industries, such as chemicals, biotechnology, and semiconductors.

Table 1 also reveals that authors have used a wide variety of performance/output indicators for SRPs. These include the following conventional measures:

- Patents
- Short Term Movements in Stock Prices

[5] These datasets are described in greater detail in Hagedoorn, Link, and Vonortas (2000).

- Total Factor Productivity
- R&D Expenditure
- R&D Employment

and numerous unconventional proxies, such as:

- Licensing of Technologies
- Citations of Patents
- Citations of Academic Articles
- Co-authoring between Academic and Industry Scientists
- Creation of Entrepreneurial Start-ups
- Firm Retention in an SRP
- Hiring of Engineering and Science Graduates
- Use of Faculty Members as Consultants
- Firm or SRP Survival
- New Products Developed and Commercialized
- Growth in Employment and Sales.

Many authors have interpreted these indicators as different ways of characterizing the spillover mechanism.

Not surprisingly, management and finance studies focus mainly on SRPs involving firms only and concentrate on explaining short-run financial performance and accounting profitability. On the other hand, economists devote their attention to public-private partnerships, the search for R&D spillovers, program evaluation (SBIR, ATP, EUREKA, Frameworks Programme) and the effects of consortia (SEMATECH), "crowding out" of private R&D investment, and the impact of SRPs on total factor productivity.

Many studies of research joint ventures and strategic alliances in the management and finance literatures use the event study methodology, which is based on the capital asset pricing model (CAPM). Event studies have been used widely by researchers in the fields of accounting, economics, and finance to assess the stock price effect that is conveyed by a major corporate announcement, such as announcements of quarterly earnings, mergers and acquisitions, new products and investments, legislation and regulatory changes, and other economically relevant events. This method measures the average change in share price that arises when an unanticipated event is announced. The event presumably provides new information on the future profitability of companies that experience it. In this instance, the event is the announcement of the formation of an SRP.

It is quite tempting to use the event study approach because firms and other organizations involved in SRPs typically do not report direct performance measures (for a given SRP). On the other hand, share price information is available for all publicly held firms. The use of this method also obviates the need to deal with difficult measurement issues associated with the measurement of total factor productivity (especially physical and technical capital). Furthermore, it is much more difficult (if not, impossible) for managers to manipulate share prices than measures of accounting profitability.

Despite these considerable strengths, event studies suffer from several critical limitations. First, as noted in McWilliams and Siegel (1997), they are based on a set of rather heroic assumptions that may be invalid for managerial decisions, such as the formation of an SRP. One such assumption is that the events are exogenous, which is clearly violated for most strategic decisions, such as the formation of an SRP.[6] Furthermore, it is important to note that the unit of observation in an event study is the firm, because stock prices are only available at the firm level, for publicly traded companies. Thus, event studies preclude an analysis of SRPs below the firm level and those involving privately held companies. That is unfortunate because many SRPs involve the creation of a small venture, which can easily be masked within a large organization. Finally, many leading economists (see Shleifer (2000)) have recently become more skeptical regarding the validity of the "efficient markets" hypothesis, which provides the theoretical basis for the capital asset pricing model (CAPM) and the associated event study methodology.

If short-run shifts in stock prices are not a good proxy for the long run performance of SRPs, we need to identify alternative measures. In the next section, I outline a set of measurement issues that help us identify "better" indicators, where the latter is defined as measures that improve our estimation of private and social returns.

## III. Measurement Issues

The growth of public investment in R&D, through "National Innovation Systems" and other programs, has led to greater interest in evaluating the social returns to publicly funded R&D. A missing link in the assessment of the social returns to publicly-funded R&D (at universities, federal research labs, and other nonprofit/public institutions) is the role that public R&D plays in the creation of new industries. A discussion of the problems researchers have encountered in quantifying the benefits of public R&D can be linked more broadly to the literature on the difficulties of measuring prices and productivity in high technology industries.

Currently, the government does a very poor job of tracking economic activity in embryonic industries and the emergence of new industries within existing sectors. This lack of coverage could result in a downward bias in estimates of the social returns to publicly-funded R&D, since it might lead to an underestimation of the impact of public R&D on economic efficiency. Presumably, these errors may also reduce the accuracy of estimates of the impact of SRPs on economic performance.

This conclusion is based on the following line of reasoning: Total factor productivity (TFP) is generally regarded to be the best metric of economic performance and thus, should be used to assess the social returns to SRPs. However, TFP is notoriously difficult to measure, mainly because of inadequate adjustments for changes in product and input quality. Using an industry's rate of introduction of new products as a proxy for mismeasurement of the quality of its output, Siegel (1994) examined the incidence of measurement errors in output prices across 348 manufacturing industries. He found that the producer price index (PPI), the most commonly used indicator of the rate of inflation used to calculate TFP, missed about 40% of quality improvements in the 1970s and early 1980s. In a subsequent paper (Siegel (1997)), the author reported that these measurement errors are especially severe in industries that invest heavily in computers and R&D. More importantly, he found that controlling for an industry's ability to generate new products yielded substantially more accurate estimates of the social returns to investment in computers and R&D.

It is reasonable to assume that the same logic might apply to assessing the social returns to SRPs, since some of these partnerships are specifically formed to develop a new product or to perfect a new

[6] While it is possible to control for partially anticipated events, many authors do not incorporate such effects in their empirical analysis.

production process. That is, the benefits of SRPs may be poorly measured because they show up in new products and industries. More comprehensive and more timely measures of the emergence of new industries by relevant statistical agencies, e.g., the U.S. Census Bureau, would likely result in more precise measures of the benefits of SRPs, in terms of stimulating product innovation and quality improvements (see Trajtenberg (1990)).

Additional critical aspects of SRP performance include their role in stimulating the diffusion of new technologies, fostering economic growth, and creating new jobs. These are considered to be of paramount importance for many public-private partnerships and it is essential, from a public policy perspective, that such institutions be able to document the global economic impact of these relationships. A notable example concerns SRPs resulting from university-industry technology transfer (UITT) activities. In this regard, it is interesting to note that a primary justification for the Bayh-Dole of Act of 1980, the landmark legislation that spurred growth in university ownership and management of intellectual property, was that it would foster a more rapid rate of technological diffusion and enhance economic growth. An evaluation of the "success" of UITT SRPs should ideally be based on an assessment of their impact on these variables.

Thus, collecting information on multiple outputs would be useful. For instance, universities have two options when they engage in commercialization of their intellectual property. One is to negotiate a licensing agreement with an existing company. Another avenue is to establish a relationship with a new company that is formed to commercialize the new technology. In some cases, the university assumes an equity position in the venture. According to the Association of University Technology Managers (AUTM), over 2,000 university technology transfer startups have been formed in the U.S. since 1980, some with funding from venture capital firms.

Despite the potential importance of university technology transfer startups as a mechanism for generating local technological spillovers and revenue to the university, there has been no systematic analysis of the determinants and consequences of university involvement in these new entrepreneurial ventures. As a result, it is difficult for policymakers and university administrators to assess the private and social returns to this activity. With regard to measures of the "outputs" of this process, special attention should be paid to three key potential dimensions of the social returns to university technology transfer: "time to market," firm growth, and survival.

Another measurement issue concerns the role of SRPs in the innovation process. SRPs can be viewed as an intermediate output of R&D, or the emergence of a new organizational form (such as an RJV or strategic alliance) that allows R&D to be conducted more effectively. This underscores the importance of tracking this activity and following these organizational entities over time, in order to determine which SRPs are accomplishing their objectives. This may be especially critical, given the embryonic nature of the technologies and industries involved in these relationships (e.g., biotechnology) and hence, the long lag between the formation of a partnership and the realization of returns to the organizations involved in the transaction.

As noted in the previous section of the paper, NSF does indeed track RJVs and there is some existing information on the survival of RJVs (e.g., case studies on SEMATECH (Link (1996), Link, Teece, and Finan (1996)). However, there needs to be a considerable expansion in the scope of coverage of SRPs, including many of the SRPs presented in Table 1. Also, more comprehensive, direct indicators of SRP "performance" (broadly defined) need to be systematically collected.

In gathering this additional information on SRPs, NSF should consider modifying its current data collection strategy with regard to R&D activity. That is, given the objective of deriving more accurate estimates of the private and social returns to innovative activity (as manifested in an SRP), there needs to be a fundamental shift from gathering data on R&D inputs to a greater focus on R&D outputs. Currently, the government does an excellent job of tracking R&D inputs, especially information on the scientific workforce and other human resource management factors, firm and university R&D expenditure, and patenting activity in academia and the industrial sector.[7]

A more fruitful approach for SRPs would involve stressing the collection of information on outcomes, such as new products, licensing agreements, formations of strategic networks, launching of startups, research collaborations (co-authoring), citations, the creation of new jobs and industries, and sales growth. This would enable researchers to extend some of the excellent work on evaluating the distribution of the private and social value of patents (see Henderson, Jaffe, and Trajtenberg (1998) and Jaffe, Trajtenberg, and Henderson (1993)) to licensing activities and other dimensions of output. Another useful methodology is the technique outlined in (2001), which is based on computing the expected private and social returns at the inception of an SRP.[8]

It is important to note that, with regard to certain outcome measures, such as total factor productivity, NSF does not have a comparative advantage in collecting its own performance data. In these instances, the best course of action would be for NSF to facilitate linkages between its own data on SRPs and other government data on economic performance. Indeed, there is a precedent for this, as some researchers have succeeded (with NSF financial support) in linking NSF's R&D firm-level R&D survey to the U.S. Census Bureau's establishment-level Longitudinal Research Database (LRD) (see Adams and Jaffe (1996) and Lichtenberg and Siegel (1991)).

In the following section, I present a proposed strategy for the collection of additional data on SRPs and economic performance.

## IV. Suggestions for Data Collection

Given the arguments and evidence presented in previous sections of the paper, I suggest that NSF contemplate adopting the following initiatives:

- Broadening its coverage of these relationships to include a wide range of SRPs, especially those involving public-private partnerships
- Focusing its data collection effort on output and performance indicators, including the role of SRPs in fostering technological diffusion and the creation of new products, firms, and industries
- Collecting similar information from (observationally equivalent) firms not engaged in SRPs, including those who applied for public subsidies for SRPs and did not receive them
- Engaging in SRPs with private organizations that have compiled data on SRPs
- Facilitating linkages between existing datasets on SRPs and economic performance.

I now consider each of these in turn.

Given the rise in the incidence and variety of SRPs, it is useful for NSF to broaden its coverage of this activity. I have also maintained that it would be desirable to target the data collection effort to public-

[7] There is considerable debate regarding whether patents constitute an input or output of the R&D process.
[8] This method is an extension of the standard Griliches/Mansfield approach to evaluating the private and social returns to innovation.

private partnerships, since there is typically more interest in assessing the social, as opposed to the private, returns to R&D. Furthermore, since private organizations involved in such relationships have accepted some form of direct or indirect governmental support or subsidy, it may be easier to convince them to respond to a new survey or an expanded version of an existing survey.[9]

I have also argued that greater attention should be paid to gathering information on R&D (and SRP) outputs, as opposed to the current data collection strategy, which appears to be focused on R&D inputs. This approach could potentially yield more precise estimates of R&D spillovers associated with publicly funded innovative activity. In a similar vein, it would also be useful to systematically collect information from as many firms as possible, including those who are not involved in SRPs and those who apply for subsidies, yet fail to receive them. This would allow for a much more accurate assessment of the effects of public support of R&D and potentially enable us to identify those SRPs that generate the highest social returns. Longitudinal analysis would also allow us to determine whether certain SRPs are indeed effectively targeting market failures, since economic theory predicts that government intervention is warranted when there is a substantial divergence between private and social returns.

Given the existence of limited resources for additional data collection, a cost-effective approach is that NSF itself should engage in public-private partnerships with organizations that have been systematically collecting data on various aspects of the new economy. These include non-profit organizations, such as the Association of University Technology Managers (AUTM). For instance, with AUTM's support, NSF could collect information from universities on various dimensions of output and performance we have discussed in this paper, such as faculty/graduate student involvement in UITT and more detailed questions on licensing activity and the formation, growth, and survival of university technology transfer startups. An alternative is to add a few questions to an existing NSF survey on relationships firms have with universities. It is also useful to note that there is some overlap in information reported to NSF is also reported to AUTM (e.g., both NSF and AUTM collect information on R&D expenditures). Another potential partner for NSF is the Technology Transfer Society (TTS), an organization of technology transfer professionals which publishes the *Journal of Technology Transfer*.

Finally, it is unwise for NSF to re-invent the wheel. As shown in Table 1, there now exist numerous proprietary databases, such as files created by the Securities Data Company, Science Citation Index, Recombinant Capital, Corporate Technology Directory, and Venture Economics, on SRPs. Furthermore, some researchers have collected their own quantitative and qualitative data on firms involved in SRPs, often with NSF support. Thus, to maximize the return on the data collection effort, linkages of existing datasets should be facilitated. Perhaps a unit could be formulated within NSF that assists researchers in constructing files that combine private and public data on SRPs and economic performance. A model for such a unit is the Center for Economic Studies at the U.S. Census Bureau, where researchers have been analyzing linked datasets since the late 1980s, subject to clearance procedures that preserve confidentiality. Similar clearance procedures could be implemented at NSF.

[9] That is, one suspects that the response rate would be significantly higher for a survey involving public-private partnerships than a survey of SRPs involving private firms only.

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**Table 1: 47 Recent Empirical Studies of the Effects of Strategic Research Partnerships (SRPs) on Performance**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Hagedoorn and Schakenraad (1994) | Strategic Technology Alliances | Public-Private Partnership/ Firm | Maastricht Economic Research Institute on Innovation and Technology (MERIT)- *Cooperative Agreements & Technology Indicators (CATI) Database* | Structural Equation Modelling (LISREL) | Patents |
| Sakakibara (1997a) | Japanese Research Consortia | Public-Private Partnership/ Firm | Quantitative and Qualitative Data on Government-Sponsored R&D Consortia at the Project and Firm-Levels | Regression Analysis | Qualitative Measures of Project-Related Firm R&D Expenditure |
| Sakakibara (1997b) | Japanese Research Consortia | Public-Private Partnership/ Firm | Quantitative and Qualitative Data on Government-Sponsored R&D Consortia at the Project and Firm-Levels | Regression Analysis | Contribution of R&D Consortia to the Establishment of Competitive Position |
| Branstetter and Sakakibara (1998) | Japanese Research Consortia | Public-Private Partnership/ Firm | Quantitative and Qualitative Data on Government-Sponsored R&D Consortia at the Project and Firm-Levels | Regression Analysis | R&D Expenditure, Patents |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Cockburn and Henderson (1998) | Collaborative Relationships Involving Public and Privately-Financed Scientists | Public-Private Partnership/ Firm | Co-authorship of Scientific Papers (from *Science Citation Index*) Involving Industry and University Scientists in the Pharmaceutical Industry, Author's Calculations of "Important" Patents, Compustat | Regression Analysis | R&D Expenditure, "Important" Patents |
| Zucker, Darby, and Brewer (1998) | Relationships Involving "Star" Scientists and U.S. Biotech Firms | Public-Private Partnership/ Firm | Authorship of Scientific Papers Reporting Genetic-Sequence Discoveries, Data on Biotech Firms from the *North Carolina Biotechnology Center (1992) & Bioscan (1993)* | Regression Analysis | Birth of Biotechnology Enterprises |
| Zucker and Darby (2001) | Relationships Involving "Star" Scientists and Japanese Biotech Firms | Public-Private Partnership/ Firm | Data on Biotechnology Firms from the *Biotechnology Guide Japan 1990-1991* and the *Nikkei Biotechnology Directory* | Regression Analysis | Patents, Number of Products Developed, Number of Products on the Market |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Lerner and Merges (1998) | Strategic Technology Alliances in the Biotechnology Industry | Private-Private Partnership/ Firm | Database of Alliances in the Biotechnology Industry Compiled By *Recombinant Capital* | Regression Analysis | No Analysis of Performance- Authors Examine Allocation Of "Control Rights" |
| Baum, Calabrese, and Silverman (2000) | Strategic Technology Alliances in the Canadian Biotechnology Industry | Private-Private Partnership/ Firm | *Canadian Biotechnology* Database, which Includes Information on Alliance Formation, Products, Growth, and Performance of Biotech Start-ups | Regression Analysis | Revenues, R&D Employees, R&D Expenditure, and Patents |
| Anand and Khanna (2000) | Research Joint Ventures and Licensing Contracts | Private-Private Partnership/ Firm | *Strategic Alliance Database* of the *Securities Data Company (SDC), CRSP* | Event Study | Short-term Movements in Stock Prices |
| Ahuja (2000) | Strategic Technology Alliances in the Chemical Industry | Private-Private Partnership/ Firm | *Dow Jones News Retrieval, Predicast's Funk and Scott (F&S) Index, Chemical Week, Plastics Technology* | Regression Analysis | Focus of Paper is Not on Performance |
| Stuart (2000) | Strategic Technology Alliances in the Semiconductor Industry | Private-Private Partnership/ Firm | *Dataquest, Predicast's Funk and Scott (F&S) Index, Lexis-Nexis, Electronic News, Infotrak, Electronic Buyer's News, Electronic Engineering Times, Electronic, Electronic Business* | Regression Analysis | Sales Growth, Patents |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Chan, Kensinger, Keown, and Martin (1997) | Strategic Technology Alliances | Private-Private Partnership/ Firm | *Wall Street Journal Index, Dow Jones News Retrieval, CRSP* | Event Study | Short-term Movements in Stock Prices |
| Reuer and Koza (2000) | Joint Ventures | Private-Private Partnership/ Firm | *Predicast's Funk and Scott (F&S) Index, Lexis-Nexis, and CRSP* | Event Study | Short-term Movements in Stock Prices |
| Merchant and Schendel (2000) | Joint Ventures | Private-Private Partnership/ Firm | *Dow Jones News Retrieval, CRSP* | Event Study | Short-term Movements in Stock Prices |
| Madhavan and Prescott (1995) | Joint Ventures | Private-Private Partnership/ Firm | *Wall Street Journal Index, Mergers and Acquisitions Magazine, and CSRP* | Event Study | Short-term Movements in Stock Prices |
| Koh and Venkatraman (1991) | Joint Ventures | Private-Private Partnership/ Firm | *Wall Street Journal Index, Mergers and Acquisitions Magazine, and CSRP* | Event Study | Short-term Movements in Stock Prices |
| Reuer (2000a) | Joint Ventures | Private-Private Partnership/ Firm | *Predicast's Funk and Scott (F&S) Index, Lexis-Nexis, and CRSP* | Event Study | Short-term Movements in Stock Prices |
| Reuer (2000b) | Joint Ventures | Private-Private Partnership/ Firm | *Predicast's Funk and Scott (F&S) Index, Lexis-Nexis, and CRSP* | Event Study | Short-term Movements in Stock Prices |
| Link and Bauer (1989) | Research Joint Ventures | Private-Private Partnership/ Firm | *Co-operative Research (CORE) Database, Authors' Survey of R&D Intensive Firms , Compustat* | Regression Analysis | Market Share, "Rate of Return" on Company-Funded R&D |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Vonortas (2000) | Research Joint Ventures | Private-Private Partnership/ Firm | *National Co-Operative Research Act (NCRA)-RJV Database (which contains Compustat and CorpTech data)* | Descriptive Analysis | No Analysis of Performance- Author Examines Patterns of Firm Collaboration |
| Scott (1996) | Environmental Research Joint Ventures | Public-Private Partnership/ Firm | *Co-operative Research (CORE)* Database, Author's Survey of R&D Managers | Regression Analysis | Self-Reported and Statistical Measures of the Effects of Cooperation on R&D |
| Link, Teece, and Finan (1996) | Research Joint Ventures- SEMATECH | Public-Private Partnership/ Firm | Interviews, Case Studies | Qualitative Analysis | Self-Reported Measures of Success |
| Link (1998) | Government-Sponsored R&D Projects-ATP (including RJVs) | Public-Private Partnership/ Firm | Interviews, Case Study | Qualitative Analysis | Effects on Research Productivity |
| Vonortas (1999) | Government-Sponsored R&D Projects-ATP (including RJVs) | Public-Private Partnership/ Firm | Interviews, Case Studies | Qualitative Analysis | Effects on Research Productivity |
| Link and Scott (1998) | Government-Sponsored R&D Projects-(including some ATP-supported RJVs) | Public-Private Partnership/ Firm | Interviews, Case Studies | Qualitative Analysis | Commercialization Results, Spillover Effects, Effects on Competitiveness |
| Irwin and Klenow (1996) | Research Joint Ventures-SEMATECH | Public-Private Partnership/ Firm | Compustat | Regression Analysis | Ratio of (Private) R&D to Sales |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Lerner (1999) | Government-Funded R&D Projects–SBIR | Public-Private Partnership/ Firm | *GAO Surveys of SBIR firms, Corporate Technology Directory, Compustat* | Regression Analysis | Growth in Employment and Sales, Ability of Firms to Attract Venture Capital Funding |
| Griliches and Regev (1998) | Government-Funded R&D Projects Conducted by Israeli Manufacturing Firms | Public-Private Partnership/ Firm | *Panel Dataset of Israeli Manufacturing Firms (Linking Production and R&D Data)* | Regression Analysis | R&D Expenditure, Total Factor Productivity |
| Klette and Moen (1998) | Government-Funded R&D Projects Conducted by Norwegian Manufacturing Firms | Public-Private Partnership/ Firm | Firm-Level R&D Survey of Norwegian Manufacturing Firms | Regression Analysis | Private R&D Expenditure, Ratio of (Private) R&D to Sales |
| Klette and Moen (1999) | Government-Funded R&D Projects in Information Technology Conducted by Norwegian Manufacturing Firms | Public-Private Partnership/ Firm | Firm-Level R&D Survey of Norwegian Manufacturing Firms | Regression Analysis | Private R&D Expenditure, Ratio of (Private) R&D to Sales |
| Wallsten (2000) | Government-Funded R&D Projects–SBIR | Public-Private Partnership/ Firm | *Federal Research in Progress (FedRIP) File, SBA's Listing of SBIR Awardees, Compustat, Dun and Bradstreet* | Regression Analysis | R&D Expenditure |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Gompers and Lerner (1999) | Firms Financed by Venture Capital Firms (Including Venture Funds Sponsored by Corporations) | Private-Private Partnership/ Firm | *Venture Economics, Securities Data Company, VentureOne, Venture Intelligence, Million Dollar Directory, Ward's Business Directory of U.S. Private-Public Companies, Directory of Leading Private Companies. LEXIS, CRSP Recombinant Capital, Corporate Technology Directory* | Regression Analysis, Event Study | Limited Analysis of Financial Performance of Venture Capital Funds |
| Hall, Link, and Scott (2000) | ATP Research Joint Ventures Involving Universities | Public-Private Partnership/ Firm | *ATP Data, Authors' Survey of Program Participants* | Regression Analysis | None Except Termination, Qualitative Measures of How Universities and Firms Interact |
| Siegel, Waldman, and Link (1999) | University-Industry Technology Transfer: Patents, Licenses, Startups, and Sponsored Research | Public-Private Partnership/ University | *Association of University Technology Managers (AUTM) Survey, NSF, and U.S. Census Data,* Interviews | Regression Analysis and Qualitative Research | Total Factor Productivity of Universities |
| Thursby, Jensen, and Thursby (2001) | University-Industry Technology Transfer: Patents, Licenses, Startups, and Sponsored Research | Public-Private Partnership/ University | *Association of University Technology Managers (AUTM) Survey,* Authors' Survey | Regression Analysis and Qualitative Research | Total Factor Productivity of Universities |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Mowery, Nelson, Sampat, and Ziedonis (2000) | University-Industry Technology Transfer: Patents and Licenses | Public-Private Partnership/ University | *Longitudinal Data from Technology Transfer Offices at Columbia, Stanford, and the University of California System* | Regression Analysis | Patents, Licensing Activity |
| Mowery and Ziedonis (2000) | University-Industry Technology Transfer: Patents and Licenses | Public-Private Partnership/ University | *Longitudinal Data from Technology Transfer Offices at Columbia, Stanford, and the University of California System* | Regression Analysis | Patents, Licensing Activity |
| Shane and Khurana (1999) | University-Industry Technology Transfer: Startups | Public-Private Partnership/ Firm | *Longitudinal Data from MIT Technology Transfer Office on all Patents, Licenses, and Startups* | Regression Analysis | Formation of Start-ups |
| Franklin, Wright, and Lockett (2001) | University-Industry Technology Transfer: Startups | Public-Private Partnership/ University | *Authors' Qualitative Survey of U.K. Technology Transfer Offices* | Correlational Analysis and Qualitative Research | Self-Reported Measures of Success and Attitudes Towards Academic Entrepreneurship |
| Meseri and Maital (2001) | University-Industry Technology Transfer: Startups | Public-Private Partnership/ University | *Authors' Qualitative Survey of Israeli Technology Transfer Offices* | Regression Analysis and Qualitative Research | Self-Reported Measures of Success |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Adams, Chiang, and Starkey (2001) | University-Industry Technology Transfer: Industry-University Research Centers, Engineering Research Centers, NSF Science and Technology Centers, and Industrial Laboratories | Public-Private Partnership/ Industrial Laboratory | *Survey of Industrial Laboratory Technologies, Survey of IUCRCs* | Regression Analysis | Hiring of Engineering and Science Graduates, Co-authoring with Academics, Using Faculty Members as Consultants, Patents, R&D Expenditure |
| Gray, Lindblad, and Rudolph (2001) | University-Industry Technology Transfer: Industry-University Research Centers | Public-Private Partnership/ Firm | Firm | Regression Analysis | Member Retention in IUCRC |
| Santoro and Gopalakrishnan (2001) | University-Industry Technology Transfer: Engineering Research Centers, and Industry-University Research Centers | Public-Private Partnership/ Firm | *Authors' Survey Of Firms Who Belong to a Publicly-Funded Research Center* | Regression Analysis and Qualitative Research | Self-Reported Measures of Technology Transfer Activity Involving Research Center |
| Caloghirou, Tsakanikas, and Vonortas (2001) | University-Industry Technology Transfer-Research Joint Ventures Involving Universities-European Frameworks Programme | Public-Private Partnership/ Firm | *STEP to RJV Database (consisting of EU-RJV file and RJV-Survey (Longer Questionnaire with Numerous Qualitative Variables))* | Regression Analysis | Self-Reported Measures of Various Aspects of R&D Performance (e.g., Ability to Achieve Synergies in Research and Proxies for Absorptive Capacity) |

**Table 1 (cont.)**

| Author(s) | Type of SRP | Nature of Institutions Involved in SRP /Unit of Observation | Data Sets | Methodology | Proxies for Performance |
|---|---|---|---|---|---|
| Adams, Chiang, and Jensen (2000) | Cooperative Research and Development Agreements (CRADAs) Involving Federal Laboratories and Firms | Public-Private Partnership/ Industrial Laboratory | *Survey of Government Laboratory R&D, Survey of Industrial Laboratory Technologies, Compustat* | Regression Analysis | Patents, R&D Expenditure |
| Jaffe, Fogarty, and Banks (1998) | Federal Laboratory (Electro-Physics Branch (EPB) of the NASA-Lewis Research Center) | Public-Private Partnership/ Firm Use of Technologies Developed at Federal Laboratory | *EPB's Patents and Citations to Those Patents by Firms* | Qualitative Analysis | Citations of Patents, Proxies for Absorptive Capacity |
| Westhead, Siegel, and Wright (2000) | Science Parks (U.K.) | Public-Private Partnership/ Firm | *Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in the United Kingdom* | Regression Analysis | Patents, Copyrights, New Products/Services to Existing Customer Base, New Products/Services in New Markets, Total Factor Productivity of Research Efforts |

## Inter-Firm R&D Partnership—
## An Overview of Major Trends and Patterns Since 1960

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### I. Introduction

This paper will attempt to present an initial analysis of some major trends and patterns in inter-firm R&D partnering since the early 1960s. The paper focuses on collaboration between independent companies through formal agreements, such as contractual agreements and joint ventures. Although companies can co-operate in many activities, I will mainly look at partnerships where R&D is at least part of the collaborative effort. R&D refers to the standard research and development activity devoted to increasing scientific or technical knowledge and the application of that knowledge to the creation of new and improved products and processes.

As will be explained below, joint R&D by companies is considered by many observers as one of the, until recently, least expected activities that companies would be willing to share with others. This is probably also one of the reasons why R&D partnering has attracted so much attention during the recent years, both in the academic and in the popular press. However, so far most studies on R&D partnerships and other forms of inter-firm collaboration are based on survey-research and, therefore, usually of a cross-sectional nature. In the 1980s a number of attempts were made to set up databases that would allow longitudinal research but the work on most of these databases was terminated after a number of years. Apart from some 'commercial' databases, that are mainly focussed on the biotechnology and information technology sectors, there are few databases that generate both cross-sectional and longitudinal insight (Hagedoorn, Link and Vonortas, 2000).

The MERIT-CATI database (see Annex I) is one the few still existing databases and it will be explored in the following to discover a number of general trends and patterns in R&D partnering. Given its history and coverage it is also one of the few databases that allow us to study patterns in R&D partnerships in several industries, both domestic and international, in different regions of the world over an extended period of several decades.

The paper is organized as follows: first I will discuss some of the motives for inter-firm partnering and its organizational setting. I will also present some definitions that are useful to understand what phenomenon is actually being studied. Second, the MERIT-CATI allows me to present a general overview of trends in R&D partnerships since 1960 in the light of the current literature. This part of the analysis looks at both growth data and the distribution according to major organizational features of these partnerships. Third, sectoral patterns are of major importance to the understanding of R&D partnerships because the literature suggests that partnerships are somewhat sector-specific as the propensity to enter into partnerships differs from industry to industry. Fourth, the same applies to the further understanding of international patterns in the forming of R&D partnerships, for which I will consider both international patterns as such and some sector-specific elements in the international distribution of R&D partnerships. The closing section of this paper presents some conclusions that can be drawn from this contribution.

## II. A Background to R&D Partnerships: Motives, Organizational Settings and Some Definitions

R&D partnerships are part of a relatively large and diverse group of inter-firm relationships that one finds in between standard market transactions of unrelated companies and integration by means of mergers and acquisitions. When inter-firm relationships began to attract attention in both the economics and the business and management literature, a number of taxonomies of different modes of inter-firm relationships were introduced that have gradually become well-integrated in the literature to the extent that it now seems sufficient to only outline the main forms of inter-firm relationships. See Auster (1987), Chesnais (1988), Contractor and Lorange (1988), Dussauge and Garetti (1999), Hagedoorn (1990 and 1993), Narula (1999), Nooteboom (1999), Osborn and Baughn (1990), Yoshino and Rangan (1995) for some of these taxonomies. As this paper concentrates on R&D partnerships I will briefly focus on those partnerships that one can expect to have an impact on R&D, innovation and technological development.

If one follows the logic of increasing organizational interdependency of different forms of inter-firm relationships to distinguish between partnerships (Hagedoorn, 1990 and 1993), one arrives at the following line-up:

- Licensing refers to agreements that provide unilateral technology access, frequently through patents, to a licensee in return for a fee. Cross-licensing is a bilateral form of licensing where companies usually 'swap' packages of patents to avoid patent infringements or to exchange existing, codified technological knowledge.
- Second-sourcing agreements regulate the transfer of technology through technical product specifications in order to produce exact copies of products. In the case of mutual second sourcing this transfer takes place between two or more companies that transfer technical specifications of different products.
- Customer-supplier relationships are co-production contracts and co-makership relations that basically regulate long-term contracts between vertically-related, but independent, companies that collaborate in production and supply. A specific case of customer-supplier relationships are R&D contracts where one company is sub-contracted by another company to perform particular R&D projects.
- Joint R&D pacts and joint development agreements are contractual relationships through which companies perform jointly funded R&D projects, or in the case of joint development agreements, jointly work on the development of new products or processes.
- Joint ventures are the combinations of the economic interests of at least two separate companies in a distinct organizational entity, where profits and losses are usually shared in accordance with the equity investments by the 'parent' companies. Joint ventures act as 'separate' organizations that have regular company objectives such as production, marketing and sales, but if relevant also R&D, as a specific objective of the partnership.

In the following I will refer to R&D partnerships as the specific set of different modes of inter-firm collaboration where two or more firms, that remain independent economic agents and organizations, share some of their R&D activities. These R&D partnerships are primarily related to two categories of the above, i.e. contractual partnerships, such as joint R&D pacts and joint development agreements, and equity-based joint ventures. As both modes of cooperation will feature so prominently in the following analysis and as they are also the most important form of bilateral R&D exchanges and joint R&D undertaking, I will briefly discuss these modes somewhat further.

Joint ventures are certainly one of the older modes of inter-firm partnering. Joint ventures, including those with a specific R&D program, have become well known during the past decades (Berg, Duncan and Friedman, 1982; Hagedoorn, 1996; Hladik, 1985). Joint ventures are organizational units created and controlled by two or more parent companies and as such they increase the organizational interdependence of the parent companies. Although joint ventures can be seen as 'hybrids' in between markets and hierarchies, they do come close to hierarchical organizational structures as parent companies share control over the joint venture (Williamson, 1996). However, joint ventures can also act as semi-independent units that perform standard company functions such as R&D, manufacturing, sales, marketing, etc. It is this semi-independent status that enables companies to apply joint ventures in a broader strategic setting where companies enter into new markets, reposition themselves in existing markets or use exit strategies in declining markets (Harrigan, 1988).

According to Hagedoorn (1996) and Narula and Hagedoorn (1999) joint ventures seem to have become gradually less popular if compared to other forms of partnering. This decreasing popularity is probably due to the organizational costs of joint ventures in combination with their high failure rate (Kogut, 1988; Porter, 1987). More specifically, problems with the continuation of joint ventures, as mentioned in the literature, are related to the risk of sharing proprietary knowledge, the 'appetite for control' by one partner and a variety of different strategic objectives as mentioned in the above (Dussauge and Garetti, 1999; Harrigan, 1985 and 1988; Hladik, 1985; Nooteboom, 1999).

Recent studies have established that non-equity, contractual forms of R&D partnerships, such as joint R&D pacts and joint development agreements, have become very important modes of inter-firm collaboration as their numbers and share in the total of partnerships has far exceeded that of joint ventures (Hagedoorn, 1996; Narula and Hagedoorn, 1999; Osborn and Baughn, 1990). These contractual agreements cover technology and R&D sharing between two or more companies in combination with joint research or joint development projects. Such undertakings imply the sharing of resources, usually through project-based groups of engineers and scientists from each parent-company. The costs for capital investment, such as laboratories, office space, equipment, etc., are shared between the partners. Although these contractual R&D partnerships have a limited time-horizon, due to their project-based organization, each partnership as such appears to ask for a relatively strong commitment of companies and a solid inter-organizational interdependence during the joint project. However, compared to joint ventures, the organizational dependence between companies in an R&D partnership is smaller and the time-horizon of the actual project-based partnerships is almost by definition shorter (Hagedoorn, 1993).

The actual difference between the two main sub-categories of contractual R&D partnerships, i.e. R&D pacts and joint development agreements, is quite small and largely depends on the role of R&D in certain industries. In high-tech industries such as biotechnology, pharmaceuticals and information technology sectors, these contractual arrangements are frequently focussed on in-depth research activities. In many other industries these partnerships will focus more on the development and engineering of new products or new processes than on research.

Given the somewhat more informal nature of this form of collaboration, these R&D pacts and joint development agreements cover a wide variety of legal and organizational arrangements. Also, even more than in the case of joint ventures, these contractual R&D partnerships are to be seen as incomplete contracts for which it is impossible to specify the concrete results of the joint effort. The popularity of these contractual arrangements has to be found in the flexibility that companies achieve through these relatively small-scale projects and the low costs of both intended and unintended termination compared to the costs of the termination of a distinct organization like a joint venture.

An interesting subject in this context refers to the motivation of companies to enter into these different R&D partnerships. In general it seems that both a cost-economizing rationale and strategic rationale play a role. The cost-economizing motivation applies when at least one company enters the partnership mainly to lower the cost of some of its R&D activities by sharing the costs with one or more other companies. This cost-economizing rationale appears to particularly play a role in capital and R&D intensive industries, such as the telecom capital goods industry, where the cost of single, large R&D projects are beyond the reach of many companies (Hagedoorn, 1993). However, the strategic rationale becomes important if, for instance, companies decide to selectively enter into R&D partnerships that are not related to their core activities while keeping their main R&D activities within their own domain (Teece, 1986). The strategic intent of R&D partnerships is also apparent in those cases where companies jointly perform R&D in new, high-risk areas of R&D of which the future importance for their technological capabilities remains unclear for a considerable period of time.

For many R&D partnerships cost-economizing and strategic motives are intertwined. This becomes most apparent if one looks at the results of some studies on motives for inter-firm partnerships. Most studies on R&D partnerships or similar forms of alliances (see amongst others, Das, Sen and Sengupta, 1998; Eisenhardt and Schoonhoven, 1996; Hagedoorn, 1993; Hagedoorn, Link and Vonortas, 2000; Lorenzoni and Lipparini, 1999; Mowery, Oxley and Silverman, 1996) stress a variety of major motives for these partnerships:

- the need to monitor and engage in the cross-fertilization of technological disciplines,
- the search for technological synergies,
- achieve economies of scale and scope in R&D,
- the need to incorporate complementary technologies,
- jointly cope with R&D uncertainty,
- share the costs of R&D projects,
- capture a partner's tacit knowledge, and
- shorten the innovation cycle.

Although these partnerships are a crucial element in the overall strategy of many companies, for others they are relevant but still only complementary to their internal activities. There is some evidence that leading companies (market leaders and technology leaders) seek partnerships outside their core activities, searching for new activities and new technological opportunities beyond their current domain (Hagedoorn, 1995; Hamel, 1991; Hamel and Prahalad, 1994). Given these different motives for partnerships and the mix of motives for different groups of companies, one can expect that for many companies their motives to enter into R&D partnerships frequently have both a cost-economizing background and a strategic intent. Furthermore, it is important to realize there is a dynamic aspect to all of this as the motives of a company with multiple research programs can change over time due to both developments in the company itself, its environment and changes within the partnership (Harrigan, 1988).

### III. General Patterns in R&D Partnerships

Previous research (Chesnais, 1988; Hergert and Morris, 1988; Hladik, 1985; OECD, 1986 and 1992) has established that, after a small growth during the 1960s and 1970s, inter-firm partnerships through all sorts of agreements seem to flourish during the 1980s. This general growth pattern is also found for the particular group of partnerships studied in this paper, i.e. R&D partnerships, see Figure 1.

During the 1960s the number of yearly established R&D partnerships, found in the MERIT-CATI database, remained at a very low level of between a couple of partnerships to around ten made each year during most of that decade. At the end of 1960s and early 1970s there were about thirty of these partnerships established each year. Already these relatively small numbers attracted some attention in the literature because, as mentioned by Hladik (1985), this phenomenon puzzled the academic observers. Most of these partnerships were organized as joint ventures and the existing literature assumed that companies would simply exclude R&D from joint ventures because of the risk involved in such sensitive activities.

During the 1970s there is a gradual increase of the newly made R&D partnerships from a couple of dozens in the early years of that decade to about fifty partnerships at the mid of the decade. At the end of the 1970s there is a sudden increase to nearly one hundred and sixty new R&D partnerships. This phenomenon appears to be taken to a next level during the 1980s. Those years mark a steep increase from about two hundred annually made partnerships to over five hundred new R&D partnerships made each year at the end of the 1980s and the turn of the decade. The first couple of years of the 1990s show a drop in the newly made partnerships to about three hundred and fifty and four hundred, but in 1995 there is another peak with a record of nearly seven hundred new R&D partnerships. At the end of the nearly forty years on which I have been able to find data, the number of new R&D partnerships is decreasing again, to about five hundred new partnerships. However, this number is still considerably higher than the figures found for most years since the early 1980s.

In other words, there is a clear pattern of growth in the newly made R&D partnerships if one looks at the historical data since 1960. In the early years of these four decades there is a steady growth pattern with an acceleration since the 1980s. Although there is definitely need for both more data on a longer period and more extensive research on this pattern of growth, data on the recent period could reveal a more cyclical growth pattern as indicated by the clear peaks and downturns in Figure 1. (All figures are appended at the end of the paper.)

In the literature the explanation for this overall growth pattern of newly made R&D partnership is generally related to the motives that 'force' companies to collaborate on R&D, as discussed in the previous section. Major factors mentioned in that context are related to important industrial and technological changes in the 1980s and 1990s that have led to increased complexity of scientific and technological development, higher uncertainty surrounding R&D, increasing costs of R&D projects, and shortened innovation cycles that favor collaboration (see Contractor and Lorange, 1988; Dussauge and Garetti, 1999; Hagedoorn 1993 and 1996; Mowery, 1988; Mytelka, 1991; Nooteboom, 1999; OECD, 1992).

In the above I indicated that previous contributions had already established that during the 1970s and 1980s the relative share of joint ventures in the total number of partnerships had dropped considerably. It appeared that in particular contractual forms of partnering had become an important instrument of inter-firm collaboration. If one considers the specific trend for R&D partnerships during the past four decades, one arrives at a similar conclusion, see Figure 2.

During the very first couple of years of the 1960s, when there were very few R&D partnerships, the share of R&D joint ventures in all R&D partnerships was subject to strong changes from year to year. However, with the increasing number of newly made R&D partnerships, a clear pattern emerges in the share of R&D joint ventures. Ignoring some small oscillations around an overall trend in Figure 2, there is a sharp decline from a 100% share in the mid-1960s to less than 10% in 1998. During the mid-1970s the share of R&D joint ventures was still at a level of about 70%, in the early 1980s this share reached slightly over 40%. After a 'sudden' increase in the late 1980s, the downward trend reached a level of 20% during the first half of the 1990's until it arrived at a small share of less than 10% at the end of the decade.

These overall trends in inter-firm R&D partnering do indicate two major developments:

- First, by and large, companies seem to increasingly prefer contractual partnerships to joint ventures.
- Second, the growth of newly made R&D partnerships since the early 1980's is largely caused by an overwhelming increase in the absolute numbers of contractual partnerships.

## IV. Sectoral Patterns in R&D Partnerships

Contributions by amongst others Ciborra (1991), Dussauge and Garetti (1999), Eisenhardt and Schoonhoven (1996), Gomes-Casseres (1996), Harrigan and Newman (1990) and Oster (1992) suggest that inter-firm partnerships are associated with so-called high-tech sectors and other sectors where learning and flexibility are important features of the competitive landscape. These partnerships enable companies to learn from a variety of sources (partners) in a flexible setting of (temporary) alliances for various company activities across the value chain. Dussauge and Garetti (1999), Hagedoorn (1993), Link and Bauer (1989) and Mytelka (1991) also indicate that many of these partnerships are concentrated in a limited number of, mainly R&D intensive, industries. As this paper concentrates on R&D partnerships, one can expect that, given the asymmetrical distribution of R&D efforts across industries, this particular group of partnerships will also be concentrated in R&D intensive industries.[1]

Interestingly, Figure 3 demonstrates that the expected dominance of R&D partnering by high-tech (R&D intensive) industries has only gradually developed and did not become apparent until the mid-1980s. During the 1960s R&D partnerships in high-tech industries (pharmaceuticals, information technology sectors and aerospace and defense) counted for only between 20 and 40% of the overall number of newly made R&D partnerships. This was substantially lower than the share for medium-tech sectors (instrumentation and medical equipment, automotive, consumer electronics and chemicals) that on average accounted for over 50% of the newly made R&D partnerships in that early

[1] Following the OECD (1997) sectoral R&D intensities (the share of total R&D expenses in total turnover) pharmaceuticals (incl. biotech), information technology and aerospace and defense are high-tech sectors with R&D intensities between 10% and 15%. Instrumentation and medical equipment, automotive, consumer electronics and chemicals are medium-tech industries with R&D intensities ranging between 3% and about 5%, other industries such as food and beverages, metals, oil and gas have a relatively low R&D intensity of below 1%.

period. During the 1970s the share of high-tech industries varied between around 35 to about 50%, whereas the share for medium-tech industries during that same period by and large remained still close to 40%.

The 1980s and 1990s, however, mark a period where the growth of R&D intensive industries, influenced by biotechnology and a range of information technologies, is reflected in the increasing importance of these high-tech industries in R&D partnering. From 1980 to 1998 the share of high-tech industries in newly established R&D partnerships increased from about 50% to over 80%. During the same period the share of medium-tech industries in these new R&D partnerships decreased sharply from about 40% to less than 20%.

As high-tech industries have become so dominant in R&D partnering, I also looked at the trends in the share of individual high-tech sectors (see Annex II). It is well known that the information technology sector (computers, telecom, semiconductors, industrial automation, and software) has become important in terms of its contribution to the total of industrial R&D efforts, production and services. This importance is certainly reflected in its share in R&D partnering. With a few exceptional years during the 1960s, the information technology sector has by far the largest share in the sectoral distribution of R&D partnerships. During the mid-1970s it had an average share of about 25% of all these partnerships, a share that quickly rose to 40% in the mid-1980s and approximately 50% during the late 1980s. After a brief period with declining shares during the first part of the 1990s, the share of the information technology sector rose again to about 50% of all newly made R&D partnerships at the end of the 1990s. The pharmaceutical sector (including pharmaceutical biotechnology) played no role during most of the 1960s. This is no surprise if one recalls that pharmaceutical biotech research did not take off until the 1970s when there was the gradual increase of new companies that entered into a wide variety of partnerships with the established pharmaceutical industry. Since the 1970s there is a gradual increase in the share of pharmaceutical R&D partnerships which rose from about 10% during most of the 1970s to approximately 20% during most of the 1980s. After a decline to about 10% at the turn of the decade, the share of the pharmaceutical R&D partnerships has risen to about 30% at the end of the 1990s. As the information technology sector and the pharmaceutical industry have become so dominant in the R&D partnering in high-tech industries (or R&D partnering at large) the share for the third high-tech industry (the aerospace and defense industry) has remained relatively small. Until the 1980s this industry had a share in newly established R&D partnerships that remained on average above 10%. Since then the share of the aerospace and defense industry has, with a few outliers, declined to about 5% of all newly made R&D partnerships during the 1980s and 1990s.

Given the above it will be no surprise that low-tech industries (for instance food and beverages, metals, oil and gas) do not seem to play an important role in all of this. If we discard some 'peaks' in low-tech R&D partnering during the late 1960's and mid-1970's, the share of low-tech industries in R&D partnering decreased from about 20% during the 1960's to slightly above 10% during most of the 1980's. During the 1990's the share of these newly made low-tech R&D partnerships has decreased to less than 5%.

In the above I already noticed that contractual partnerships had become the dominant form of inter-firm R&D partnering which, combined with the current dominance of R&D intensive industries, would suggest that high-tech industries are probably also the industries where contractual arrangements are more important than in the medium-tech and low-tech industries. The literature also seems to suggest that the degree of technological sophistication or the degree of technological change in industries might influence the preferred form of partnering by companies. According to Harrigan

(1985 and 1988) rapid technological change in sectors of industry induces the formation of somewhat informal forms of partnering such as non-equity, contractual partnerships. Osborn and Baughn (1990) and Osborn et al (1998) suggest that the technological instability of industrial sectors is a crucial factor in explaining different patterns for joint ventures and contractual partnerships. Yu and Tang (1992) emphasize that stable sectoral environments favor joint venturing as the main form of inter-firm partnering, whereas unstable sectoral environments lead to a preference for contractual arrangements. Although these contributions differ with respect to their theoretical framework, their major research questions and the actual indicators used in research, the general picture that emerges is that contractual agreements are particularly preferred in high-tech industries, whereas joint ventures still play some role in other sectors. I submit that a similar pattern can be expected for joint ventures and contractual alliances in R&D partnering.

In order to measure the sectoral differences in contractual R&D partnerships, I will apply a 'relative contractual partnering index' per sector, which expresses the degree to which contractual R&D partnerships are more important in some sectors that in others.[2] This index can be calculated by setting the ratio of contractual partnerships versus joint ventures for each sector against the overall contractual partnerships-joint ventures ratio.

If one considers the relative contractual partnering indexes for high-tech, medium-tech and low-tech industries during the period 1960-1998, one finds that this index for high-tech industries is about 1.7, the index for medium-tech industries is about 0.4 and for low-tech industries it is about 0.55. These figures do indicate that R&D partnering in high-tech industries is of a disproportionate contractual nature. A more detailed overview of these relative contractual partnering indexes during the four decades of this analysis at the level of industries is found in Figure 4.

Figure 4 indicates that R&D partnering in the pharmaceutical industry (including relevant biotech activities) is over twice as much concentrated in contractual R&D partnerships than the average for all industries. The information technology industries and the aerospace and defense industry have about 1.5 times as many contractual R&D partnerships as the industry-wide average. Given this dominance of these high-tech industries it will not come as a surprise that the medium and low-tech sectors are (with the exception of the most R&D intensive non-high tech sector, instruments and medical equipment) below the industry-wide average.

Further information on trends in these relative contractual partnering indexes is found in Annex III. Some major characteristics of the importance of contractual partnering or joint ventures at the level of individual sectors and changes over time worth mentioning are:

- In pharmaceuticals and the information technology industry, one sees an above-average preference for contractual R&D partnering throughout most of the past decades, whereas the aerospace and defense industry shows a rapid decline in the importance of contractual R&D partnering, in particular during the most recent decade.

[2] This relative contractual partnering index (RCI) is calculated per sector as the relative distribution of the number of sectoral contractual partnerships ($CP_i$) and sectoral joint ventures ($JV_i$) set against the distribution of all contractual partnerships (TCP) and all joint ventures (TJV): $RCI_i = (CP_i / JV_I) / (TCP / TJV)$.

- In chemicals, electrical engineering industries, food and beverages, and metal products, which are all non-high tech industries, joint ventures have had a disproportionate importance throughout most of the past decades.
- In instruments and medical technology, a rather R&D intensive sector within medium-tech industries, joint ventures have gradually become less important as contractual R&D partnering has become the dominant mode of partnering.
- In the automotive industry and consumer electronics there appears to be two opposite developments: in the automotive industry it seems that contractual partnering is becoming less important whereas the opposite seems to hold for consumer electronics.

## V. International Patterns in R&D Partnerships

In many contributions to the management literature (de Woot, 1990; Ohmae, 1990; Osborn and Baughn, 1990; Yoshino and Rangan, 1995) and the international business literature (Auster, 1987; Contractor and Lorange, 1988; Dunning, 1993; Duysters and Hagedoorn, 1996; Hagedoorn and Narula, 1996; Mowery, 1988; Mytelka, 1991) international partnerships or alliances are considered an important element in the international strategies of a growing number of companies. The basic argument in most of these contributions is that increased international competition between companies forces them to pursue international strategies. Through these international strategies companies do not only seek foreign market entry but they also seek foreign assets (both of a tangible and an intangible nature) and build international inter-firm partnerships for international sourcing of R&D, production and supply. From a traditional transaction cost economics perspective (Williamson, 1996) one would expect that companies are somewhat hesitant to enter into R&D partnerships with foreign companies due to the lack of control over long-distance, lack of trust between companies from different countries and the high asset specificity of R&D. However, as increased international competition has led many companies to follow a strategy of gradual internationalization, one can assume that this experience gradually also opens the way to non-domestic R&D partnerships (Hagedoorn and Narula, 1996). Consequently, one could expect that, in the context of the overall importance of internationalization to companies and their partnerships, the share of international R&D partnerships in the total number of R&D partnerships should also have increased during the last four decades.

However, the past forty years indicate a somewhat irregular and slightly downward trend in the share of international R&D partnerships, see Figure 5. During the 1960s and early 1970s, when there were only few of these partnerships, the share of international R&D partnerships dropped from an average of about 75% to close to 40%. During the mid-1970s the share rose again to nearly 80%, after which the trend gradually turned slightly downward from about 70% during the first years of the 1980s to about 60% during in the early 1990's. The late 1990s end with a share of international partnerships below 50% of all newly made R&D partnerships.

For a further understanding of this development and the sectoral differences that might have occurred I calculated a 'relative international partnering' index per sector.[3] This measure is somewhat similar

[3] As with the previous index, the relative international partnering index (RII) is calculated per sector as the relative distribution of the sectoral number of international partnerships ($IP_i$) and sectoral domestic partnerships ($DP_i$) set against the distribution of all international partnerships (TIP) and all domestic partnerships (TDP): $RII_i = (IP_i / DP_i) / (TIP / TDP)$.

to the relative contractual partnering index as it indicates the degree to which international R&D partnerships are more important in some sectors than in others. This index can be calculated by setting the ratio of international partnerships versus domestic ventures for each sector against the overall international partnerships/domestic partnerships ratio.

The relative international partnering indexes during the period 1960-1998 are 0.9 for high-tech industries, 1.5 for medium-tech industries and 0.85 for low-tech industries. These findings, in particular for high-tech sectors, are somewhat surprising and they certainly merit a more detailed look at the data. A first step towards a more detailed overview of relative international partnering indexes at the level of individual industries is found in Figure 6.

This indicates that the propensity for international partnering is unevenly distributed across industries. Most medium-tech industries, with the exception of the instruments and medical equipment sector which is close to the all-industry average, have an above average propensity to engage in international R&D partnering. As mentioned in the above, somewhat surprisingly, both high-tech and low-tech sectors appear to be less internationalized in their R&D partnering. High-tech industries such as pharmaceuticals and the information technology sectors, but not aerospace and defense, are clearly below the industry-wide average of international R&D partnering since the 1960s.

Some additional information on relative international partnering indexes is found in Annex IV but this information at the level of individual sectors does not suggest a very clear pattern for most industries. Only two major industries demonstrate a clear pattern in their international R&D partnering. In the information technology industry international partnering has remained below average throughout the past decades, whereas international R&D partnering has been of a disproportionate importance in the chemical industry. For most other industries it appears that there is no clear pattern as the relative international partnering indexes fluctuate from decade to decade.

Given this somewhat unclear pattern in international R&D partnering, I decided to take a closer look at the role that the different international economic and trading blocks play in all of this. In the following I will differentiate between partnerships and companies from Europe (the EU and EFTA countries), North America (USA and Canada), Asia (Japan and South Korea) and all other countries. Previous work by Freeman and Hagedoorn (1994), OECD (1992), Ohmae (1985 and 1990) and Yoshino and Rangan (1995) already revealed that the Triad (North America, Europe and Japan) dominates inter-firm partnering. South Korea is mentioned by Freeman and Hagedoorn (1994) and Duysters and Hagedoorn (2000) as a recent 'player' of some importance.

If one looks at the overall pattern in R&D partnering during the past four decades (see Figure 7), it becomes clear that companies from the Triad (Europe, Asia and North America) participate in over 99% of the R&D partnerships. North America (of which between 90-95% stands for US companies) clearly dominates the world of R&D partnering. Almost 70% of the R&D partnerships I found for the past four decades has at least one North American partner. Partnerships within North America account for nearly a third of all the R&D partnerships. Nearly a quarter of the inter-firm R&D partnerships are made between European and North American companies, which is substantially higher than the nearly 16% share found for intra-European R&D partnerships. R&D partnerships made between companies from North America and Japan and South Korea account for about 11%. Intra-Asian R&D partnerships and partnerships between Europe and Japan and South Korea remain at a relatively low level of about 5%.

Figures 8a-d reveal some striking changes in the overall distribution of R&D partnerships since the 1960s. First of all it becomes clear that the important role of intra-North American partnerships is only a relatively recent development. During the 1960s and 1970s less than 20% of these R&D partnerships were established within North America and even in the 1980s less than a quarter of all R&D partnerships were made between two or more North American companies. However, the 1990s mark a sudden increase in the share of intra-North American R&D partnerships to over 41%. Second, the share of intra-European partnerships has gradually eroded from nearly 40% during the 1960s and 27% during the 1970s to 19% during the 1980s and to only 11% during the most recent decade. Third, European-North American R&D partnering has gradually grown from about 16% during the 1960s to about 25% during the 1990s. Additional analysis of these data reveals that the dominance of intra-North American R&D partnering is particularly strong in high-tech industries such as pharmaceuticals (biotechnology) and information technology. These sectors also represent a large share of the European-North American R&D partnerships.

## VI. Conclusions

A major conclusion from the above is that R&D partnering is a 'game' dominated by companies from the world's most developed economies. As companies from the developed economies participate in 99% of the R&D partnerships and 93% of these partnerships are made amongst companies from North America, Europe, Japan and South Korea, little appears left for companies from other regions. Grim as this picture might look it does parallel the current world-wide distribution of R&D resources and capabilities (Freeman and Hagedoorn, 1994). In that context the dominance of North America, particularly the USA, also reflects the leading role that this continent plays in R&D and production in major high-tech industries such as the information technology sectors (computers, telecom, software, industrial automation, semiconductors) and pharmaceutical biotechnology (OECD, 1992). This dominance had not only led companies from other countries to actively search for R&D partnerships with North American companies, the North American dominance of technological development in many of the above-mentioned fields has led to a situation where most of the recent R&D partnerships are formed between companies within in the USA. The growing importance of intra-US R&D partnerships also largely explains why international partnerships, despite a strong growth in absolute numbers, still take only about 50% of all R&D partnerships and why the trend towards a further internationalization appears to be stagnating.

It is also important to note that the absolute number of R&D partnerships has increased dramatically during the past decades. This growth is largely caused by the number of contractual agreements, i.e. R&D pacts and joint development agreements. If joint ventures once dominated inter-firm R&D partnering, this activity is now almost completely dominated by contractual agreements as about 90% of the recently established partnerships are of a contractual nature.

Contractual R&D partnerships enable companies to increase their strategic flexibility through short-term joint R&D projects with a variety of partners. This flexibility in R&D partnerships ties into the more general demand for flexibility in many industries where inter-firm competition is affected by increased technological development, innovation races and the constant need to generate new products. There is an interaction between these strategic incentives per se, those that increase the flexibility of companies, and cost economizing incentives for these partnerships which relate to the sharing of the increasing costs of innovative efforts with some other companies for, at least part of, the costs of the overall R&D budget.

The role of technological development in all of this is also apparent in the sectoral background of R&D partnering. Over the last forty years there has been a gradual increase in the share of high-tech industries in R&D partnering. At the end of the 1990s over 80% of the newly made R&D partnerships are found in the information technology sectors and the pharmaceutical industry. It is also here that we find an over-representation of contractual partnerships, which again stresses the role that flexibility should play in an understanding of inter-firm R&D partnering. Joint ventures, which are less flexible as companies have to set up separate organizations with a variety of functions, are primarily found in medium-tech and low-tech industries where technological development is usually less turbulent and of a more gradual nature. In contrast, contractual R&D partnerships that regulate relatively small-scale collaboration in a flexible setting of multiple companies are major drivers of inter-firm networks that have become so apparent in many high-tech industries.

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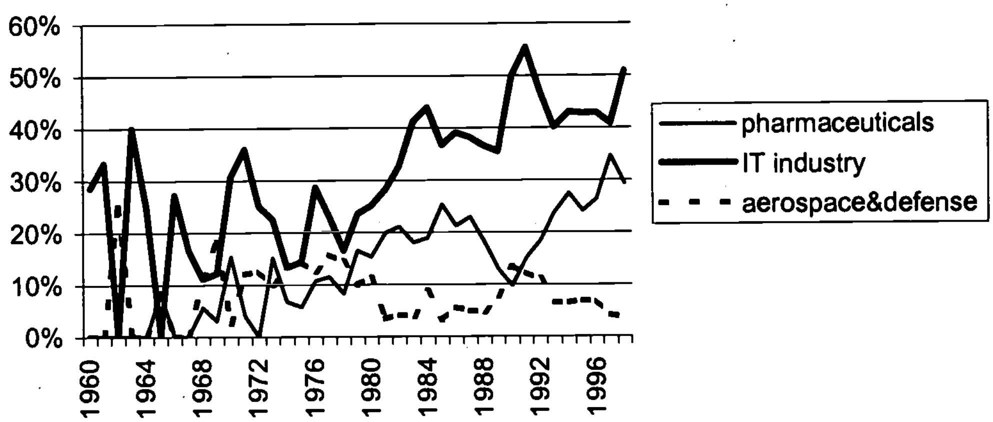
**Annex I**
**THE MERIT-CATI Database**

The CATI data bank is a relational database which contains separate data files that can be linked to each other and provide both disaggregated and combined information from several files. So far information on thousands of technology-related inter-firm partnerships has been collected for the period 1960-1998. Systematic collection of inter-firm partnerships started in 1987. Many sources from earlier years are consulted to establish a retrospective view. In order to collect information on inter-firm alliances various sources are consulted: newspaper and journal articles, books dealing with the subject, and in particular specialized journals which report on business events. Company annual reports, the Financial Times Industrial Companies Yearbooks and Dun & Bradstreet's 'Who Owns Whom' provide information about dissolved equity ventures and investments, as well as ventures that were not registered when surveying alliances.

This method of information gathering which one can refer to as 'literature-based alliance counting' has its drawbacks and limitations due to the lack of publicity for certain arrangements, low profile of certain groups of companies and fields of technology. Despite these shortcomings, which are largely unsolvable even in a situation of extensive and large-scale data-collection, this database is able to produce a clear picture of the joint efforts of many companies. This enables researchers to perform empirical research, which goes beyond case studies.

The data bank contains information on each agreement and some information on companies participating in these agreements. The first entity is the inter-firm cooperative agreement. Cooperative agreements are defined as common interests between independent (industrial) partners who are not connected through (majority) ownership. In the CATI database only those inter-firm agreements are being collected that contain some arrangements for transferring technology or joint research. Joint research pacts and second-sourcing are clear-cut examples. Information is also collected on joint ventures in which new technology is received from at least one of the partners, or joint ventures having some R&D program. Mere production or marketing joint ventures are excluded. In other words, this material is primarily related to R&D collaboration and technology cooperation, i.e. those agreements for which a combined innovative activity or an exchange of technology is at least part of the agreement.

**Annex II. The share (%) of high-tech industries in all newly-established R&D partnerships (1960-1998)**




**Source:** MERTI-CATI

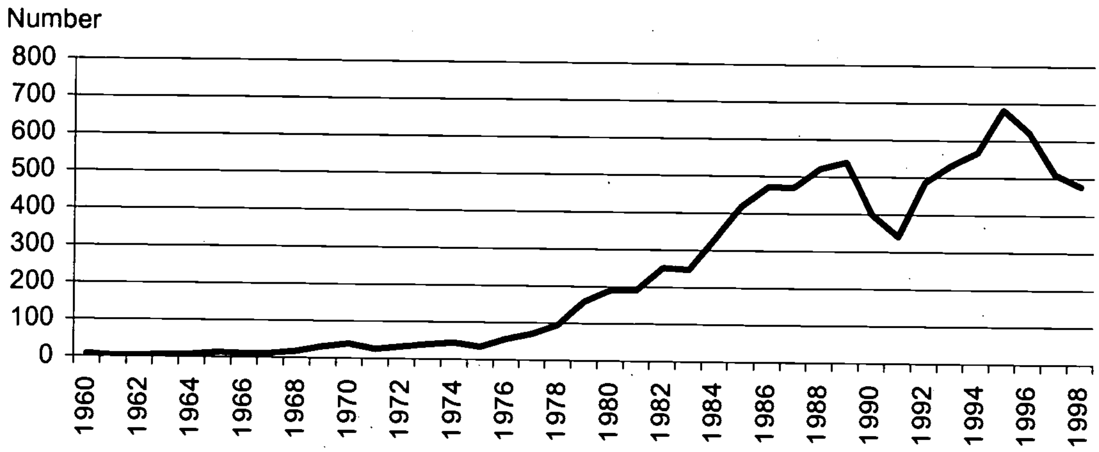
| Annex III. Relative Contractual Partnering Indexes, All Sectors, 1960-1998 | | | | |
|---|---|---|---|---|
| | | | | |
| Industry Sector | *60-69* | *70-79* | *80-89* | *90-98* |
| pharmaceuticals | 2.65 | 2.48 | 2.29 | 1.48 |
| information technology | 1.06 | 0.91 | 1.27 | 1.64 |
| aerospace & defense | 7.94 | 5.34 | 3.57 | 0.58 |
| instruments and medical equipment | 0.00 | 0.18 | 0.92 | 1.64 |
| automotive | 1.32 | 3.16 | 0.46 | 0.57 |
| chemicals | 0.38 | 0.26 | 0.35 | 0.24 |
| consumer electronics | 0.00 | 0.99 | 0.28 | 1.18 |
| electrical equipment | 1.99 | 0.34 | 0.66 | 0.83 |
| food and beverages | 0.00 | 0.21 | 0.43 | 0.27 |
| metals | 0.00 | 0.29 | 0.99 | 0.44 |
| engineering and exploration | 0.81 | 1.24 | 0.75 | 1.20 |

**Source**: MERIT-CATI Database

| Annex IV. Relative International Partnering Indexes, All Sectors, 1960-1998 | | | | |
|---|---|---|---|---|
| Industry Sector | *60-69* | *70-79* | *80-89* | *90-98* |
| pharmaceuticals | 0.00 | 0.60 | 0.64 | 1.18 |
| information technology | 0.90 | 0.55 | 0.94 | 0.76 |
| aerospace & defense | 1.34 | 0.63 | 0.85 | 1.74 |
| instruments and medical equipment | 0.57 | 0.66 | 1.77 | 0.77 |
| automotive | 0.86 | 1.43 | 1.90 | 0.83 |
| chemicals | 2.87 | 1.90 | 1.47 | 1.61 |
| consumer electronics | 3.44 | 4.87 | 3.35 | 0.98 |
| electrical equipment | 0.13 | 1.33 | 1.63 | 1.06 |
| food and beverages | 1.15 | 1.59 | 0.63 | 1.14 |
| metals | 0.86 | 2.62 | 0.46 | 1.29 |
| engineering and exploration | 0.50 | 1.00 | 1.45 | 1.18 |

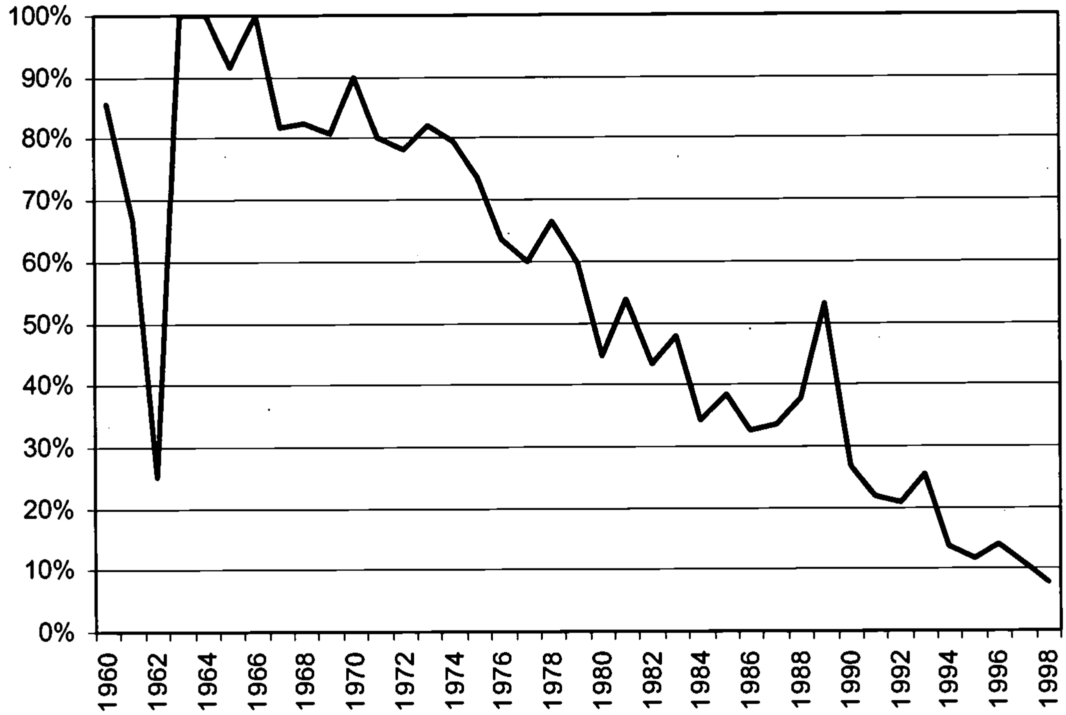
**Source**: MERIT-CATI Database

**Figure 1. The growth of newly-established R&D partnerships (1960-1998)**



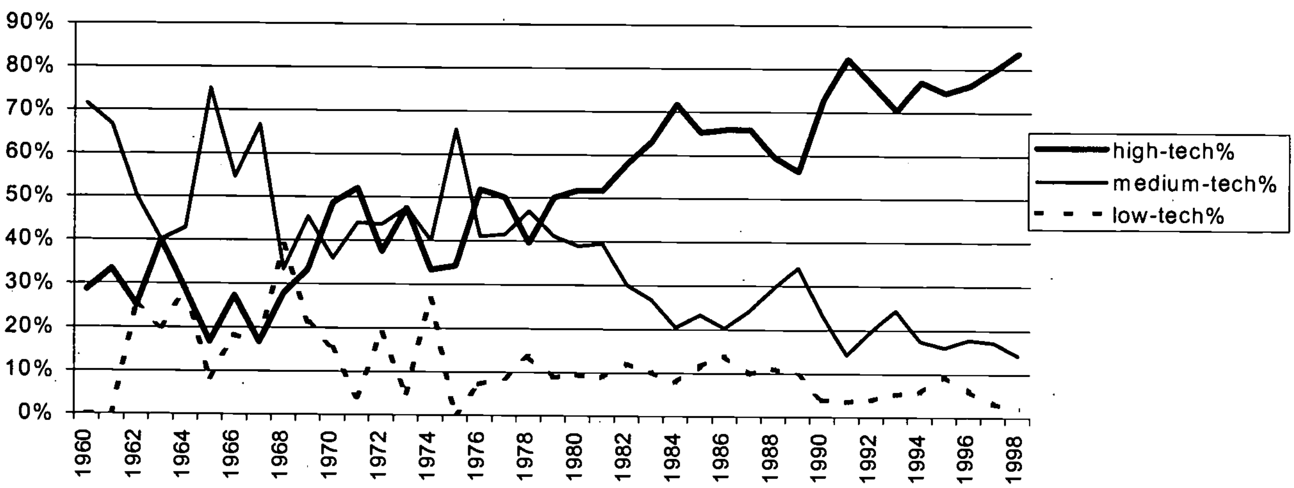

Source: MERIT-CATI

**Figure 2. The share (%) of joint ventures in all newly-established R&D partnerships (1960-1998)**



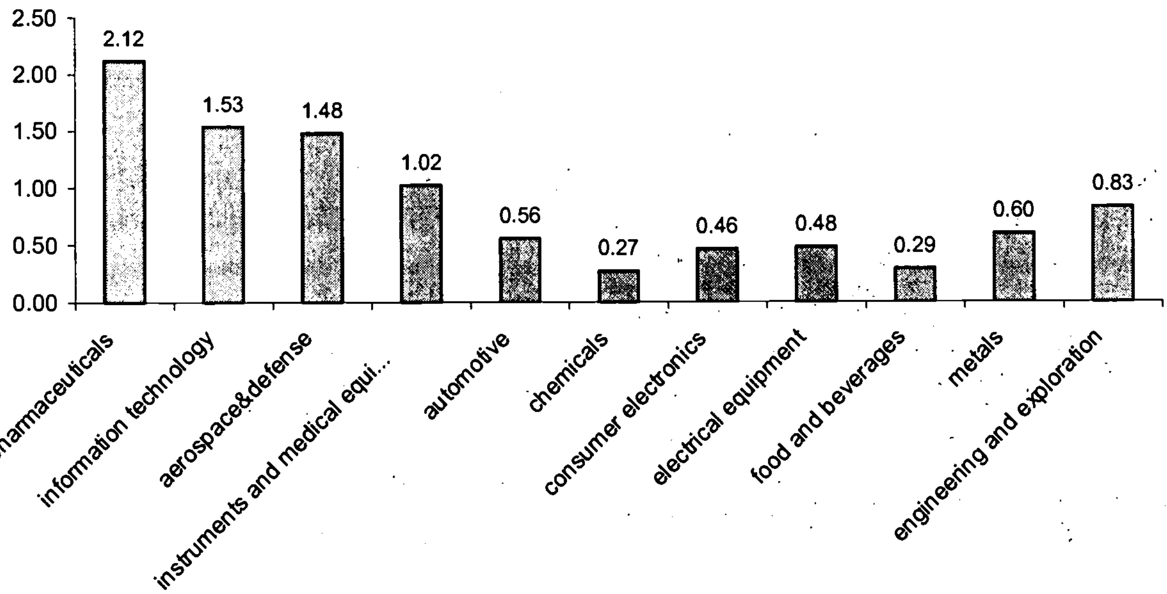

Source: MERIT-CATI

**Figure 3. The share (%) of high-tech, medium-tech and low-tech industries in all newly-established R&D partnerships (1960-1998)**



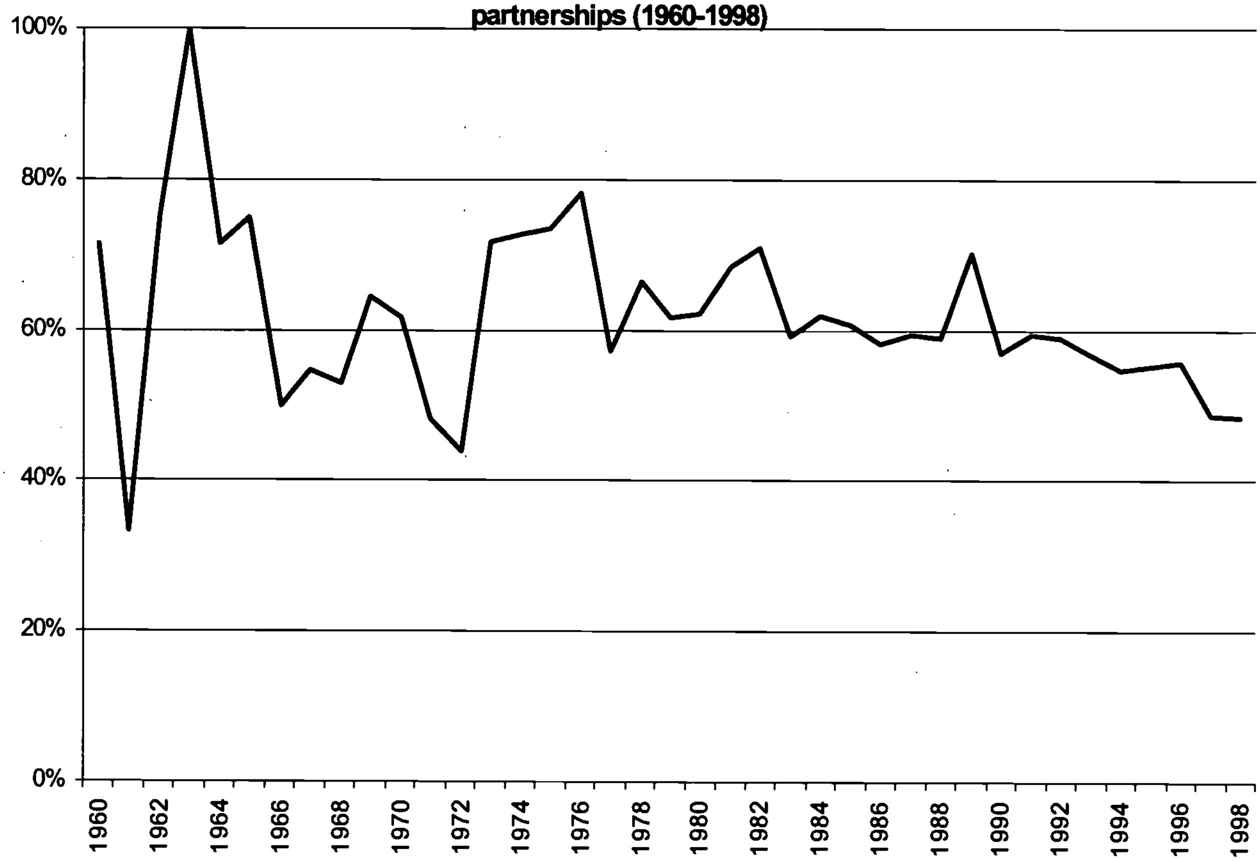

Source: MERIT-CATI

**Figure 4. Relative contractual partnering indexes, per sector (1960-1998)**



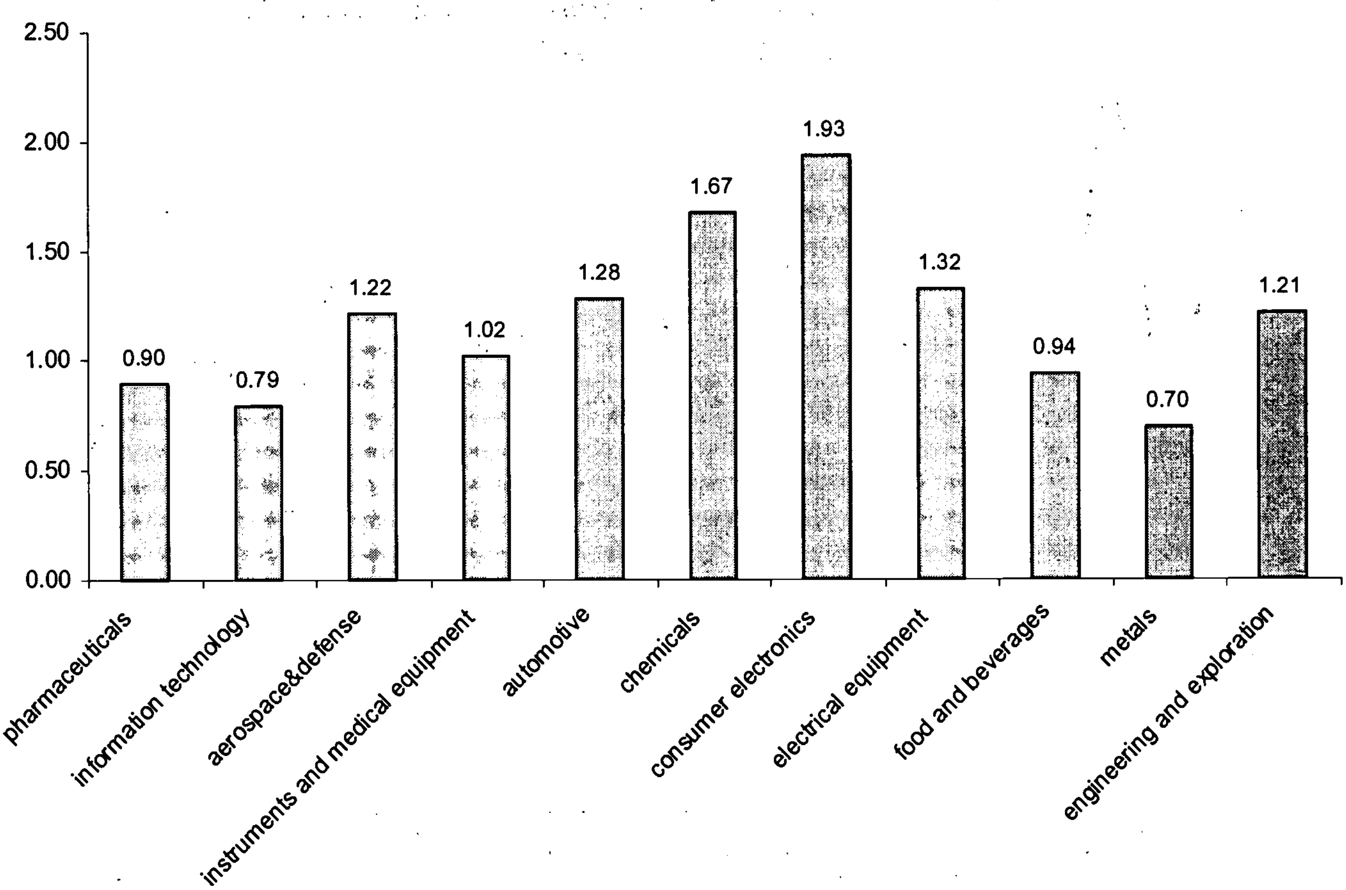

Source: MERIT-CATI

Figure 5. Share (%) of international partnerships in newly-established R&D partnerships (1960-1998)



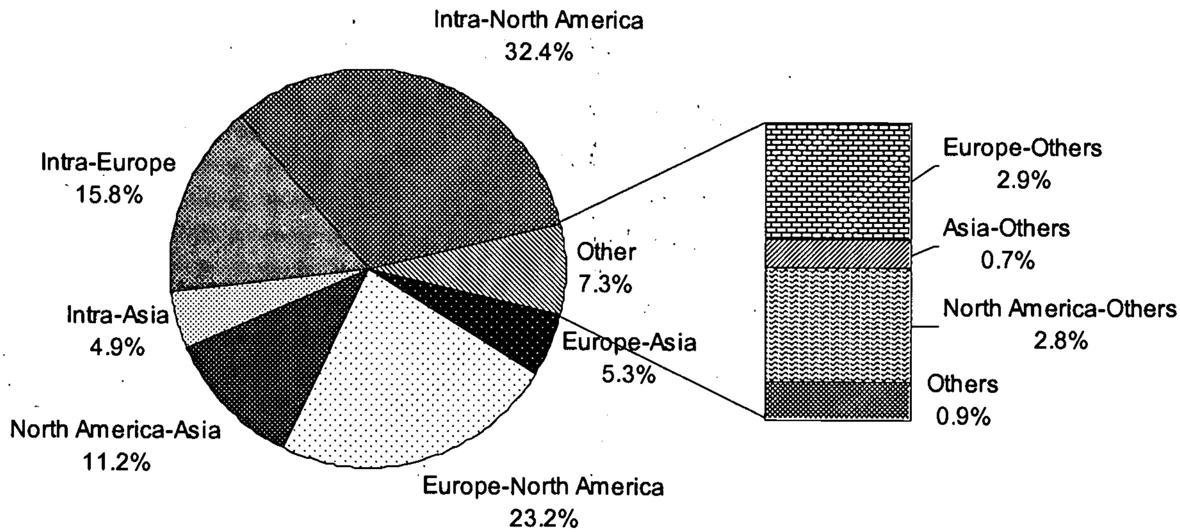

Source: MERIT-CATI

**Figure 6. Relative internationalization indexes, per sector, 1960-1998**



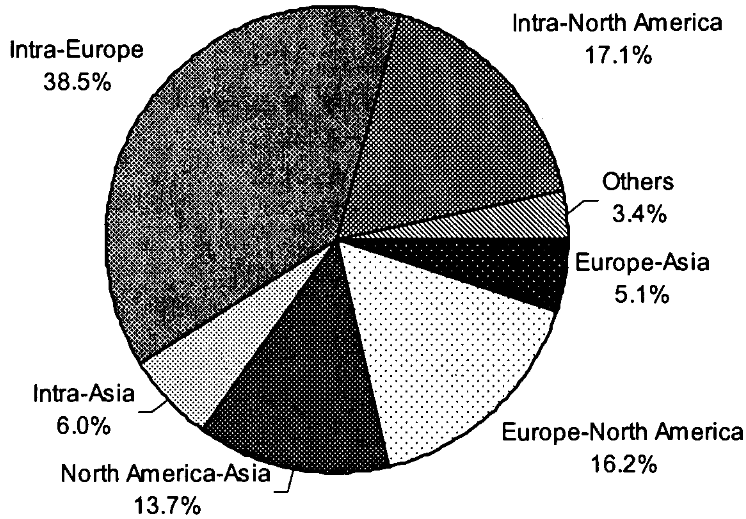

Source: MERIT-CATI

**Figure 7. Distribution of R&D partnerships, economic regions (1960-1998)**



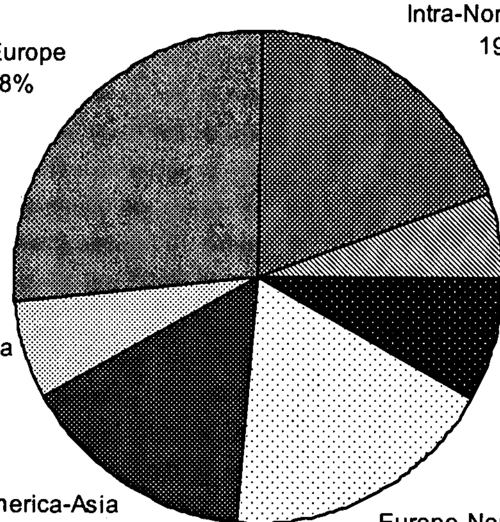

Source: MERIT-CATI

**Figure 8a. Distribution of R&D partnerships, economic regions (1960-1969)**



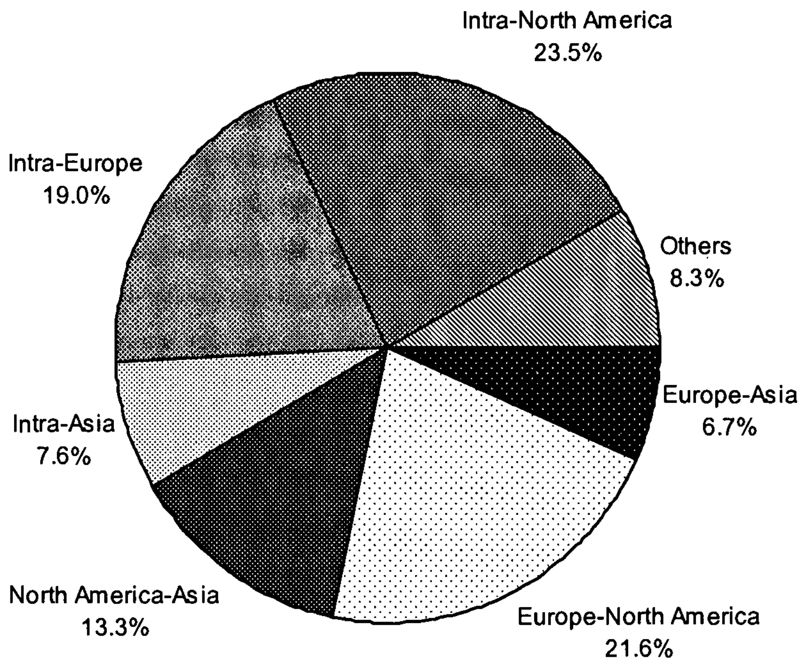

Source: MERIT-CATI

**Figure 8b. Distribution of R&D partnerships, economic regions (1970-1979)**



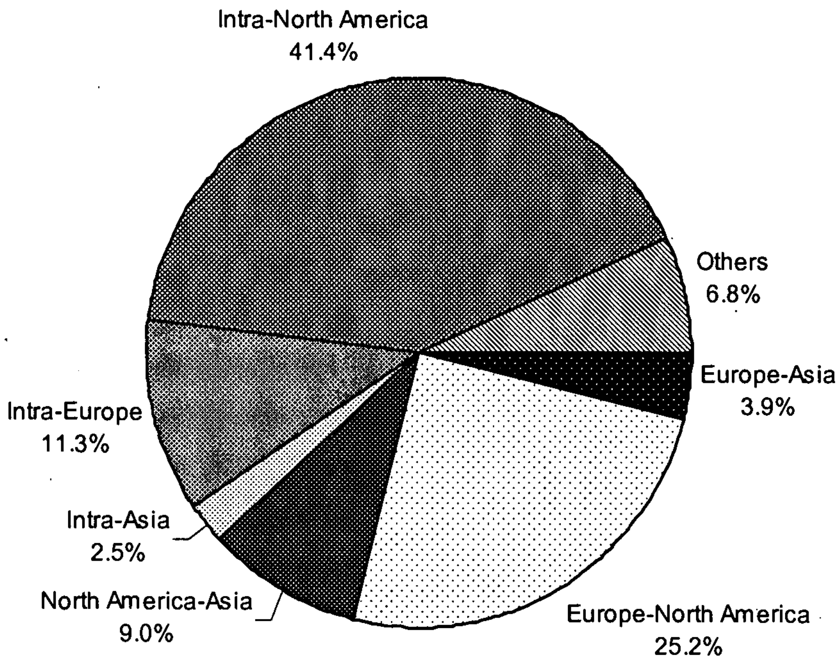

Source: MERIT-CATI

**Figure 8c. Distribution of R&D partnerships, economic regions (1980-1989)**




Source: MERIT-CATI

**Figure 8d. Distribution of R&D partnerships, economic regions (1990-1998)**




Source: MERIT-CATI

# Using Cooperative Research and Development Agreements as S&T Indicators: What Do We Have and What Would We Like?

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## I. Introduction

The U.S. "industrial competitiveness crisis" of the 1980s spawned a number of experiments in civilian technology policy. Among these was the Cooperative Research and Development Agreement (CRADA), an instrument that was created in the Technology Transfer Act of 1986. A CRADA is a contractual arrangement between a federal laboratory and participating firm that enables the laboratories to conduct joint R&D projects with private firms. Federal agencies are prohibited from providing direct funding to the industrial participants in CRADAs, but federal funds can be used to support the overhead and other expenses of the government research facilities participating in CRADAs. Under the terms of a CRADA, the private-firm partner can be assigned the rights to any intellectual property resulting from the joint work, while the federal government retains a nonexclusive license to the intellectual property.

The CRADA represents an interesting initiative in the restructuring of the U.S. industrial R&D system and U.S. technology policy that accelerated in the aftermath of the Cold War. At present, however, relatively little information on CRADAs is collected or disseminated by the National Science Foundation. As a result, we lack sufficient information to address the following basic questions: What are the characteristics of firms and laboratories that participate in CRADAs? What are the results of CRADAs and how do they affect the innovative performance of the private-firm or federal-laboratory participants over the long term? How do the size of the federal investment in support for CRADAs and the results of CRADAs compare with other federal programs for supporting industrial innovation?

This short paper reviews the limited data on CRADAs that are published by the National Science Foundation (mainly in the biennial *Science and Engineering Indicators* volume), in an effort to shed some light on a few of these questions. But as I have noted, addressing even this basic list of questions requires more information than currently is available from NSF and non-NSF sources. Nevertheless, several scholars have conducted interesting empirical analyses of the effects of CRADAs on industrial innovation, and their findings suggest that there is considerable value in collecting and disseminating additional information on these federal policy instruments. Immediately below, I review the existing evidence on the number and characteristics of CRADAs formed during the 1990s, drawing on NSF and non-NSF data. I follow this discussion with a survey of the limited literature on the effects and effectiveness of CRADAs. The final section of the paper outlines additional CRADA-related data that NSF should consider collecting and disseminating as part of its activities on the description and analysis of the U.S. R&D system.

## II. Current Evidence on CRADAs

Although CRADAs were created by the Federal Technology Transfer Act of 1986, government-owned, contractor-operated federal laboratories (GOCOs), such as those in the Department of Energy laboratory system, were allowed to conduct CRADAs with private firms only with the passage of amendments to the Act in 1989.[1] Federal agencies and research laboratories have signed hundreds of CRADAs each year since the late 1980s. The data in Table 1, drawn from the forthcoming *Science and Engineering Indicators* volume, report the number of "active CRADAs," based on agency reports that are tabulated by the Department of Commerce's Office of Technology Policy (U.S. Department of Commerce, 2000), for each year during 1987-98.

The number of active CRADAs grew sharply after 1990 (the first full year during which GOCO laboratories could negotiate such agreements), more than doubling by 1992 and more than doubling again by 1994. The number of active CRADAs peaked in 1996, and declined during 1996-98. Unfortunately, these NSF data do not report either "births" or "deaths" of CRADAs, and therefore say little about the reasons for these trends in the number of active CRADAs. CRADA activity is dominated by the Departments of Energy and Defense, which in some years accounted for more than two-thirds of all active CRADAs. Other federal agencies with large numbers of CRADAs during this period include the Department of Agriculture and the Commerce Department, both of which also maintain large laboratory networks. These data suggest that a great deal of government-industry collaboration was carried out through CRADAs during the 1990s, but they provide no information on the scale of industrial or federal investments in the R&D carried out within these CRADAs. Nor do the NSF data establish any clear links between the number of CRADAs reported and the other data on federal agencies' technology transfer activities (invention disclosures, patents, licenses, licensing income) reported in this section of the *Indicators* volume.

**Table 1: Active CRADAs, by Federal Agency, 1987-1998**

| Agency | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 9 | 51 | 98 | 128 | 177 | 172 | 172 | 208 | 229 | 244 | 273 | 288 |
| Commerce | | 9 | 44 | 82 | 115 | 177 | 292 | 368 | 407 | 406 | 377 | 337 |
| Defense | 3 | 10 | 36 | 113 | 193 | 277 | 365 | 563 | 845 | 1086 | 1360 | 1424 |
| DOE | | | | 1 | 43 | 250 | 582 | 1094 | 1392 | 1677 | 963 | 868 |
| EPA | | | 2 | 11 | 31 | 30 | 28 | 35 | 30 | 35 | 34 | 37 |
| HHS | 22 | 28 | 89 | 110 | 144 | 146 | 149 | 147 | 152 | 158 | 161 | 163 |
| Interior | | | 1 | 12 | 11 | 1 | 3 | 9 | 15 | 22 | 23 | 30 |
| Transportation | | | | 1 | 9 | 17 | 30 | 38 | 37 | 43 | 36 | 39 |
| All agencies[2] | 34 | 98 | 271 | 460 | 731 | 1078 | 1628 | 2471 | 3121 | 3688 | 3239 | 3201 |

**Source:** *Science and Engineering Indicators: 2000.*

[1] The Federal Technology Transfer Act of 1986 and its 1989 amendment extended the legislative framework developed in the Stevenson-Wydler and Bayh-Dole Acts of 1980, which authorized recipients of federal research to gain title to the intellectual property created in such projects.

[2] "All agencies" includes several not listed in the table, including the VA.

Indeed, the statement in the forthcoming *Indicators* discussion that the "invention disclosures" data are entirely attributable to CRADAs[3] appears to be incorrect. The data reported by NSF on invention disclosures reveal that nearly 3000 such disclosures were made by the Department of Energy, most of whose laboratories are GOCOs, during FY 1987-89. Since the DOE's GOCO laboratories were unable to execute CRADAs during this period, the average annual flow of more than 900 invention disclosures during FY 1987-89 presumably reflected other inventive and technology transfer activities.

Since federal agencies have several alternative vehicles for patenting and licensing their technologies in addition to CRADAs, there appears to be no basis for the claim in the discussion of these data in the NSF *Indicators* volume that these invention disclosures are all associated with CRADAs. The 1999 report of the U.S. Department of Energy's "Technology Transfer Working Group" (U.S. Department of Energy, 1999), for example, identifies seven "Technology Partnership Mechanisms" other than CRADAs or programs targeted specifically at small firms.[4]

Significantly, the Commerce Department report from which the NSF *Indicators* data are drawn makes no claims about the linkages between CRADAs and any of these outcomes. Moreover, the report notes that some federal agencies generate significant numbers of patents outside of CRADAs: "...NIH reports that intellectual property is being generated at approximately the same level in CRADA research as in non-CRADA research—about 15 percent of projects." (p. 19). Commerce Department staff responsible for assembling these agency-level data also assert that a large fraction of reported invention disclosures, perhaps as much as 50%, derive from activities unrelated to CRADAs (Paugh, 2000). Unfortunately, the Commerce Department data provide no information on the linkage between CRADAs and these other measures of the outcomes of federal agencies' technology transfer and collaborative activities. Better data on the different federal technology transfer policies that produced the disclosures, patents, licenses, and licensing revenues tabulated in the NSF and Commerce Department reports are badly needed.

Some additional information on trends in CRADA formation is available in the NSF's *Science and Engineering Indicators: 1998*, which tabulates the number of new CRADAs signed by major federal agencies during 1992-95 (see Table 2). These data on CRADA formation, which do not appear to be replicated in the 2000 *Indicators* volume, reveal rapid growth, from roughly 500 new agreements in 1992 to more than 1100 in 1994, followed by a slight decline in 1995. The 1994-95 decline in new CRADAs spans all of the federal agencies in Table 2, with the exception of the Defense Department, where the number of new CRADAs continued to grow during the 1994-95 period. The trendline for "new CRADAs" roughly parallels that for "active CRADAs" in Figure 1 during the brief period covered by these data, turning downward two years before the "active CRADAs" trendline does.

[3] "Invention Disclosures arising out of CRADAs increased rapidly at first, rising from 2,662 in 1987 to 4,213 in 1991..." (National Science Board, forthcoming).

[4] The eight mechanisms are "Cooperative Agreements," "Cost-Shared Contracts/Subcontracts," "Licensing," "Personnel Exchange Programs," "R&D Consortia," "User Facility Agreements," and "Work-for-Others" (U.S. Department of Energy, 1999, Appendix A, p. 1).

**Table 2: New CRADAs Signed, by Federal Agency, 1992-1995**

| Agency | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| USDA | 41 | 103 | 72 | 54 |
| Commerce | 86 | 147 | 97 | 82 |
| Defense | 131 | 201 | 298 | 371 |
| DOE | 160 | 367 | 564 | 462 |
| EPA | 20 | 5 | 10 | 8 |
| HHS | 53 | 25 | 36 | 22 |
| Interior | 3 | 15 | 39 | 4 |
| Transportation | 8 | 14 | 14 | 0 |
| TOTAL | 502 | 877 | 1130 | 1003 |

**Source:** National Science Board, 1999, p. 4-32.

The NSF 1998 *Indicators* volume contains a modest amount of information on the structure of the CRADAs contained in Table 2. According to NSF (National Science Board, 1999, p. 4-32), nearly three-quarters of the new CRADAs executed in 1995 were single-firm CRADAs, involving collaboration between a federal agency and an individual industrial firm. "Consortia and nongovernmental organizations," which are not defined by NSF, accounted for 87 of the 1995 new CRADAs. Universities accounted for 86 new 1995 CRADAs and state and local governments executed 10 new CRADAs in 1995. The 1003 new 1995 CRADAs involved 688 private-sector organizations, 124 of which executed two or more CRADAs during 1995. Similar information on the structure of the CRADAs reported in Table 1 would be very valuable.

Very little published data provides additional detail on CRADA activities by agency. A recent paper by Guston (1998) on CRADAs in the National Institutes of Health, the largest single source of federal funding of nondefense R&D, provides some information on NIH CRADAs during the 1990s. Guston's data on trends in the execution of NIH CRADAs (Figure 2) display trends that contrast somewhat with those in Figure 1 for overall CRADA formation. Rather than a rapid increase throughout the 1990s, Guston's data depict rapid growth in CRADAs during the late 1980s, followed by a period of stability in the rate of new CRADA formation during the FYs 1990-95 period.[5] The sharp increase in executed CRADAs during FY 1995-96, according to Guston, reflects the execution of a large number of "material transfer agreement CRADAs" (MTA CRADAs) during this period. MTA CRADAs are initiated by NIH researchers to gain access to research materials from non-NIH researchers in situations where a simple materials transfer agreement will not suffice.

According to Guston, almost one-half of the 352 CRADAs executed by the NIH during the FYs 1985-96 period were still active as of FY 1997. NIH CRADA execution is dominated by the National

[5] The "fair pricing" debates of the early 1990s may have depressed the rate of CRADA formation at the National Institutes of Health. NIH CRADAs originally included a clause allowing NIH to require that a licensee submit confidential documentation "showing a reasonable relationship between the pricing of a Licensed Product, the public investment in that product, and the health and safety needs of the public" (quoted in Guston, 1998, p. 236). The clause led to public controversies over the pricing of the AIDS drugs AZT and ddI, but it was eliminated in the spring of 1995. Although we lack sufficient post-1995 data on CRADA formations to determine whether the elimination of this pricing clause has been followed by a significant upsurge in CRADAs, the data in Table 1 do not indicate a dramatic surge in overall HHS CRADAs during FYs 1996-98.

Cancer Institute, which accounted for 106 (30.6%) of all CRADAs formed during this period. The NCI is followed by the National Institute of Allergy and Infectious Diseases (NIAID), which accounts for 56, almost 16% of total executed CRADAs. The Institute of Diabetes and Digestive and Kidney Diseases (8.8%), the Institute of Mental Health (7.4%) and the Institute of Neurological Disorders and Stroke (7.9%) are the next most active NIH entities in CRADA formation. The five most active components of the NIH complex account for more than 70% of CRADA executions during this period.

The NSF data and the data reported in Guston (1998) provide no information on the size of federal expenditures in support of CRADA-related research. Additional information from internal agency sources on expenditures on CRADAs by DOE, the federal agency responsible for the majority of CRADAs, are available for FYs 1993-99. As was noted above, most of the CRADAs signed by DOE during the early 1990s included cost-sharing provisions that provided laboratory support (either funding or "in-kind" contributions) for up to 50% of total project costs. Internal DOE data indicate that federal funding for the federal portion of CRADA expenses rose from $176 million in fiscal 1993 to more than $346 million in fiscal year 1995, declining to an estimated level of $94.5 million in fiscal year 1999 (Table 3).

DOE expenditures on CRADAs have amounted to more than $1.4 billion during the 1990s in constant (1999) dollars. This amount represents a small share of DOE's cumulative R&D budget during this period (also in constant dollars) of almost $50 billion, but its CRADA program is among the larger DOE initiatives dedicated to the support of civilian "pre-commercial" technology development. These data indicate that the expenditures by DOE on support for CRADAs are roughly comparable to the budget of another federal technology policy initiative of the late 1980s and early 1990s, the Advanced Technology Program (ATP). The ATP's budget has been cut sharply in recent years, but at its peak in fiscal year 1995, total budget authority for the program amounted to $341 million, below the nearly $350 million peak budget for DOE support of CRADAs.[6] Cumulative appropriated budget authority for ATP during fiscal years 1994-97 amounted to $986 million in current-year dollars (Hill, 1998), less than DOE expenditures (in current-year dollars, slightly more than $1 billion) in support of CRADAs during the same period.

6 The Small Business Innovation Research (SBIR) program, which mandates a 2.5% "set-aside" of large federal agencies' R&D budgets for small firms, is estimated by Walsten (1998) to have spent more than $1 billion in FY 1997, well above either ATP or the DOE expenditures on CRADAs.

**Table 3: Federal Expenditures on DOE CRADAs, FY 1993-99**

| Fiscal Year | Current ($000) | Constant ($000) |
|---|---|---|
| 1993 | 175,799 | 194,747 |
| 1994 | 259,598 | 281,686 |
| 1995 | 346,437 | 368,065 |
| 1996 | 251,414 | 241,003 |
| 1997 | 148,700 | 152,591 |
| 1998 | 110,239 | 111,804 |
| 1999 (est.) | 94,156 | 94,516 |
| TOTAL | 1,386,703 | 1,444,411 |

**Source:** DOE, "Preliminary A-11 Data," 3/3/99.[7]

In other words, the annual expenditures by a single federal agency on support for CRADAs (albeit an agency that accounts for the largest share of overall federal CRADAs) appear to exceed the annual budget for one of the "flagship" civilian technology programs of the Clinton Administration. Total annual federal expenditures on support for CRADAs are likely to be substantial, although data on this point are not available. Despite their large number and the (apparently) substantial expenditure on public funds on CRADAs, virtually nothing is known about their structure or composition, in contrast to ATP.[8]

This brief summary of available data on CRADAs suggests that they may have accounted for significant public expenditures during the 1990s in support of the federal portion of the joint research activities at their center. Yet no annual data are available on total federal expenditures on CRADAs. The data on CRADAs reported by the National Science Foundation omit some detail (e.g., the breakdown by agency of the structure of CRADAs executed in 1995) that would be very useful to scholars, analysts, and policymakers. CRADAs are only one of several mechanisms for federal agencies to manage collaboration with and technology transfer to industrial firms; but virtually no data are reported by NSF on these other mechanisms. Indeed, the Commerce Department's reports on federal technology transfer activities, which form the basis for the NSF *Indicators* data on CRADAs, do not link the reported "outcomes" of these activities to the different channels through which federal agencies are authorized to conduct them.

[7] These data from DOE, which are denoted as "Annual Federal Funding for CRADAs," indicate substantially higher federal expenditures on support for the public laboratories' participation in CRADAs than the figures cited in Guston (1998, footnote 39). Guston provides no source for his data, which report the costs of the federal and non-federal contributions to DOE CRADAs during FYs 1993-96.

[8] Data reported in Hall et al. (2000) indicate that since its first funding awards in 1991, ATP has provided financial support for 352 projects, 234 of which are single-firm and 118 of which involve multiple non-federal participants. The mean total project budget (federal plus private funds) for ATP projects was roughly $6.6 million, although project budgets ranged from $490,000 to nearly $63 million. Mean project budgets for single-firm projects are $3.24 million, roughly one-quarter the size of those for "joint venture" projects ($13.24 million). The majority of ATP projects are in the information and computer technology field (29%), followed by biotechnology (19%) and materials (16%). Very little data are available as yet on the outcomes of ATP projects, reflecting the fact that the program is relatively new. Interestingly, and in some contrast to the situation with CRADAs, ATP has sponsored a number of evaluation studies.

The available data reveal almost nothing about the effects of CRADAs on the performance of participating laboratories or industrial firms. The "performance measures" collected by both the DOE and NSF report outcomes that may reflect the use of any of several technology transfer mechanisms, rather than CRADAs alone. The next section summarizes the limited evidence on the effects of CRADAs on industrial innovation, drawing on several recent studies that employ diverse methodologies.

## III. The Effects of CRADAs

The paucity of public data on CRADAs may be partly responsible for the small amount of empirical analysis of their effects or effectiveness. As I noted earlier, the data now being reported by NSF on CRADAs provide no information on CRADA outcomes, nor do they distinguish between CRADAs and other federal policy vehicles for the support of collaboration, patenting or licensing. The small number of studies that have been undertaken rely on data collected (or selected) by researchers, and the conclusions of these studies accordingly may not apply to all CRADAs, firms, or federal laboratories. Nevertheless, both quantitative and case study evidence reveal some interesting findings concerning the effects of CRADAs on firm performance and the conditions that appear to support effective management of CRADAs. But these studies reveal little about the long-term effects of CRADA participation on the federal laboratories.

### A. Quantitative studies

Two recent quantitative studies that shed some light on the role of CRADAs in industrial innovation are those by Adams et al. (2000) and by Jaffe and Lerner (1999). The study by Adams et al. examines the effects of CRADAs on industrial firms' innovative performance, and finds these effects to be significant. These conclusions must be interpreted with considerable caution, however, because of the characteristics of the data used by Adams and colleagues. Indeed, these data themselves illustrate both the potential of better public data on CRADAs to support research on industrial innovation and the inadequacy of the available data for these purposes.

The Adams et al. (2000) study was part of a broader project that sought to understand the effects of firms' "external linkages" on their innovative performance. The particular project reported in the research team's 2000 paper focused on the effects on firms of relationships with federal laboratories. Because of the inadequacy of publicly available data, Adams and colleagues conducted two surveys—one focusing on the activities of the industrial R&D laboratories of U.S. firms, and the other focusing on federal laboratories' investments in specific research fields.

Adams' survey of industrial firms was confined to relatively large firms, since he required that all respondents be publicly traded (in order to obtain additional firm-specific data on sales, etc. that are included in Compustat). In addition, his measures of industrial labs' "external linkages" with federal laboratories relied on laboratory directors' assessment of the importance of various mechanisms for knowledge transfer and interaction, including CRADAs. Finally, of course, Adams' data on industrial firms are confined to those firms with dedicated industrial research laboratories, and thus exclude many small or new firms. Several of the firms whose CRADAs were included in the Ham and Mowery (1998) study (see below) were firms that are excluded from the Adams et al. study.

The Adams et al. measure of CRADAs does not capture the existence or nonexistence of a CRADA between a given industrial and federal laboratory; nor does it measure the number of CRADAs that a given industrial laboratory maintains at any point in time. Instead, Adams' data provide information on the characteristics and inventive performance of industrial laboratories that report that CRADAs are "important" or "unimportant." Adams' data measure the influence of CRADAs deemed by laboratory managers to be important, without controlling for the number, the cost, or the failure rate of such undertakings.

These caveats notwithstanding, Adams et al. (2000) find that industrial laboratories that rank CRADAs as "important" vehicles for technology transfer display significantly higher rates of patenting, the primary measure of laboratory performance used in the study.[9] This "CRADA effect," which is much stronger among laboratories affiliated with firms that are not government contractors, outweighs the influence of virtually all other measures of federal laboratories' linkages with or influence on the industrial laboratories in the Adams et al. study. Adams and colleagues also find that industrial laboratories indicating that CRADAs are important also spend more on R&D in federal laboratories; they spend more on in-house R&D; and they have larger in-house R&D budgets funded from federal sources. In addition to these strong firm-level effects, Adams et al. also find considerable differences among the measured influence on industrial innovation of R&D investments by the laboratories of various federal agencies—the "knowledge stocks" resulting from the R&D investments of DOE and DOD laboratories negatively influence industrial laboratories' patenting. This result may reflect the tendency for DOE and DOD laboratories to work with government contractors that patent a smaller share of the results of their R&D.

The Adams et al. (2000) study is virtually the only systematic, rigorous study of the influence of CRADAs on innovative performance within a large sample of firms. Both firm-level and agency-level effects also appear to be important influences on the relationship between industrial laboratories' external linkages and their innovative performance (as measured, imperfectly, by total patenting). Although the study's findings must be qualified by a recognition of the unrepresentative nature of the sample of firms and the characteristics of its measure of "CRADA influence," its findings are intriguing and important. The results of the study underscore the need for the collection and dissemination by federal agencies of more reliable aggregate data on CRADAs.

The second paper does not examine the effects of CRADAs per se on industrial innovation. Instead, Jaffe and Lerner set out to analyze the effects of the much broader array of post-Cold War federal "technology transfer" initiatives (including CRADAs) on the 23 largest DOE laboratories. Their analysis compares the characteristics of DOE laboratories' patenting before and after 1987, a year chosen to mark the inception of the "technology transfer" initiatives. In addition, they examine laboratory-specific influences on the number of CRADAs executed by each during 1991-97 (omitting 1996). They find considerable laboratory-specific differences. Laboratories operated by universities appear to patent more heavily, as do laboratories that shift to narrow their distribution of patents among technology classes. Laboratories that focus more heavily on "basic science" patent less, controlling for size and other characteristics. Patent output also is significantly higher during the post-1987 period, with no measured decline in the significance (measured in terms of citations) of laboratory patents relative to patents from other sources within the same technology class.

9 Adams and colleagues do not adjust patents for "quality" based on citations, possibly because of the relatively recent time period covered by the study.

Similarly significant laboratory-specific differences appear in the analysis of the determinants of the number of CRADAs executed by laboratories, than as the beginning of the periods. Defense-oriented laboratories execute fewer CRADAs during this period, as do laboratories with a greater "basic science" focus. A recent change in contractor (at GOCO laboratories) also is associated with a higher number of CRADAs.

Taken together, these quantitative studies suggest the importance of disaggregating the CRADA activities of different federal agencies and laboratories. The Jaffe-Lerner study suggests that at least some of these laboratory-specific differences may be explained by competition and organizational focus, results that have interesting implications for the management of the enormous network of federal laboratories. The interesting results of the Adams et al. study also suggest that CRADAs may influence innovative performance, although more information on the number and cost of CRADAs is needed to place this finding in context. Both of these quantitative studies' coverage of the CRADA activities of the overall federal laboratory establishment is incomplete, meaning that care must be exercised in interpreting their results. The inability of either study to develop a more comprehensive dataset on CRADAs reflects the sorry state of the publicly available data, even as these studies' findings indicate the high payoff to improving the quality of these data.

**B. Case studies**[10]

As part of a larger comparative study of the U.S. "R&D system," Bozeman and Crow (1998) compiled data on the benefits of R&D collaboration (including technology transfer) from a sample of large federal laboratories and industrial-firm collaborators. The sampling strategy employed by these researchers made no attempt to compile a "representative" sample of federal laboratories, and (like other authors) Bozeman and Crow appear to have more extensive data on relatively large federal laboratories. Because their study focused primarily on the pre-1993 period, Bozeman and Crow have limited information on CRADAs (which became important technology-transfer vehicles for federal GOCO laboratories only after 1989), and their observations on CRADAs cover a period during which many federal laboratories were still learning to employ this instrument. Nevertheless, at least two interesting findings emerge from this study.

Consistent with this paper's earlier discussion of alternatives to CRADAs, Bozeman and Crow find that industrial firms rely on a number of non-CRADA mechanisms to interact with federal laboratories. The authors examined more than 330 "interactions" between industrial laboratories and 27 large federal laboratories; 70% of these interactions involved DOE laboratories. According to the authors:

> There are three dominant categories [of interaction]: CRADAs, technical assistance, and cooperative R&D other than CRADAs. A total of 56% of the 1992-93 projects are CRADAs. While all of the projects in this study have start dates after implementation of the Cooperative Research Act of 1984 (which enabled CRADAs), only 28% of the projects started before 1990-92 are CRADAs. (Bozeman and Crow, 1998, p. 195).

The authors' data suggest that even during the period of extensive use of CRADAs, these vehicles still accounted for only slightly more than one-half of the "interactions" between industrial firms and

[10] This section draws on Ham and Mowery (1998) and on Linden et al. (1999).

large federal laboratories. The second interesting finding in Bozeman and Crow (1998) draws on the same study of "interactions" between federal and industrial laboratories:

> ...CRADAs are considerably more likely not to lead to a product result [commercialization of a new product]...Since CRADAs have not been in force during the entire period during which this set of interactions has occurred, one might assume it [the finding] is simply a time related measure. Such is not the case; there is little relation between the initiation date and commercialization, and few of the earliest projects in the data set led to commercial results. (Bozeman and Crow, 1998, pp. 201-202).

The authors speculate that this surprising finding may reflect political pressure on the DOE laboratories to increase the number of CRADAs in the early 1990s, resulting in a large number of nonviable projects. The case studies discussed immediately below suggest that internal DOE financial incentives also may have contributed to the execution of a number of CRADAs during this period that had significant operational problems.

Ham and Mowery (1998) conducted a series of case studies of individual CRADAs undertaken by Lawrence Livermore National Laboratory (LLNL), a DOE nuclear weapons laboratory operated by the University of California, in 1994-95. The case studies covered five single-firm CRADAs ranging in size from less than $1 million to more than $20 million, and involved extensive interviews with project personnel from the laboratory and from the participating industrial firms. It is important to note that these case studies covered CRADAs that were executed in the early phases of DOE's CRADA program; a number of policies have been instituted subsequently that seek to address some of the problems highlighted in these cases. Nonetheless, these case studies illustrate the high variance in CRADA outcomes, as well as the importance of project- and firm-specific factors in affecting these outcomes. A subsequent study by Linden et al. (1999) examined the development of a very large CRADA, dealing with "extreme ultraviolet" (EUV) photolithography technologies for semiconductor manufacture. This multi-laboratory, multifirm CRADA, which was initiated in 1997, is structured quite differently from those examined in Ham and Mowery (1998), and its operations suggest some other important characteristics of the CRADA mechanism.

The legislative and administrative requirements of CRADAs produced long delays in the negotiation and approval by DOE of many of the projects examined in Ham and Mowery (1998). Such delays imposed serious handicaps on the projects that were exacerbated by the inability of most LLNL research teams to begin work before a project's final approval. Since most of the CRADAs had insufficient budgetary flexibility to allow for a gradual "ramp-up" of project activities, informal agreement between the firm and laboratory researchers on the specific goals of a project was in some cases followed by months of inactivity. During these prolonged lapses in communication between laboratory and firm personnel, project goals often changed considerably.

Another budget-related problem emerged during the final stages of several projects in the Ham and Mowery study. Laboratory researchers, rather than gradually phasing out their involvement with firm personnel and assisting with technical issues associated with the transition from laboratory prototype to high-volume manufacturing, frequently had to terminate their participation as soon as the project's budget was exhausted, often as soon as a prototype had been demonstrated. Translation by private firms of a prototype into a commercially desirable (and manufacturable) product, however, requires extensive, technically demanding work. In several of our cases, laboratory personnel continued to work informally with the firm after the end of CRADA-related funding, but they did so without budgetary support.

Other budgetary policies made it difficult for firms pursing smaller projects to obtain timely access to the laboratory's expertise and resources once the project was under way. Project managers from LLNL noted that inflexible internal budgetary allocation policies and the high unit costs of the laboratory's R&D (especially when overhead charges are included) prevented senior engineers and managers from committing significant portions of their time to small-budget projects. Budgetary constraints also limited the ability of LLNL managers to respond to changes in the technical or budgetary scope of the project.

Commercialization of the results of a technology codevelopment project requires considerable technical sophistication and managerial competence within the private-firm partner, which may be particularly scarce in smaller firms. The demands for such expertise extend to the formulation of projects--in one of our cases, technical and managerial weaknesses within the small-firm partner produced an unrealistic set of project goals that impeded the execution of the CRADA and contributed to a commercially unsuccessful product. R&D consortia in other high-technology industries, such as SEMATECH, have also found that many of the small firms with whom they collaborate need more than technology--in addition to technological collaboration or assistance, the management, marketing, and manufacturing skills of these enterprises must be improved (Grindley, et al., 1994). This task requires a more ambitious and multidisciplinary effort than most DOE laboratories can support within a CRADA.

The findings of these case studies suggest the importance of developing clear criteria for selecting projects and (at least as important) industrial clients for CRADAs. These studies also underscore the need for both federal laboratories and their erstwhile industrial collaborators to consider an array of non-CRADA alternatives in structuring a joint R&D project. The political salience of CRADAs in the early 1990s and the associated efforts to expand the number of DOE CRADAs rapidly, paradoxically may have undercut the effectiveness of these vehicles. Finally, the financial incentives that led many DOE laboratory managers to aggressively promote CRADAs to prospective industrial partners may have reduced the effectiveness of these vehicles for collaboration and technology transfer. All of these factors underscore the importance of examining a much broader array of channels and vehicles for federal technology transfer in any assessment of the level or effectiveness of these activities.

Although the number of new CRADAs executed by the Department of Energy has declined, a large DOE CRADA with the "Extreme Ultraviolet Limited Liability Company" (EUV LLC), was begun in 1997. The EUV LLC is a consortium owned by three U.S. semiconductor manufacturers, Intel Corporation, Motorola, and AMD. The EUV LLC has established a CRADA with three of the largest DOE laboratories—Sandia, Lawrence Livermore, and Lawrence Berkeley National Laboratories--to develop technologies for "next-generation lithography" (NGL) in the semiconductor manufacturing industry. The EUV initiative relies on both government-industry and intra-industry collaboration to develop a technically effective and commercially feasible next-generation lithography technology. How if at all do the structure and management of the EUV CRADA address the problems of CRADA management and collaboration discussed earlier?

Perhaps the most important difference between the EUV CRADA and those examined in Ham and Mowery (1998) is the relationship between the private firms and the participating DOE laboratories. Rather than a jointly funded undertaking, in which both laboratory and firm participants shared management responsibility, the EUV CRADA is one in which the private firms provide all of the operating budget, as well as contributing a number of pieces of costly laboratory equipment. The participating DOE laboratories provide unique facilities and research skills, but they do so in a capacity that resembles that of a research contractor, rather than a collaborator with significant control over the agenda or budget.

The structure of the EUV CRADA avoids an important pitfall in the previous DOE laboratory CRADAs that relied in part on funding from the DOE headquarters. The availability of matching funding from DOE created strong incentives for laboratory personnel to market the research facilities and capabilities of DOE laboratories. In some cases these marketing efforts created unrealistic expectations among private-firm participants about the size, cost, and likely time horizon of technical and commercial benefits from the CRADA. The availability of public subsidies for these CRADAs encouraged laboratory personnel to pursue activities that were too distant from the historical strengths and capabilities of laboratories, especially those specializing in nuclear weapons design.

In the case of the EUV CRADA, however, the private firms that are providing the operating budget are unambiguously in charge of the research agenda. Moreover, their continued financial support depends on the ability of laboratory personnel to address the challenges of the collaborative research agenda, reducing some of the incentive conflicts associated with previous CRADAs that drew in part on DOE funds. Rather than competing among themselves for private-firm partners in order to obtain additional funds from DOE headquarters, these three large DOE laboratories are motivated to collaborate by the structure of the EUV LLC CRADA. Indeed, one participant interviewed for this study characterized the level of cooperation among the labs as unusually high, and argued that this effective collaboration was attributable in part to the unusual nature (and large size) of this CRADA.

Private financing also may allow for greater flexibility in CRADA administration, enabling the project to "ramp down" more gradually in the transition from laboratory to prototype development and production of the equipment under development. At the same time, however, the scope of the technological challenges posed by this CRADA is such that participation yields benefits for the DOE laboratory personnel. The ambitious technological goals of this CRADA contrast with those of the CRADAs studied in Ham and Mowery (1998)—in several of those cases, the availability of DOE funding led laboratory researchers to pursue short-term "job-shop" projects with limited technical benefits for the laboratories' missions. More technically challenging CRADAs address another long-standing problem for the DOE laboratories, especially those focusing primarily on national security missions--maintaining the technical expertise of laboratory researchers.

Another important contrast with many other CRADAs is the sheer scale of the EUV CRADA, whose 3-year budget is $250 million. Given the relatively high operating costs of the DOE laboratories when indirect charges are included, private firms in small-budget CRADAs often had problems in gaining or maintaining access to senior laboratory staff researchers. The scale of this CRADA, however, means that even senior laboratory managers and researchers are more likely to become involved. In addition, the size and technical capabilities of the participating firms dwarf those of the private-sector participants in many of the CRADAs examined in Ham and Mowery (1998). As a result, the firms leading the EUV CRADA are better able to sustain the considerable investments in supporting this collaboration. These include frequent face-to-face meetings, temporary assignment of firm personnel to work in the DOE laboratories, and the necessary in-house investments in related R&D that improve these firms' ability to evaluate, absorb and exploit the results of the project.

Although these characteristics of the EUV CRADA appear to represent improvements over the structure of previous DOE CRADAs, significant political and management challenges remain. Perhaps the greatest challenge is that of "handing off" the results of this CRADA to enterprises capable of developing commercial versions of the tools embodying these results. The LLC members are semiconductor manufacturers who have expressed no interest in entering the production of manufacturing equipment (indeed, any such entrant would face serious competitive challenges in selling equipment to semiconductor manufacturers who are competitors).

The role of leading semiconductor manufacturers in supporting the development of the EUV technology and the two-year period of exclusive access by LLC members to commercial versions of the EUV tool could impede commercialization of a next-generation lithography technology. The EUV LLC partners, rather than their competitors, will have early access to commercial versions of the EUV equipment. Competitors of the EUV LLC partners may elect not to adopt the technology, choosing instead to pursue alternative technologies with no delays in early access to commercial tools. Such reluctance could fragment the market for EUV or other lithography technologies, making it difficult for equipment manufacturers to recover their development investments.[11]

Other difficult issues affecting the commercialization of an EUV prototype are associated with the management of the intellectual property produced by the LLC and with the need to assemble a substantial portfolio of patents to develop the EUV technology. LLC members require access to the intellectual property of nonmember firms to develop this technology. LLNL, Lucent, and Ultratech are among the organizations that control EUV-related intellectual property, and commercial development of the technology requires that they license their patents to the EUV LLC. At least one of these owners of EUV-related intellectual property (Lucent) is a manufacturer of semiconductor devices who competes with the LLC member firms. This fact may reduce Lucent's willingness to license a group of competitors that will in turn profit from the application of Lucent's patents to EUV. Moreover, since Lucent is committed to the development of a substitute for EUV (SCALPEL), facilitating the development of EUV could undercut the returns to its SCALPEL-related intellectual property, further reducing its incentives to license.

Still another uncertainty affecting the development of EUV concerns the ability of U.S. equipment firms to support the investments in product development, high-quality manufacture, and product support that are necessary to commercialize this technology. In particular, product-support issues (maintenance, troubleshooting, spare parts) have proven critical to the success and failure of semiconductor equipment producers in the past[12] and remain a serious issue at many U.S. equipment

[11] It is interesting to note in this connection that the SEMATECH consortium ultimately abandoned a similar policy of exclusive access (involving a two-year period of exclusivity) by member firms to tools incorporating SEMATECH-funded improvements because of opposition by equipment firms participating in the consortium, who argued that the more restrictive policy limited the market for their tools (Grindley et al., 1994).

[12] See Grindley et al., 1994 or Randazzese 1996 for a discussion of the case of GCA, formerly a leading U.S. semiconductor equipment supplier. GCA's attempts to commercialize its state-of-the-art optical lithography tool, despite assistance from SEMATECH, ultimately failed, partly because of the firm's poor reputation for product quality and field support.

suppliers. The uncertain commercialization capabilities of many equipment producers (particularly U.S.-based equipment firms) argue in favor of widespread dissemination of EUV-related intellectual property, in order that as many equipment firms as possible have an opportunity to undertake the costly investments. But the policies of the EUV LLC member firms emphasize profitable (and therefore, restricted) licensing, which may limit entry by prospective producers of the equipment and could impede the commercial development of EUV. Moreover, potential licensing of foreign equipment producers has sparked political controversy and remains contentious.[13]

The EUV CRADA illustrates the importance of another critical gap in the data collected by the federal government on CRADAs. Information on the financing and the structure of these undertakings is currently unavailable in any centralized tabulation; yet this brief descriptive case study suggests that both the financing and the structure of CRADAs influences their effectiveness.

## IV. Conclusion and Recommendations

There are three basic deficiencies in the current reporting by NSF of data on federal Cooperative Research and Development Agreements:

1. the National Science Foundation has incorrectly interpreted the data available from other federal agencies on the relationship between CRADAs and invention disclosures;
2. the data available from other federal agencies on CRADAs lack a great deal of crucially important information; and
3. data on CRADAs need to be supplemented with information on other vehicles for collaboration and technology transfer, especially if "outcomes" data are being reported.

As I noted earlier, the current discussion in *Science and Engineering Indicators: 2000* by NSF of the data compiled by the Commerce Department on CRADAs and technology transfer "outcomes" incorrectly attributes all of the invention disclosures reported by federal agencies during fiscal years 1987-98 to CRADAs. Instead, a substantial fraction, perhaps as much as 50%, of the disclosures

[13] Discussions among the LLC member firms, DOE and foreign firms over their participation in the EUV CRADA attracted Congressional criticism in October 1997. Although the language of the EUV CRADA was not revised in response to the Congressional criticism, at least one leading foreign lithographic equipment supplier, Nikon, elected not to participate in the CRADA as a result of the controversy (see Holstein, 1988).

In February 1999, DOE permitted the Dutch firm ASML, which also heads an EUV lithography program in Europe ("EUCLIDES"), to negotiate a license with EUV LLC. Descriptions in the press of ASML's agreement with DOE, which is not public, state that it requires ASML to produce any EUVL tools sold in the U.S. at a U.S. factory comparable to its Netherlands facility. The Dutch firm also must use a sufficient quantity of U.S.-produced components to meet local content goals, and was required to establish a U.S. research center. ASML, which is a partner for Lucent's SCALPEL project and a participant in a European effort to develop ion-beam projection lithography, signed a contract with EUV LLC in June 1999.

Still another controversy over foreign participation in the EUV LLC erupted in the spring of 2000. In June 2000, Infineon Technologies, the semiconductor manufacturing subsidiary of Siemens of Germany, agreed to become a member of the EUV LLC. Although Infineon's membership in the EUV LLC was approved by DOE, the Department of Commerce objected to the German firm's participation, arguing that no "domestic production" requirements similar to those of ASML are present in the Infineon agreement (Leopold and Lammers, 2000).

reported by each agency result from other activities, including intramural research or other types of collaborative R&D with industry.

The data reported by NSF suffer from two other broad defects: like other "evaluations" of federal agencies' performance in technology transfer, they place too much emphasis on CRADAs, to the exclusion of other instruments; and the data on CRADAs omit a great of important information. Although NSF cannot be faulted for failing to report data that it does not have, it seems clear that the emphasis within the Indicators discussion on CRADAs is misplaced. NSF, along with the Department of Commerce, should urge other federal agencies to report technology transfer activities in areas other than CRADAs, including the number of "work-for-others," "user facility agreements," "personnel exchange," and other technology-transfer activities.

Rather than just the total number of licenses, the number of licenses associated with each of these vehicles, as well as licenses from other sources, should also be reported. Similarly, the sources of "invention disclosures" should be reported in the Commerce Department and NSF data. The data currently reported by the Department of Commerce and the National Science Foundation on "technology transfer outcomes" provide very little information on the importance or performance of the numerous different federal policies to encourage technology transfer that have been instituted since 1980. The bias in the NSF and Commerce Department reporting reflects the inexplicable bias in overall federal technology transfer policy that emphasizes CRADAs above alternative instruments for technology transfer, even in situations where CRADAs may be less desirable than these alternatives. But this bias makes no more sense in data reporting than it does in overall policy.

The data collected by the Commerce Department and reported by the NSF on CRADAs also are deficient in a number of dimensions. Among the most glaring omissions is the failure to report agency-level expenditures on support of CRADA-related research and other activities. Expenditures for this purpose by the Department of Energy, the agency accounting for the largest number of CRADAs, were substantial during the FYs 1993-99 period, exceeding federal spending on the Advanced Technology Program. The DOE appears to have provided more extensive financial support for CRADAs, and its expenditures on this activity may not be representative of other agencies' spending. But CRADAs are not a "free good"—their execution requires federal resources. The lack of data on agency expenditures on CRADAs distorts evaluation of these instruments of federal policy.

Other data on CRADAs that should be collected by the Commerce Department on a regular basis include information on the number of new CRADAs executed each year, by agency, and the number of CRADAs terminated each year, by agency, along with some basic information on the reasons for termination (e.g., "project was completed," "failure to realize objectives," "goals of partners changed"). Data on the financial structure of the CRADAs (i.e., the size and share of any federal funding for agency R&D expenses), by agency and year, also should be collected. Finally, the data on CRADAs collected by the Commerce Department and reported by the National Science Foundation lack any detail on the characteristics of the industrial partners or other participants in CRADAs. Additional detail on the number of entities, whether they are industrial firms, universities, or other types of organizations, and additional detail on the characteristics of the participating firms (size, primary industry) would be very valuable. Disclosure of some of this information, especially that on the characteristics of participating firms, may be restricted. But the information on the number and type of CRADA participants, by year and sponsoring agency, are not subject to disclosure restrictions and should be made available to the public.

Cooperative Research and Development Agreements have been the focus of a great deal of political "hype" and (perhaps not coincidentally) very little systematic evaluation. The limited scholarly research on CRADAs suggests that these instruments may be associated with superior inventive performance, and that the performance of CRADAs depends on a number of factors that are specific to individual projects, such as the project budget, characteristics of the industrial participants, and sponsoring agency. Other evidence suggests that CRADAs may have absorbed substantial federal spending during the 1990s. But the data reported by the NSF and the Commerce Department do not permit a more systematic assessment of CRADAs. Worse yet, these data perpetuate a form of evaluative myopia, in which agency-level technology transfer performance is judged solely in terms of the number of CRADAs that they report, ignoring the numerous alternative and important tools available to agencies to support collaborative R&D and technology transfer activities.

If federal policymakers wish to do more than issue platitudinous endorsements of "public-private collaboration" in R&D, they might consider trying to understand the shape and contours of the landscape. Without better data on both CRADAs and agency-level R&D collaboration and technology transfer, such understanding will remain elusive.

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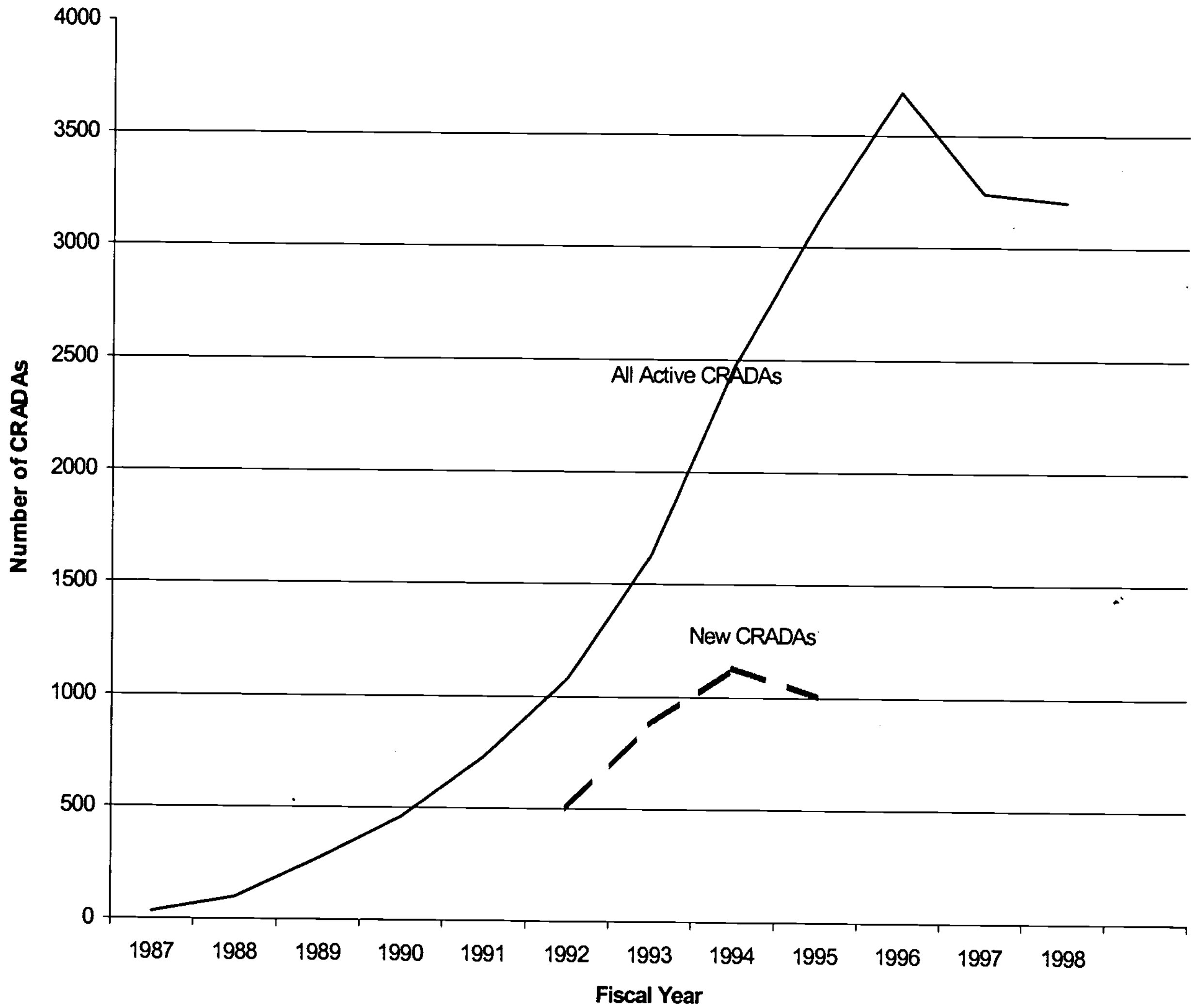
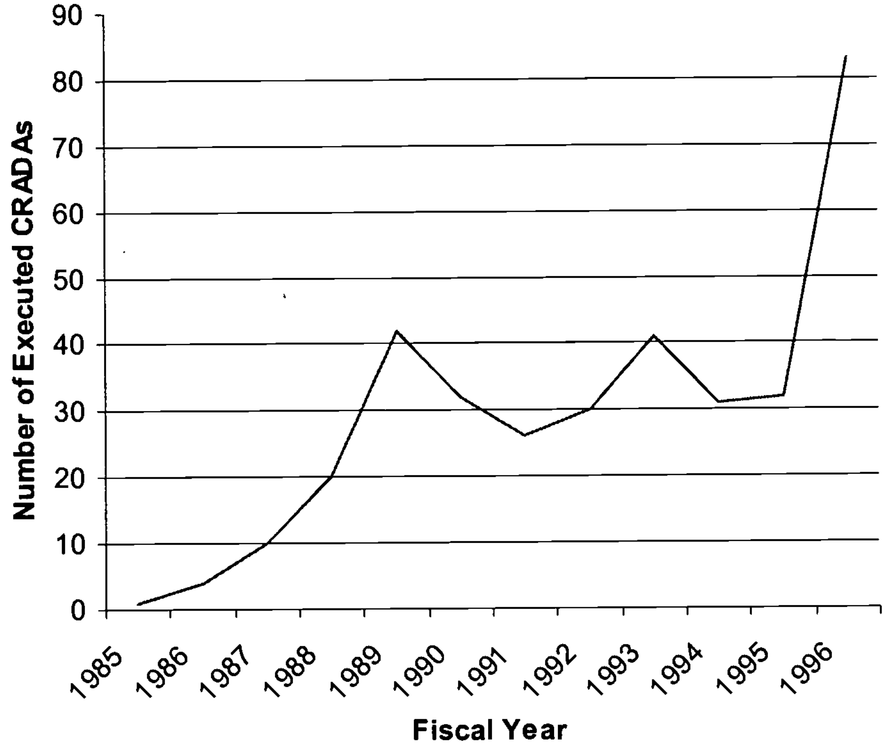
**Figure 1: CRADA activity, FY 1987-98**




**SOURCE**: National Science Board. *Science and Engineering Indicators (2000).*

**Figure 2: NIH Executed CRADAs, FY 1985 - 1996**




**SOURCE:** D.H. Guston (1998).

## Strategic Research Linkages and Small Firms

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### I. Introduction

Until recently small firms were the invisible man of innovative activity. Most of the measurement and empirical analyses of innovation focused solely on large corporations (Scherer, 1965; and Mansfield, 1983). This reflected a theoretical framework that applied to the innovation process in large corporations but not necessarily small enterprises (Chandler, 1990).

Only within the last fifteen years has the vast degree of innovative activity contributed by small enterprises been uncovered (Scherer, 1991). Systematic, comprehensive empirical studies have provided compelling evidence that small firms generate a significant amount of innovative activity, especially in new and emerging industries (Caves, 1998).

However, there is very little systematic evidence about the role that strategic research partnerships play in small firms. Part of the reason for this paucity of knowledge is theoretical. As was the case for the innovation literature only several years ago, the theoretical frameworks to analyze joint research partnerships are predominately oriented towards large corporate partners. Measurement provides even greater challenges. Small firms have systematically lower rates of survival. In high-technology industries, small-firm survival rates are still lower. At the same time, startup rates are higher. This makes it difficult to even identify firms and track them over time. In addition, small firms are notorious for forsaking formal R&D for informal research, which typically defies measurement (Kleinknecht, 1989a and 1989b; and Roper, 1999). Measuring research partnerships between firms reporting no research is even more challenging.

At the same time, however difficult they are to measure, the importance of research linkages and partners to small firms is undeniable. While it may not make sense for firms that are new and most likely transitory to formalize strategic research partnerships with other firms and institutions, such linkages are clearly at the heart of some small-firm strategies. For example, Saxenian (1994) argues that the rich network of linkages and partnerships in the Silicon Valley region has contributed to a superior innovative performance. According to Saxenian (1990, pp. 96-97) "It is not simply the concentration of skilled labor, suppliers and information that distinguish the region. A variety of regional institutions—including Stanford University, several trade associations and local business organizations, and a myriad of specialized consulting, market research, public relations and venture capital firms—provide technical, financial, and networking services which the region's enterprises often cannot afford individually. These networks defy sectoral barriers: individuals move easily from semiconductor to disk drive firms or from computer to network makers. They move from established firms to startups (or vice versa) and even to market research or consulting firms, and from consulting firms back into startups. And they continue to meet at trade shows, industry conferences, and the scores of seminars, talks and social activities organized by local business organizations and trade associations. In these forums, relationships are easily formed and maintained, technical and market information is exchanged, business contacts are established, and new enterprises are conceived. ... This decentralized and fluid environment also promotes the diffusion of intangible technological capabilities and understandings."

Where systematic evidence does exist, it suggests that strategic research partnerships may, in fact, be more important for small firms than for their larger enterprises. As is documented in this paper, empirical evidence from the biotechnology industry shows that both formal strategic research partnerships as well as less formal linkages among firms, scientists and universities play a central role in the innovative activities of firms.

The purpose of this paper is to draw together disparate strands of literature to draw out what has been learned about the role of strategic research partnerships for small firms. The second section of the paper documents the innovative contribution made by small firms. At the same time, small firms do not undertake high amounts of research activity. The third section reconciles the paradox posed by the high degree of innovative activity combined with the relatively low level of research by suggesting that small firms rely on external knowledge sources, such as strategic research partnerships. The fourth section provides a theoretical framework for analyzing strategic research partnerships for small firms and suggests why such strategic alliances may, in fact, be more important for small enterprises than for large corporations. The fifth section focuses on the role of small-firm strategic research partnerships in high-technology industries. Finally, in the last section a summary and conclusions are provided. In particular, while objective measures of formal agreements are invaluable to fully understand the role that strategic research partnerships play in small firms, future research needs to develop subjective measures using surveys may be invaluable in order to more systematically identify (1) the extent of strategic research partnerships in small firms, (2) their determinants, and (3) their impact on economic performance.

## II. Innovation

The starting point for most theories of innovation is the firm. In such theories the firms are exogenous and their performance in generating technological change is endogenous (Arrow, 1962). For example, in the most prevalent model found in the literature of technological change, the model of the knowledge production function, formalized by Griliches (1979), firms exist exogenously and then engage in the pursuit of new economic knowledge as an input into the process of generating innovative activity. The most decisive input in the knowledge production function is new economic knowledge. Knowledge as an input in a production function is inherently different than the more traditional inputs of labor, capital and land. While the economic value of the traditional inputs is relatively certain, knowledge is intrinsically uncertain and its potential value is asymmetric across economic agents.[1] The most important, although not the only source of new knowledge is considered to be research and development (R&D). Other key factors generating new economic knowledge include a high degree of human capital, a skilled labor force, and a high presence of scientists and engineers. The most decisive input in the knowledge production function is new economic knowledge. And as Cohen and Klepper conclude, the greatest source generating new economic knowledge is generally considered to be R&D. Certainly a large body of empirical work has found a strong and positive relationship between knowledge inputs, such as R&D, on the one hand, and innovative outputs on the other hand.

[1] Arrow (1962) pointed out this is one of the reasons for inherent market failure.

The knowledge production function has been found to hold most strongly at broader levels of aggregation. The most innovative countries are those with the greatest investments to R&D. Little innovative output is associated with less developed countries, which are characterized by a paucity of production of new economic knowledge. Similarly, the most innovative industries, also tend to be characterized by considerable investments in R&D and new economic knowledge. Not only are industries such as computers, pharmaceuticals and instruments high in R&D inputs that generate new economic knowledge, but also in terms of innovative outputs (Audretsch, 1995). By contrast, industries with little R&D, such as wood products, textiles and paper, also tend to produce only a negligible amount of innovative output. Thus, the knowledge production model linking knowledge generating inputs to outputs certainly holds at the more aggregated levels of economic activity.

Where the relationship becomes less compelling is at the disaggregated microeconomic level of the enterprise, establishment, or even line of business. For example, While Acs and Audretsch (1990) found that the simple correlation between R&D inputs and innovative output was 0.84 for four-digit standard industrial classification (SIC) manufacturing industries in the United States, it was only about half, 0.40 among the largest U.S. corporations.

The model of the knowledge production function becomes even less compelling in view of the recent wave of studies revealing that small enterprises serve as the engine of innovative activity in certain industries. These results are startling, because as Scherer (1991) observes, the bulk of industrial R&D is undertaken in the largest corporations; small enterprises account only for a minor share of R&D inputs. Thus the knowledge production function seemingly implies that, as the *Schumpeterian Hypothesis* predicts, innovative activity favors those organizations with access to knowledge-producing inputs—the large incumbent organization.

The model of the knowledge production function becomes particularly weak when small firms are included in the sample. This is not surprising, since formal R&D is concentrated among the largest corporations, but a series of studies (Audretsch, 1995) has clearly documented that small firms account for a disproportional share of new product innovations given their low R&D expenditures.

Knowledge regarding the relationship between firm size and innovation has been largely shaped by measurement. Measures of technological change have typically involved one of the three major aspects of the innovative process: (1) a measure of inputs into the process, such as R&D expenditures, or the share of the labor force accounted for by employees involved in R&D activities; (2) an intermediate output, such as the number of inventions that have been patented; or (3) a direct measure of innovative output.

The earliest sources of data, R&D measured, indicated that virtually all of the innovative activity was undertaken by large corporations. As patent measures became available, the general qualitative conclusions did not change, although it became clear that small firms were more involved with patent activity than with R&D. The development of direct measures of innovative activity, such as data bases measuring new product and process introductions in the market, indicated something quite different. In a series of studies, Acs and Audretsch (1988 and 1990) found that while large firms in manufacturing introduced a slightly greater number of significant new innovations than small firms, small-firm employment was only about half as great as large-firm employment, yielding an average small-firm innovation rate in manufacturing of 0.309, compared to a large-firm innovation rate of 0.202. The relative innovative advantage of small and large firms was found to vary considerably across industries. In some industries, such as computers and process control instruments, small firms provide the engine of innovative activity. In other industries, such as pharmaceutical products and aircraft, large firms generate most of the innovative activity. Knowledge regarding both the determinants and the impact of technological change has been largely shaped by measurement.

Acs and Audretsch (1988, 1990) concluded that some industries are more conducive to small-firm innovation while others foster the innovative activity of large corporations corresponds to the notion of distinct technological regimes—the routinized and entrepreneurial technological regimes.

**III. Knowledge Sources**

The breakdown of the knowledge production function at the level of the firm raises the question, *Where do innovative firms with little or no R&D get the knowledge inputs?* This question becomes particularly relevant for small and new firms that undertake little R&D themselves, yet contribute considerable innovative activity in newly emerging industries such as biotechnology and computer software. One answer that has recently emerged in the economics literature is from other, third-party firms or research institutions, such as universities. Economic knowledge may spill over from the firm conducting the R&D or the research laboratory of a university.

That knowledge spills over is barely dispute. However, the geographic range of such knowledge spillovers is greatly contested. In disputing the importance of knowledge externalities in explaining the geographic concentration of economic activity, Krugman (1991) and others do not question the existence or importance of such knowledge spillovers.[2] In fact, they argue that such knowledge externalities are so important and forceful that there is no compelling reason for a geographic boundary to limit the spatial extent of the spillover. According to this line of thinking, the concern is not that knowledge does not spill over but that it should stop spilling over just because it hits a geographic border, such as a city limit, state line, or national boundary.

Krugman (1991a, p. 53) has argued that economists should abandon any attempts at measuring knowledge spillovers because " ... knowledge flows are invisible, they leave no paper trail by which they may be measured and tracked." But as Jaffe, Trajtenberg and Henderson (1991, p. 578) point out, "knowledge flows do sometimes leave a paper trail"—in particular in the form of patented inventions and new product introductions.

Despite Krugman's warning, a recent body of empirical evidence developing novel measures of knowledge flows clearly suggests that R&D and other sources of knowledge not only generate externalities, but studies by Audretsch and Feldman (1996), Jaffe (1989), Audretsch and Stephan (1996), Feldman (1994a and 1994b), and Jaffe, Trajtenberg and Henderson (1993) suggest that such knowledge spillovers tend to be geographically bounded within the region where the new economic knowledge was created. That is, new economic knowledge may spill over but the geographic extent of such knowledge spillovers is limited.

While the literature on knowledge spillovers has identified that knowledge externalities exist, and are geographically bounded, they shed little light on the mechanisms by which knowledge is transmitted to small firms. One such mechanism is via strategic research partnerships.

[2] Macki (1996) points out that these views are not original with Krugman (1991).

## IV. Alliance Strategy

According to Kogut (1988), a joint venture occurs when two or more firms pool a portion of their resources within a common legal organization. Conceptually, a joint venture is a selection among alternative modes by which multiple firms can transact. Gomes-Casseres (1997, p. 34) defines alliances more broadly as "an administrative arrangement to govern an incomplete contract between separate firms in which each partner has limited control."

According to Gomes-Casseres (1996), three factors shape the formation of alliances—capabilities, control and context. Capabilities refers to the set of tangible and intangible assets making it feasible for a firm to develop, produce and sell goods and services. Control refers to the authority of the firm to deploy those capabilities. The context refers to the external environment within which the firm operates.

Kogut (1988) emphasizes that if all three of these elements—capabilities, control and context—are present within the firm, there will be no need for it to externally seek a strategic alliance. However, if one of these elements is lacking or weak, the firm has an incentive to seek an external partner or set of partners. If an alliance is formed, the set of capabilities required by the firm shapes the structure of control in the organization. The structure of control similarly shapes the manner in which the capabilities are managed, and the nature of investments made to upgrade the capabilities over time.

Gomes-Casseres (1996) points out that in a context where size bestows a competitive advantage—due to economies of scale or scope—large enterprises will tend to have the competitive advantage. To compensate for this size-inherent cost disadvantage, small firms then have a clear incentive to engage in a strategic alliance in effectively increase their scale and scope.

An implication of the Gomes-Casseres (1996) framework is that not every small firms are at a competitive disadvantage, *per se*, even if larger and even very large enterprises exist in the same industry. As long as no size-inherent cost disadvantages exist, there will be no compelling reason to participate in a strategic alliance.

In addition, occupying a strategic niche provides small firms with an opportunity for viability in a context where either no scale economies exist, or there are even modest diseconomies of scale. According to Penrose (1959, pp. 222-223), "The productive opportunities of small firms are composed of those interstices left open by the large firms which the small firms see and believe they can take advantage of. The nature of the interstices is determined by the kind of activity in which the larger firms specialize, leaving other opportunities open." Caves and Porter (1978) and Newman (1978) provided compelling empirical evidence for the existence of such strategic niches.

By contrast, when a small firm is at a competitive disadvantage vis-à-vis larger competitors developing a strategic partnership or alliance is a mechanism to compensate for size-inherent disadvantages. Gomes-Casseres (1994) provides an example of how a strategic alliance generates compensating competitiveness for small firms. A relatively small computer firm, Mips Computer Systems, operated in the same market as IBM and Hewlett-Packard. Production scale economies and market penetration determined commercial success. Mips produced reduced instruction-set computing (RISC) processors, which required large-scale production. Because of these scale economies, it was clear that only a few of the producers in the market would ultimately survive. This also meant that those designs with the greatest market penetration were likely to be among the survivors. Thus, it was crucial for Mips to obtain a large market share and influence the industry standard. Mips created an alliance including semiconductor partners and a number of systems vendors. These partners contributed production capacity, market presence, technological competencies, and finance. Mips contributed a highly specialized and unique semiconductor design. Along with one of its partners, Sun, Mips was able to attain the scale, scope, and market impact that otherwise would have been unimaginable.

Through the strategic alliance, Mips succeeded in leveraging its small size to a larger unit of competitiveness. Gomes-Casseres (1997, p. 37) observed that "Increasingly, the talk in the industry became one of how the Mips 'camp' was faring versus the camps centered around other firms."

A different factor motivating compensating strategic research partnerships for small firms is the need for finance. As Lerner and Merges (1998, p. 125) note, "Young firms with novel technologies frequently lack the financial resources to effectively introduce a new product and may find it difficult to raise equity or debt due to the informational asymmetries surrounding the project. In many cases, young firms lack complementary assets such as sales forces and manufacturing know-how, which may take many years to develop. As a result, small, research-intensive firms frequently rely on alliances with larger corporations."

In reviewing the role of financial constraints on investment behavior, Chirinko (1993, p. 1902) observed that, "The investment literature has been schizophrenic concerning the role of financial structure and liquidity constraints." As (1988, p. 141) point out, "Empirical models of business investment rely generally on the assumption of a 'representative firm' that responds to prices set in centralized security markets. Indeed, if all firms have equal access to capital markets, firms' responses to changes in the cost of capital or tax-based investment incentives differ only because of differences in investment demand." That is, the financial structure of a firm does not play an important role in investment decisions, since the firm can costlessly substitute external funds for internal capital. Under the assumption of perfect capital markets, then, firm-specific investment decisions are generally independent of the financial condition of that firm.

The assumption of perfect capital markets has, of course, been rigorously challenged. Once it is no longer assumed that capital markets are perfect, it also can no longer be assumed that external capital is a costless substitute for internal capital. An implication of this view is that the availability of internal finance, access to new debt or equity finance, and other financial factors may shape firm investment decisions.

Which view is correct? According to Fazzari, Hubbard and Peterson (1988, p. 142), "Conventional representative firm models in which financial structure is irrelevant to the investment decision may well apply to mature companies with well-known prospects. For other firms, however, financial factors appear to matter in the sense that external capital is not a perfect substitute for internal funds, particularly in the short run."

There are compelling reasons why liquidity constraints become more severe as firm size decreases. Stiglitz and Weiss (1981) pointed out that, unlike most markets, the market for credit is exceptional in that the price of the good—the rate of interest—is not necessarily at a level that equilibrates the market. They attribute this to the fact that interest rates influence not only demand for capital but also the risk inherent in different classes of borrowers. As the rate of interest rises, so does the riskiness of borrowers, leading suppliers of capital to rationally decide to limit the quantity of loans they make at any particular interest rate. The amount of information about an enterprise is generally not neutral with respect to size. Rather, as Petersen and Rajan (1992, p. 3) observe, "Small and young firms are most likely to face this kind of credit rationing. Most potential lenders have little information on the managerial capabilities or investment opportunities of such firms and are unlikely to be able to screen out poor credit risks or to have control over a borrower's investments." If lenders are unable to identify the quality or risk associated with particular borrowers, Jaffe and Russell (1976) show that credit rationing will occur. This phenomenon is analogous to the lemons argument advanced by Akerloff (1970). The existence of asymmetric information prevents the suppliers of capital from engaging in price discrimination between riskier and less risky borrowers. But, as Diamond (1991) argues, the risk associated with any particular loan is also not neutral with respect to the duration of the relationship. This is because information about the underlying risk inherent in any particular customer is transmitted over time. With experience a lender will condition the risk associated with any class of customers by characteristics associated with the individual customer.

## V. Strategic Research Partnerships in High-Tech

The problems of uncertainty, asymmetric information and high transactions cost are exacerbated in innovative small firms highly reliant upon research. Biotechnology is a new industry that is knowledge based and is predominantly produced by new startups and small firms. The industry is characterized by the type of incomplete contracting described by Grossman and Hart (1986), Hart and Moore (1988), Hart (1995) and Aghion and Tirole (1994). The knowledge conditions underlying the biotechnology industry—high uncertainty, asymmetries, and high transactions costs—result in, "Redefining the work when the unexpected happens, as it invariably will. Research is by its very nature an iterative process, requiring constant reassessment depending on its findings. If there is a low risk of unexpected findings requiring program reassessment, then it is probably not much of a research program" (Sherbloom, 1991, pp. 220-221).

The relative small scale of most biotechnology firms may be attributable to the diseconomies of scale inherent in the "bureaucratic process which inhibits both innovative activity and the speed with which new inventions move through the corporate system towards the market" (Link and Rees, 1990, p. 25). Zucker, Darby and Brewer (1998, p. 1) provide considerable evidence suggesting that the timing and location of new biotechnology firms is "primarily explained by the presence at a particular time and place of scientists who are actively contributing to the basic science."

Strategic research partnerships are particularly important in the biotechnology industry (Table 1). These strategic research partnerships and linkages occur between entrepreneurial firms, between the scientists involved with the firms, between the firms and universities, and between corporations and biotech firms.

**Table 1: Inter-firm Alliances by Biotechnology Firms**

Panel A presents the number of publicized alliances by US firms in information technology, and advanced materials between 1980 and 1994. Panel B presents only alliance involving U.S. biotechnology companies between 1981 and 1995 filed with the U.S. Securities and Exchange Commission or with state regulatory bodies that make such information public. Presented are the number of new filed alliances each year, the sum of all promised pre-commercialization payments in the filed alliances that year (the sum of the nominal payments is expressed in millions of 1995 dollars), and the actual payments to a sample of 49 of the largest biotechnology firms in each year (in millions of $1995).

| *Panel A: Inter-firm alliances by US firms in three research-intensive industries 1980-1994* | | | |
|---|---|---|---|
| | **Number of new alliances publicized, by national of firms** | | |
| *Year* | *US-US* | *US-Europe* | *US-Japan* |
| 1980 | 42 | 40 | 15 |
| 1981 | 48 | 30 | 26 |
| 1982 | 57 | 54 | 39 |
| 1983 | 51 | 37 | 51 |
| 1984 | 88 | 60 | 55 |
| 1985 | 86 | 82 | 52 |
| 1986 | 118 | 78 | 47 |
| 1987 | 133 | 95 | 53 |
| 1988 | 141 | 98 | 39 |
| 1989 | 122 | 89 | 44 |
| 1990 | 121 | 66 | 34 |
| 1991 | 106 | 53 | 51 |
| 1992 | 155 | 89 | 43 |
| 1993 | 192 | 104 | 45 |
| 1994 | 235 | 145 | 40 |

| *Panel B: Intern-firm alliances by US biotechnology firms, 1981-1995* | | | |
|---|---|---|---|
| | | *Payments through alliances (millions of 1995 dollars)* | |
| *Year* | *Number of new filed alliances* | *Pre-commercial payments promised in new alliances* | *Actual payments during year to 49 leading firms* |
| 1981 | 30 | | 9 |
| 1982 | 35 | | 111 |
| 1983 | 31 | | 152 |
| 1984 | 42 | | 210 |
| 1985 | 57 | | 149 |
| 1986 | 63 | | 184 |
| 1987 | 62 | | 415 |
| 1988 | 64 | | 298 |
| 1989 | 71 | | 205 |
| 1990 | 81 | | 851 |
| 1991 | 115 | 741 | 647 |
| 1992 | 75 | 931 | 392 |
| 1993 | 113 | 1373 | 806 |
| 1994 | 66 | 1772 | |
| 1995 | 171 | 3421 | |

**Source:** Lerner and Merges (1998).

Strategic research partnerships between large corporations and biotechnology companies have been particularly important for biotech companies specializing in therapeutics. This is because the cost of developing a new drug, complying with the various layers of regulation, manufacturing the product, and then marketing the product, have required a level of finance that far exceeds the budgets of most small firms. Cullen and Dibner (1993) estimate that the cost of bringing a therapeutic drug from basic research to the market is around $250 million. At the same time, the average budget for research and development of a biotech firm is $12.5 million. To close this gap, biotech firms have engaged in a broad range of marketing and licensing agreements. Under these agreements, the biotech firm provides access to cutting edge technology in exchange from an infusion of capital from their corporate partners.

In documenting the evolution of strategic alliances in biotechnology, Cullen and Dibner (1993, p. 18) conclude that, "The primary strategic goal of small and medium-sized biotechnological companies was to develop products to be marketed by their partners and their primary concern was finding and developing alliances." The obvious advantages to such strategic research partnerships is that they enable a small, new company to concentrate on its core mission—moving from basic research to commercialization through technological innovation. The strategic alliances also enable the biotech company to reduce financial risks as well as operating costs. In addition, the biotech firm is able to better offset the major liabilities associated with biotech startups—acquiring manufacturing capabilities, marketing and sales.

The established firms are generally quite positive and supportive towards biotechnology firms. This is because of the strong complementary nature between biotechnology firms and established firms, particularly in the pharmaceutical industry. There are a number of reasons why such a complementary relationship has evolved between established and biotechnology firms. The first is that the former have recognized that it may be a more efficient structure to engage in an arms length market relationship to obtain new biotechnology products than to produce them internally. The market exchange is apparently more efficient than the internal transaction. The reason for this involves agency problems in undertaking research that is highly uncertain and asymmetric. In addition, the exposure to legal liabilities resulting from biotechnology research is reduced when that research is undertaken at a small firm with limited assets rather than in a large corporation with massive assets.

Sharp (1999) identifies three main phases in the relationship between established firms and biotechnology companies. The first phase involved the formation and incipiency of the biotechnology industries. Sharp (1999, p. 137) reports that "most of the established pharmaceutical companies were uncertain what to make of the new technology and especially of the hype surrounding its development that grew with the small firm sector in the U.S." This uncertainty combined with a considerable degree of skepticism resulted in most established pharmaceutical companies distancing themselves from the fledgling biotechnology industry in this initial phase. At the same time, Sharp points out that most established companies invested in sufficient scientific expertise to enable them to keep abreast of developments in biotechnology and monitor the industry.

The second phase began in the mid-1980s, when the period of watching and waiting ended. The established pharmaceutical recognized that, in fact, biotechnology had a valuable market potential. While strategies pursued by the established enterprises varied, most devised and implemented a strategic biotechnology policy. One common strategy that all companies pursued was to invest heavily to develop an in-house competence in biotechnology. How this was done varied considerably across companies. In some companies, scientific teams were assembled. Other pharmaceutical companies acquired such competence through the acquisition of biotechnology firms or, in some cases through mergers. Another strategy was to engage in external linkages with biotechnology companies. As Cullen and Dibner (1993) document, strategic alliance between biotechnology firms and established enterprises exploded in the mid-1980s.

The third phase, which started around a decade ago involves the commercialization of biotechnology products. The first successful biotechnology products reached the market in the early 1990s. As Juergen Drews, head of R&D at Hoffman LaRoche observed in 1993, "While there are some redundancies among the 150 or so novel proteins in development, about 100 represent truly novel substances that have no precedent in medical therapy. Not all of these proteins will reach the market, but it is fair to assume that their attrition rate will be lower than that for small chemical entities because they should cause few unmanageable toxicological problems. A conservative estimate would expect 30-40 of the recombinant proteins now under development to become successfully marketed products over the next 5-6 years. This means that an average of 5-8 novel proteins should become available each year...If we assume an average sales volume for the forthcoming recombinant proteins equal to the average revenues generated by today's recombinant drugs, the portfolio of recombinant proteins now in clinical trials should amount to $10-$20 billion."

In this third phase, the large established companies take the new biotechnology products developed by biotechnology companies and convert them into large-scale marketed products. For example, Intron A was developed by Biogen but marketed by Schering-Plough, resulting in $572 million of sales in 1993. Humulin was developed by Genetech but marketed by Eli Lilly, for $560 million of sales in 1993. Engerix-B was developed by Genetech but marketed by SmithKline Beecham for $480 million. RecombiNAK HB was developed by Chiron but marketed by Merck for $245 million.

In addition, this third phase has experienced a shift by the established companies away from the broad learning strategies of phase two and increasingly towards a more focused approach, targeting specific technologies. For example, Ciba Geigy reduced its portfolio of interests in biopharmaceuticals in 1989 in order to focus more narrowly on the development of just several targeted products. Ciba Geigy subsequently increased its investment in those targeted areas and engaged in a number of research and licensing agreements with biotechnology companies. Similarly, Bayer reduced its biotechnology research in agro-chemicals while concentrating its focus on pharmaceuticals. Hoffman LaRoche similarly pulled out of agro-biotechnology to concentrate its focus on pharmaceuticals.

**Table 2: Characteristics of Filed Research Alliances**

Each column indicates the year and stage at the time the agreement was signed and the primary focus for a different set of agreements. The first column indicates the distribution of all alliances, licensing arrangements, and asset sales involving biotechnology companies between 1980 and 1995 filed with the U.S. Securities and Exchange Commission or state regulatory bodies who make such information public. The second column indicates the distribution of all such agreements summarized by Recombinant Capita. The final column characterizes the final sample of 200 technology alliances initiated between biotechnology and pharmaceutical companies or between biotechnology firms in the 1980-1995 period.

| | **All Filed Agreements** | **All Summarized Agreements** | **Final Sample** |
|---|---|---|---|
| Time Period: | | | |
| 1980-1987 | 20% | 11% | 14% |
| 1988-1990 | 18 | 21 | 21 |
| 1991-1992 | 26 | 26 | 34 |
| 1993-1995 | 36 | 42 | 31 |
| Stage of Product at Signing: | | | |
| Discovery/Lead Molecule | 65 | 57 | 64 |
| Pre-Clinical Development | 9 | 11 | 21 |
| Undergoing Regulatory Review | 17 | 23 | 15 |
| Approved for Sale[a] | 9 | 9 | 0 |
| Primary Focus of Agreement: | | | |
| Human Therapeutics | 75 | 83 | 92 |
| Human Diagnostics[b] | 18 | 15 | 4 |
| Agricultural or Veterinary Applications | 6 | 2 | 4 |

**Source:** Lerner and Tsai (2000)

[a]The sample is constructed to include only alliances with a research or a product development component. Thus, many of the agreements in the database involving approved products, which solely entail the marketing or sale of an existing product or process, are excluded from the sample.

[b]Many of the agreements involving human diagnostics entail the marketing or sale of an existing product or process developed by a biotechnology company in the course of a program to introduce a new therapeutic. (Because diagnostics tests are frequently of modest economic importance and viewed as tangential to the firm's product development focus, biotechnology firms often sell these outright to major firms specializing in this area.) Because these agreements are not alliances with a research or product development component, they are excluded from the sample.

Lerner and Merges (1998) use a novel data base identifying biotechnology research alliances complied by Recombinant Capital, a San Francisco-based consulting firms specializing since 1988 in tracking the biotechnology industry. As of December, 1998, Recombinant Capital had identified over 7,000 alliances between private biotechnology firms by examining SEC and state filings, the news media, and press releases (Lerner and Tsai, 2000). Lerner and Merges (1998) drew a random sample of 200 of the alliances to encode. Table 1 shows the distribution by time period, stage of product at signing, and the primary focus of the agreement. Table 3 provides a summary of the characteristics of the research alliances. It should be noted that most of the biotech alliances are arranged at a very early stage. Most of the alliances were signed prior to the beginning of clinical studies.

Another important point from Table 3 is that the biotechnology firms have only modest financial resources. On average, the biotech firm had around $10 million in revenue in the year prior to the alliance. However, given the mean expenditures of over $21 million, mostly on R&D, virtually all of the biotech firms were making losses. The loss corresponds to about one-third of the mean firm's shareholder equity and one-half of its cash and equivalents. The final point from Table 3 is that the strategic partners providing finance are typically much larger than the biotechnology companies, suggesting that the large pharmaceutical companies are providing finance, while the small biotechnology firms provide knowledge.

Lerner and Mergers(1988) use this sample of strategic research alliances between small biotechnology companies and large pharmaceutical companies to examine the determinants of the control rights in the alliances. The control rights consist of:

- management of clinical trials
- control of the initial manufacturing process
- control of manufacturing after product approval
- creation of exclusive territory for the biotechnology (small research) firm
- creation of co-marketing rights for the biotechnology (small research) firm.

The empirical evidence suggests that the assignment of control rights between the large pharmaceutical corporation and the small biotechnology company is done in a manner that maximizes innovative output. The exception involves those strategic alliances where the small biotech firm has few resources and little external financing is available.

**Table 3: Characteristics of the Biotechnology Research Alliances**

The sample consists of 200 technology alliances initiated between biotechnology and pharmaceutical companies or between biotechnology firms in the 1980-1995 period. The table summarizes the financial market conditions around the time of the alliance and the characteristics of the firms in the alliance and the alliance itself. The stage of product, focus or alliance, and characteristics of pair of firms in alliance measures are all dummy variable. The financial condition and alliance payment variables are expressed in millions of 1995 dollars. The date variable is expressed as a decimal (e.g., July 1, 1995 is coded as 1995.5).

| *Variable* | **Mean** | **Median** | **Standard Deviation** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|
| Stage of Lead Product at Time of Alliance | | | | | |
| Discovery/Lead Molecule | 0.64 | | | 0 | 1 |
| Pre-Clinical Development | 0.21 | | | 0 | 1 |
| Undergoing Regulatory Review | 0.15 | | | 0 | 1 |
| Focus of Alliance: | | | | | |
| Human Therapeutics | 0.92 | | | 0 | 1 |
| Human Diagnostics | 0.04 | | | 0 | 1 |
| Agricultural or Veterinary Applications | 0.04 | | | 0 | 1 |
| Condition of Financing Firm: | | | | | |
| Revenues in Prior Year | 8912 | 5218 | 18649 | 1 | 179601 |
| R&D Expenditures in Prior Year | 588 | 457 | 499 | 2 | 1958 |
| Net Income in Prior Year | 645 | 473 | 623 | -457 | 2232 |
| Cash Flow from Operations in Prior Year | 970 | 668 | 943 | -448 | 5234 |
| Cash and Equivalents at End of Prior Year | 1048 | 644 | 1066 | 1 | 4938 |
| Total Assets at End of Prior Year | 7765 | 5716 | 8210 | 1 | 53632 |
| Shareholders' Equity at End of Prior Year | 3738 | 2851 | 3569 | 0 | 17505 |
| Condition of R&D Firm: | | | | | |
| Revenues in Prior Year | 11 | 0 | 80 | 0 | 1029 |
| R&D Expenditures in Prior Year | 9 | 5 | 16 | 0 | 171 |
| Net Income in Prior Year | -6 | -5 | 14 | -65 | 134 |
| Cash Flow from Operations in Prior Year | -5 | -5 | 18 | -62 | 171 |
| Cash and Equivalents at End of Prior Year | 16 | 8 | 26 | 0 | 229 |
| Total Assets at End of Prior Year | 36 | 14 | 111 | 0 | 1079 |
| Shareholders' Equity at End of Prior Year | 25 | 11 | 68 | -17 | 665 |
| Age of R&D Firm | 5 | 4 | 3 | 0 | 36 |
| Characteristics of the Alliance: | | | | | |
| Date of Alliance | Jun 1991 | Dec 1991 | 3.1 Years | Jan. 1980 | Dec. 1995 |
| Minimum Length of R&D Alliance (years) | 3.79 | 3.00 | 2.65 | 0.75 | 31.00 |
| Total Pre-Commercialization Payments | 29.01 | 21.42 | 28.94 | 0.19 | 216.28 |
| Payment at the Time of Signing | 1.76 | 0.51 | 3.02 | 0.00 | 12.00 |
| Previous Alliance Between Firms | 0.06 | | | 0 | 1 |
| Control Rights Given to R&D Firm (out of 25) | 9.22 | 9 | 2.68 | 0 | 16 |

**Source:** Lerner and Tsai (2000)

In a subsequent paper, Lerner and Tsai (2000) use the same data set to address two additional questions, (1) Whether success rates differ in agreements that are (i) signed in periods with little external equity financing availability and (ii) cede the bulk of the control to the financing firm; and (2) Whether the less attractive agreements are renegotiated. They find that contracts for strategic research alliances that are signed at times when biotechnology firms are raising little external financing and that assign the most control rights to the large corporation perform significantly worse. These agreements are also more likely to be renegotiated if financial market conditions improve.

Audretsch and Stephan (1995) document the strong research partnerships that exist among universities and biotech firms. These partnerships are crucial because biotechnology companies are strongly defined by their scientists. Many of these scientists, particularly senior scientists with strong reputations, do not work for the biotechnology company full time, but instead are members of university faculties.

For example, Audretsch and Stephan (1999) show that, of 101 founders of new biotechnology firms in the early 1990s, nearly half (50) are from universities. Of these fifty, 35 remain associated with their universities on a part-time basis, while the remaining 15 founders left the university to work full-time for their biotech firm.

These university-based scientists fulfill a variety of roles within biotechnology companies. Some are founders, others serve as members of scientific advisory boards (SAB's), while still others serve as directors. The degree of knowledge provided by university-based scientists varies according to the role played by the scientist. Scientific founders seek out venture capitalists in order to transform technical knowledge into economic knowledge. Scientific advisors provide links between scientific founders and other researchers doing work in the area. They, along with founders, also provide the possibility of outsourcing research into university laboratories staffed by graduate students and post-docs. The concept of scientific advisory boards also provides the firm the option of having, at minimal cost, a full roster of the key players doing research in the firm's area of expertise.

In addition to providing knowledge to newly formed biotechnology companies, university-based scientists also provide a signal of firm quality to the scientific and financial communities. An effective way to recruit young scientists is to have a scientific advisory board composed of the leading scientists in the field. George B. Rathman, president and Chief Executive Officer of Amgen, attributes much of the company's success to an SAB of "great credibility" whose "members were willing to share the task of interviewing the candidates for scientific positions." Rathman goes on to say that the young scientists that Amgen recruited would not have come "without the knowledge that an outstanding scientific advisory board too Amgen seriously" (Burrill, 1987, p. 77).

Certain roles, such as being a founder of a biotechnology firm, are more likely to dictate geographic proximity between the firm and the scientist than are other roles that scientists play. This is because the transmission of the knowledge specific to the scientist and firm dictates geographic proximity. Presumably scientists start new biotechnology companies because their knowledge is not transferable to other firms for the expected economic value of that knowledge. If this were not the case there would be no incentive to start a new and independent company. Because the firm is knowledge-based, the cost of transferring that knowledge will tend to be the lowest when the firm is located close to the university where the new knowledge is being produced. In addition, the cost of monitoring the firm will tend to be minimized if the new biotechnology startup is located close to the founder.

By contrast, the role of scientific advisor to a biotechnology company does not require constant monitoring or even necessarily specialized knowledge. Thus, the inputs of scientific advisors are less likely to be geographically constrained. Furthermore, geographic proximity of all major researchers in a particular scientific field is unlikely given the opportunity cost that universities face in buying into a single research agenda. Thus, if firms are to have access to the technical knowledge embodied in the top scientists in a field, they will be forced to establish links with researchers outside of their geographic area. Scientists whose primary function is to signal quality are also less likely to bet local than are scientists who provide essential knowledge to the firm. Their quality signal is produced by lending prestige to a venture they have presumably reviewed—a task that can be accomplished with credibility from a distance.

To identify the links between knowledge sources, the incentives confronting individual scientists, and where the knowledge is commercialized, Audretsch and Stephan (1996) rely upon a data base collected from the prospectuses of biotechnology companies that prepared an initial public offering (IPO) in the United States between March 1990 and November 1992. This includes a total of 54 firms affiliated with 445 university-based scientists were identified during this time period. By carefully reading the prospectuses, it was possible to identify the names of university-based scientists affiliated with each firm, the role that each scientist plays in the firm, and the name and location of their home institutions. Universities and firms were then grouped into regions, which are generally larger than a single city but considerably smaller than a state. Certain areas, for example, metropolitan New York, cross several state lines.

Only 138 of the 445 links observed between scientists and biotechnology companies are local in that the scientist and firm are located in the same region. This suggests that geographic proximity does not play an important role for links between biotechnology companies and scientists in general. However, the geographic link between the scientist and the founder is influenced by the particular role played by the scientist in working with the firm. Most strikingly, 57.8 percent of the scientist-firm links were local when the scientist was a founder of the firm; 42.1 percent were non-local. By contrast, when the scientist served as a member on the SAB, only 31.8 percent of the links were local, while 68.2 percent were non-local. This disparity suggests that the nature of the knowledge transmitted between the university and the biotechnology firm may be different between scientists serving as founders and those serving on a SAB. Presumably it is the difference in the nature and quality of the knowledge being transferred from the university to the company that dictates a higher propensity for local proximity in the case of the founders, but not for SAB members.

## VI. Conclusions

If strategic research partnerships are important to large corporations, they are even more important to small firms. This is because that a small enterprise is more likely than its larger counterpart to be lacking a key component involving control, capabilities and context. As a consequence, small firms may be more dependent upon strategic research partnerships as a mechanism to compensate for size-inherent competitive disadvantages.

Unfortunately, if measurement of strategic research partnerships is challenging for large corporations, it is even more of a problem for small firms. Just as small firms are a more heterogeneous population than large corporations, strategic research partnerships may take on more heterogeneous forms with small firms than with their larger counterparts. Very little comprehensive and systematic empirical evidence exists about the role that strategic research partnerships play for small firms. Just as scholars were slow to measure the innovative activity of small firms, they have been equally slow to measure and analyze the role that strategic research partnerships play for small firms.

While formal agreements clearly play a role in biotechnology, this may be less true in other industries. A virtue of the Recombinant Capital data base is the objectivity in measurement – strategic research alliances are measured externally and reflect contractual agreements. Of course, a cost of that objectivity is the omission of informal research alliances. Just as informal R&D is more important for small firms than for large corporations (Kleinknecht, 1987; Roper, 1999), informal research partnerships may also be of greater significance for small enterprises. These informal research partnerships clearly involve scientists from different firms and institutions working together, scientist mobility, as well as informal linkages among firms. This might suggest that developing subjective measures using surveys may be invaluable in order to more systematically identify (1) the extent of strategic research partnerships in small firms, (2) their determinants, and (3) their impact on economic performance.

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# Strategic Research Alliances and 360 Degree Bibliometric Indicators

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## I. Introduction

To some, scientific research produces discoveries and information which can be codified into documents that circulate easily around the world. Such information then helps guide applied research. Others emphasize that research depends upon and generates an interwoven stream of heterogeneous assemblages comprising codified knowledge in papers, but also embodied skills and craft knowledge, know-how, laboratory techniques, biological substances, materials, software and equipment. The resources are varied in nature and interlinked in complex ways making them hard to separate. They also emerge and evolve continuously. Except for information contained in papers, these resources are not freely available (Hilgartner, 1994). When the localized resources do move, traditionally they have been exchanged in relationships that fall outside markets or organizations (Collins, 1982). These relationships constitute a network form of organization. Callon argues that the most important result of research is to produce new heterogeneous networks, such as those formed by the relationships between researchers exchanging their resources (Callon, 1995).

This suggests that to understand the science and technology relationship, we need to know more about the networks through which embodied skills and tacit knowledge, materials and substances are exchanged. The networks organizing knowledge exchange facilitate innovation and fall outside markets or firms. Freeman argues that external sources of information accessed by firm personnel through networking have long been found to be important for successful innovation. There is a paucity of evidence because networks are mostly informal and so extremely difficult to trace and to analyze (Freeman, 1991). Although informal, the OECD considers them extremely important for diffusing the non-codified components of knowledge (OECD, 1996).

Even when networking relationships are strengthened into research partnerships, a great many remain informal, with no systematic way to track these partnerships or study them in detail (Hagedoorn et al., 2000). For those that reach the formalized stage, strategic alliance databases such as those maintained by Hagedoorn, Link and Vonortas have been developed into an excellent tracking tool. We argue here that bibliometric indicators, particularly in combination, may provide another method of tracking networks of innovation, one which gets closer than the strategic alliance databases to the informal networks and partnerships that are otherwise so difficult to trace.

## II. Co-assigned Patents

It seems logical to surmise that formal R&D alliances if they are to produce anything of substance, should produce some jointly owned patents. Therefore we began our search for alliance-bibliometric relationships with co-assigned patents. We have nothing to build upon because co-assigned patents apparently have not been studied previously. Here, we can only make a small contribution to filling this vacuum.

The singular characteristic of coassigned patents is that they are so rare, which probably accounts for our ignoring them. Companies seem to have a positive aversion to sharing their intellectual property, although some may be moving beyond this as Figure 1 illustrates. Figure 1 displays the share of US invented US patents coassigned. For this count, individual inventor patents were removed and parent-subsidiary joint patenting was removed for the largest patenting companies. Domestic coassigned patents accounted for about 0.2% of US invented patents owned by companies and universities in the early 1980s. Beginning in 1984 this percentage began to climb and reached 1.4% by 1998/99. In absolute terms the number of coassigned patents increased from about 50 in the early 1980's to 875 in 1998/99.[1]

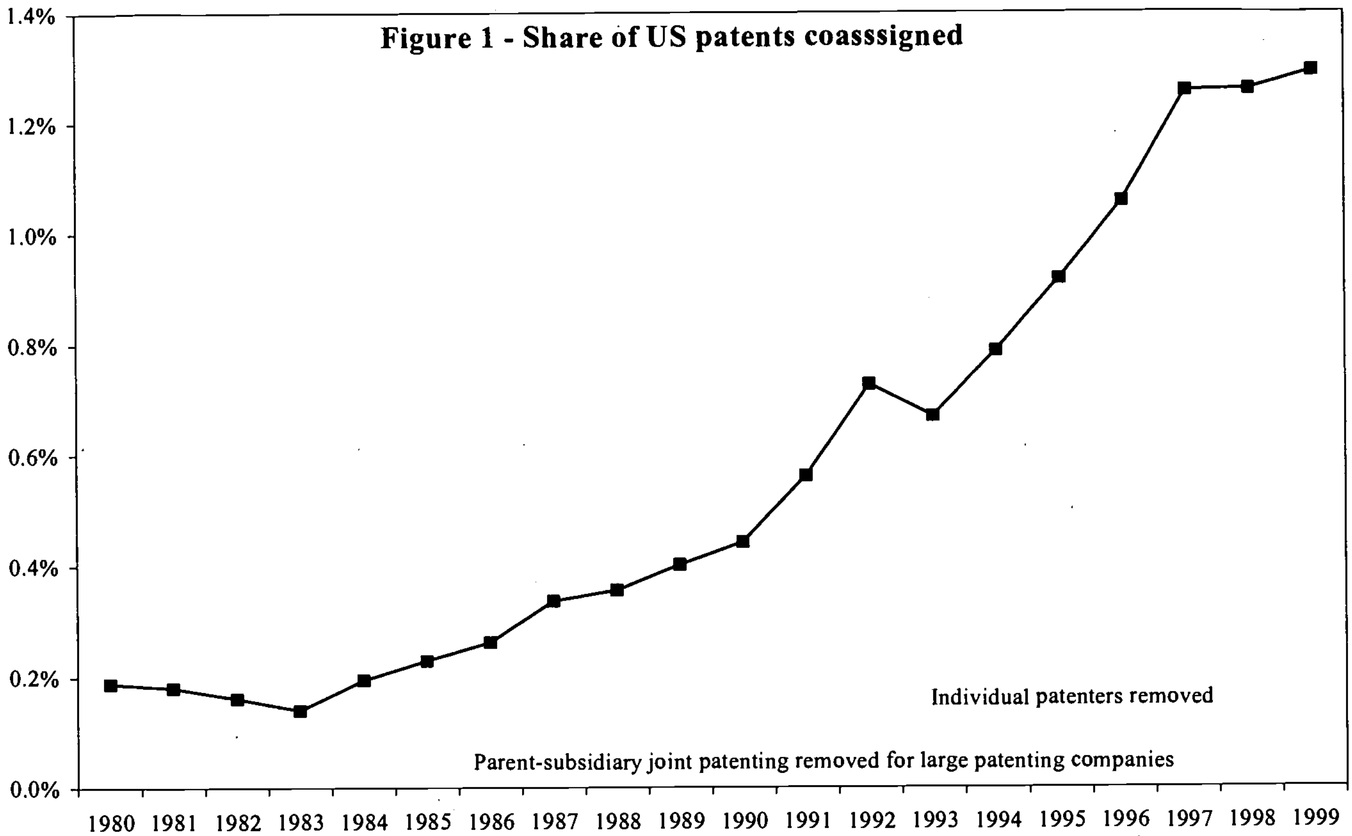
It is hard to believe that so few patents could be economically significant, but we should be cautious in drawing this conclusion. Since the value of patents is so unevenly distributed, with many worthless patents and a few of high value, if joint patents were of extremely high value, they might well carry an economic weight belied by their numbers. Logically, very high value inventions might be more likely to be jointly patented as the high value of the invention might help companies overcome their natural aversion to joint intellectual property ownership. A check on the citation characteristics of the patents suggests that joint patents are in fact not more valuable than other patents. CHI defines the CII or "current impact index" as the number of times the previous five years of patents are cited in the current year, relative to all patents in the U.S. patent system. A value of 1.0 represents average citation frequency; a value of 2.0 represents twice average citation frequency; and 0.25 represents 25% of average citation frequency. The Current Impact Index for the coassigned patents is 1.16 compared with 1.19 for all US invented patents assigned to companies or universities suggesting that coassigned patents are no different in impact from patents in general.

The rate of coassignment varies across technologies. In chemicals, for example, almost no patents are coassigned (0.08%), while in biotechnology about 7% are coassigned. The growth in coassignment is also uneven. In some areas, coassignment has taken off; in others, the rate has not changed in 20 years. In 1980, excluding biotechnology which always had a higher rate of coassignment, the maximum share of patents coassigned in any one of CHI's 30 technology classification was 1.43% and the minimum was 0. By 1999, the maximum had risen to 7.1% while the minimum remained at 0%.

Figure 2 illustrates these differences between technologies, plotting the share of patents coassigned in 1999 against the right-hand axis using the line and the public-private composition of coassigned patents against the left hand axis using the bars. Technologies with a high rate of coassignment on the figure are also those in which coassignment has grown since 1980. In health technologies,[2] the public sector (universities and government laboratories) are involved in a high percentage of coassigned patents and the growth in coassignment may be driven by the growth in university patenting.

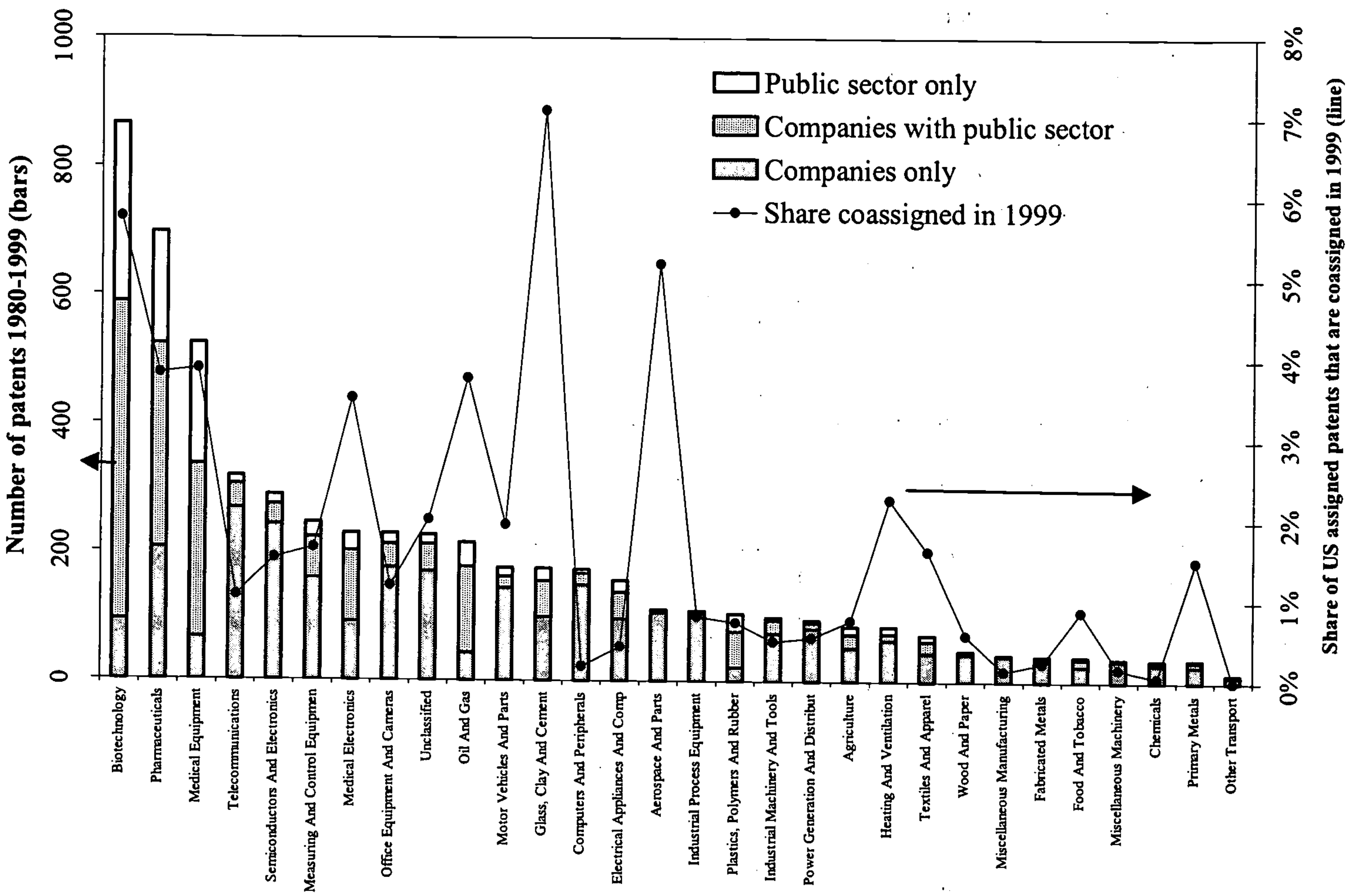
[1] Foreign coassigned patents are more numerous. Hagedoorn has investigated this more closely and finds that this is accounted for by intra-keiretsu joint patenting by Japanese companies (Hagedoorn, private communication).

[2] Health technologies are: biotechnology, pharmaceuticals, medical equipment and medical electronics.




Source: CHI Research, Inc.

**Figure 2 - Share of patents coassigned and types of coassignees**




Source: CHI Research Inc.

The figure suggests areas for further investigation. What accounts for the huge difference in coassignment between pharmaceuticals and chemicals? What has happened in glass, clay and cement and in aerospace to make co-patenting so attractive? The figure also suggests that biotechnology, whose coassignment rate was always high, is unusual only in that public sector institutions patent heavily in this area, and as they do with their papers, they are much more willing to share ownership of their patents than are companies.

## III. 360 Degree Bibliometric Indicators

In addressing the question of the relationship between strategic alliances and bibliometric data, we broadened the remit beyond joint patents, indeed beyond patent data to include eight of the ten possible paper and patent linkage dimensions. We pursued this question through a case study of a successful biotechnology firm—Chiron. This case study was undertaken as part of a collaboration with Woody Powell of Stanford University who has supplied information on strategic alliances.

Constructing this analysis was an intricate and time consuming task, as three databases had to be cleaned and aligned: alliances, the CHI's Science Literature Indicators database of papers and citations constructed for NSF using the *Science Citation Index* and CHI's patent indicators database. Eight bibliometric dimensions of citation and collaborative production were examined. We will use the term "linkage" to refer collectively to the set of relationships we are working with namely: co-authorship, co-patenting, referencing and citation[3]. The analysis amounts to examining the science and technology network from the perspective of Chiron. In essence we ask which institutions produced the papers and patents referenced by or citing to Chiron papers and patents, and which institutions co-authored papers or co-patented with Chiron. Details of methodology are described in Appendix A.

The eight dimensions of science & technology linkage information are easy to mix up, so in an effort to keep things straight, the notation in Table 1 will be used to label them.

**Table 1 – Explanation of Notation Used to Describe Bibliometric Relationships**

| Notation | Meaning |
|---|---|
| pub | SCI indexed papers, publications |
| pat | US patents |
| → | citation relationship, arrow points from the referencing to the cited document |

The eight dimensions are:

*Chiron publication links*

1) Co-authored papers (research links): The first dimension examines the institutions that co-authored paper with Chiron.

[3] Following Wouters, we will distinguish references from citations. References are "outgoing" and citations are "incoming." That is, references are in lists at the end of scientific papers, and citations are found in the *Science Citation Index* indexed under the receiving paper. The contents of references are bibliographic descriptions of the receiving papers, and the contents of citations are abbreviated bibliographic descriptions of the papers giving the citation.

2) Chiron pubs → pubs (research links): The second dimension examines institutions listed on papers referenced by Chiron authors. This is a relatively neglected dimension in bibliometrics.
3) pubs → Chiron pubs (research links): The third dimension examines institutions whose papers cite Chiron papers. This is the evaluative dimension in which citations are most often counted to assess the impact of an institution on a field.
4) pat → Chiron pubs (science-technology linkage): The fourth dimension examines institutional assignees on patents that reference Chiron papers.

*Chiron patent links*

5) Chiron pats → pubs (science-technology linkage): The fifth dimension examines institutions producing papers cited in patents assigned to Chiron.
6) Chiron pats → pats (technology links): The sixth dimension examines institutional assignees on patents referenced by Chiron patents.
7) pats → Chiron pats (technology links): The seventh dimension examines institutional assignees on patents citing Chiron patents.
8) Co-invented patents (technology links).

The result of the analysis is a table of institutions linked to Chiron in one or more dimensions—see Figure 3. The linkage data is reported as ranks in each dimension; these are obtained by sorting the institutions descending by number of links in the dimension and then assigning ranks. The list is ordered first descending by number of dimensions in which an institution is linked to Chiron and then ascending by the sum of the ranks across dimensions. In addition to linkage information, the table lists the number of life science papers from the institution and the number of patents to facilitate a normalized perspective on the strength of linkage. For example, Creative Biomolecules is very highly ranked, and the publication and patent data reveal how small the organization is compared to other highly ranked organizations.

## IV. Alliances and the Bibliometric Dimensions

Is there a correlation between formal R&D alliances and the bibliometric dimensions? Logically, we might expect to find a relationship, particularly between R&D alliances and joint patenting. The joint development of intellectual property that presumably occurs in an R&D alliance should result in joint ownership. However, research forthcoming from Hagedoorn demonstrates the opposite, namely that joint patents and R&D alliances are uncorrelated. In our case study we ran a similar exploratory analysis on Chiron's data. Taking organizations that have at least one paper link, one patent link and one R&D alliance, and controlling for publishing and patenting size, we find no correlation between R&D alliances and any bibliometric dimension. This means that none of the bibliometric dimensions can be used to predict the number of alliances Chiron has with an organization.

## Figure 3: Chiron 360 Degree Bibliometric Linkage Analysis

| Institution | Life pubs 1986-97 | Patents 1988-99 | Rank of institution when list is ordered descending by number of links | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Alliance-years | R&D Alliances | Chiron pub coauthors | Chiron pubs → pubs | Pub → Chiron pubs | Chiron pats → pubs | Pats → Chiron pubs | Chiron pats → pats | pats → Chiron pats | Chiron co-patenters | # pub & pat & alliances | sum pub & pat & alliances |
| University of California | 117,394 | 3,008 | 4 | | | | | | | | 0.5 | | 0 | 4.5 |
| New York University | 11,186 | 299 | 6.5 | | 8 | 3 | 4 | 5 | 2 | 4 | 13.5 | 1.5 | | 57.5 |
| Stanford University | 18,398 | 893 | 1.5 | | | | 0 | 9 | 2 | 10 | 13.5 | .5 | | 05.5 |
| CREATIVE BIOMOLECULES, INC. | 103 | 104 | 6.5 | | 8.5 | 46 | 14.5 | 3 | 13.5 | 0.5 | 13.5 | .5 | | 90.5 |
| US Dept Health & Human Service | 72,513 | 1,438 | .5 | | | | | | | | | .5 | | 6 |
| Roche Holding Ltd | 6,823 | 5,263 | 0 | 7 | | | | 2 | | | | | | 8 |
| University of Texas | 41,746 | 1,244 | 1.5 | 3 | | 4 | | 3 | .5 | 5 | 2.5 | | | 64.5 |
| Pharmacia & Upjohn | 4,840 | 3,164 | 5 | 9 | 8.5 | 9.5 | 3 | 8 | 1.5 | | 0.5 | | | 90 |
| Abbott Laboratories | 2,453 | 2,444 | 1 | | 4.5 | 1 | 6 | 6 | .5 | 6 | 2.5 | | | 93.5 |
| American Home Products Corp | 1,860 | 3,838 | | | 37 | 7.5 | 5.5 | | 3 | | | .5 | | 97.5 |
| Bristol-Myers Squibb Co | 3,627 | 3,228 | 5.5 | | 7.5 | 8 | 4 | | | 6 | 8.5 | | | 31.5 |
| Amgen Inc. | 1,383 | 367 | | | 16 | 5.5 | 6.5 | 4 | 5.5 | 5 | 6.5 | | | 35 |
| Merck & Co Inc | 4,360 | 3,976 | | | 37 | 5 | 2 | 5 | 4 | 9.5 | 7.5 | | | 49 |
| Aventis S.A. | 637 | 17,235 | .5 | | | 08 | 61 | 6.5 | 7 | | | .5 | | 11.5 |
| Novartis AG | 1,929 | 7,690 | | | 9 | 35 | 51.5 | 4 | 7 | 6 | | | | 71.5 |
| Novo Nordisk A/S | 268 | 1,686 | 5 | 4 | | 51 | 13.5 | 5.5 | 9.5 | 0.5 | | 1.5 | | 95.5 |
| Johnson & Johnson | 813 | 5,289 | | | 5 | 42 | 49.5 | 08 | 0 | 4 | 0.5 | | | 30 |
| E I DuPont de Nemours & Co | 2,896 | 9,951 | 1.5 | | 48.5 | 9 | 11 | 1.5 | 0.5 | 4 | 5.5 | | | 31.5 |
| University of Maryland | 14,102 | 251 | | | 8.5 | 3 | 8 | 4.5 | 58.5 | 30.5 | 07.5 | 0 | | 10.5 |
| Eastman Kodak Co | 550 | 14,763 | | | 8.5 | 32 | 51.5 | 43 | 56 | 2.5 | 5 | 1.5 | | 070 |

**Source**: CHI Research, Inc.

However, there is another question that can be asked, namely: of the organizations working in similar scientific and technical areas, is Chiron more likely to conclude an alliance with an organization with whom it has a joint patent or vice versa—is Chiron more likely to patent jointly with an organization with whom it has an alliance? To answer this question we must first identify the pool of organizations similar enough to Chiron that an alliance or a joint patent would not be out of the question. Our criterion here is that the organizations have a link to Chiron in two of the three databases used: alliance, patent or paper. There are 260 organizations that meet this criterion; these are our "pool." Even within this pool, joint patents and alliances are both rare events. Chiron has R&D alliances with 17 of these organizations and joint patents with 16. If alliances and joint patents were created randomly within this pool, the probability of a company having both an R&D alliance and a joint patent with Chiron would be: 16/260 * 17/260 = 0.004. The number of companies we might expect to see with both an R&D alliance and a joint patent would then be: 0.004 * 260 = 1.05. Instead there are six organizations with whom Chiron both patents and has R&D alliances. This suggests that Chiron chooses alliance partners preferentially from among those with whom it has joint patents or vice versa, that Chiron co-patents preferentially with those with whom it has an alliance. The relationship is not all that strong; after all, in the majority of cases alliance and joint patent partners differ.

Conducting the same analysis on the other bibliometric dimensions suggests no relationship to alliances in most cases as the number of overlapping organizations is equal to the number expected by chance. The one possible exception is organizations whose patents are cited by Chiron patents for whom we expect 8 overlapping organizations and find 12, or 1.5 times more than expected.

The possibility of some relationship between R&D alliances and joint patenting is intriguing. Previous work investigating Du Pont's joint patenting and other bibliometric indicators found that coassignees were not predictable using factors such as geography or industry which influence citation and coauthorship (Hicks, 2000). This made it seem more likely that behind each joint patent is a unique and substantive story of companies coming to share technology in spite of their natural distaste for doing so.

The lack of correlation between alliances and Chiron's bibliometric dimensions creates some obvious anomalies. Examining all alliances (not just R&D) we find that Chiron's top alliance partner is Johnson & Johnson with whom Chiron has joint ventures, marketing agreements, finance agreements and more complex arrangements. Apparently this relationship is all about marketing and not about technology because although Johnson & Johnson appears in many bibliometric dimensions, its rank is quite low. In contrast, Chiron has no agreements with American Home Products, arguably the company with which its technology appears most interdependent.

Although there may be some overlap between alliances and joint patenting, it seems prudent to consider what the bibliometric dimensions might be tracking other than strategic R&D alliances and whether they might be used as indicators that complement formal strategic alliances in enhancing our understanding of firm's scientific and technological networking.

**V. Coauthorship**

We begin with coauthorship because here the clearest link to informal networking can be made. We maintain that co-authored papers tell us something about how knowledge moves. The movement of scientific and technical knowledge, particularly between universities and companies, is often called "technology transfer." Cohen et al. surveyed 511 university-industry research centers in the United States asking how effective were various technology transfer mechanisms. They conclude that:

> the most highly ranked technology transfer mechanisms include collaborative R&D, having industry personnel work within the UIRC, delivery of prototypes or designs, having UIRC personnel work in industry labs, and informal meetings between industry and university personnel. The respondents indicated that the traditional ways of transferring academic findings, namely research papers and technical reports and seminars were not as effective as these other mechanisms, and roughly as effective as telephone conversations (Cohen et al., 1994 p. 25).

Because papers are not effective in transferring technology, and this is often reported in the literature, papers can be seen as irrelevant to moving knowledge. However, using papers to study the patterns of knowledge distribution does not require that papers effectively convey knowledge. It would be enough if processes that transferred knowledge also tended to produce a paper. Then the papers would be signals of the underlying process and indicators of knowledge transfer could be developed using them. We argue that co-authored papers indicate links between firms and public sector research that effectively transfer technology. Indeed, of the five most effective mechanisms of transferring technology listed by Cohen et al., three are likely to produce co-authored papers: collaborative R&D, secondment to the university or secondment to the company.

Co-authored papers can be produced by other types network relationships through which science and technology can be linked. For example, a paper listing two addresses can result from a single author holding a joint appointment, indicating a substantive link between two institutions through which knowledge and expertise can be exchanged. Co-authored papers can result from students hired as they finish their PhD degrees (who list both their previous and current addresses when publishing their PhD research), indicating one of the most important mechanisms through which knowledge is diffused in the economy.

Of course, to expect a one-to-one matching between every informal relationship and a co-authored paper is unrealistic (Katz & Martin, 1996). In addition, collaborative relationships can be maintained over many years, but papers may appear in the SCI only once or twice; so the duration of a relationship is less reliably indicated by papers than its existence. Nevertheless, a set of co-authored papers can be used to construct indicators providing unique information. There is no other way to obtain a quantitative, longitudinal overview of informal linkages across all types of research-producing organizations.

Zucker and Darby have studied biotechnology in the US; they quote a manager as saying: "Copublishing is about as good an indicator as you can get of commonality of interests between [the company] and an academic collaborator. Although formal relationships are on a publicly available list, many relationships are not publicly acknowledged." They continue: "In this and other fieldwork we have repeatedly validated the usefulness of linking academic scientists to firms by bibliometric research on patterns of co-publication. ... this concept of linkage is powerfully predictive of firm success when academic star scientists are involved." (Zucker & Darby, 1995, p. 22).

Given the paucity of studies using coassigned patents, we can only speculate that it is likely that they too reflect an informal yet substantive level of technological networking.

## VI. The Citation and Referencing Dimensions

The core of knowledge production is believed to rest in tacit knowledge, artifacts and the networks of communication through which these are developed and exchanged. Neither the objects nor the tacit knowledge in these chains can be communicated in a publication, so documents have often been dismissed as irrelevant to understanding the processes of research. Hope has been expressed that the links created through referencing might mirror the communications between authors of documents, but close study of referencing proved disappointing in this regard (Meyer, 2000; MacRoberts & MacRoberts, 1989). A way forward to interpreting the relationship between bibliometric indicators and networks of scientific and technical work has been provided by anthropologists.

Anthropologists of science have argued that the work of research connects heterogeneous elements. Latour and Woolgar pointed to the integration of informal communication with documents including the highly stylized scientific paper (Latour and Woolgar, 1989, p. 52-53). Hilgartner and Brandt-Rauf pointed to the chains of products from scientific work which brought together instrumentation, materials, craft skills, information, documents, informal communications and so on (Hilgartner and Brandt Rauf, 1994, p. 7). Because heterogeneous elements are integrated in these chains of products, a paper describing research points to other elements in the chain and so indicates that the authors possess certain tacit knowledge and materials. Papers carry signals about the areas in which researchers work, the craft skills they possess, the materials they use, their instrumentation and the quality of their work. Papers alert us to the existence of underlying tacit knowledge, skills, substances and so on possessed by the authors. Published papers thus point to unpublished resources. The same logic applies to the patent document.

Papers and patents also explicitly point to other papers and patents. The making of this link constitutes a suggestion that there may be some logical relationship between the resources underlying the linked documents. This hints that the documents' authors may have something to talk about; if they have actually communicated we would have a network type of link. Mowery, Oxley and Silverman (1998) found that alliances were more likely between firms with higher patent-to-patent citation interdependence. But this held only up to a certain point and that very highly interdependent firms did not form alliances (presumably because direct competitors often have very high patent citation overlap but direct competitors are unlikely to form alliances). If this result extends to the other dimensions, we may find that networks are more likely among those linked to some degree by referencing and citation than those not so linked or those highly linked.

Bibliometric documents and links have varying properties. Papers are research related; patents innovation related. Citations are incoming and references outgoing, suggesting a provide/use difference. Paper-paper links are scientific; patent-patent links technological, and paper-patent links join science and technology. The eight bibliometric dimensions exhibit the permutations of these properties which may enable a sensitive delineation of scientific and technological networks.

At this preliminary stage, we can only conclude that it might be possible to develop the 360 degree look at bibliometric citation dimensions into a tool to increase understanding of the networks of scientific and technological work. The referencing dimensions are a reflection of the somewhat unintentional and promiscuous linking processes of paper and patent referencing. The co-production dimensions reflect much more focussed, intentional, substantive investments of effort into joint work. None of the dimensions measures exactly same thing as formal alliances, suggesting that more informal processes underlie the bibliometric dimensions. In analogy with Von Hippel's concept of informal know-how trading, we might hypothesize that these processes of linkage are embedded in day-to-day knowledge work and yet are practically invisible at the strategic management level.

## VII. Summary

This has been a preliminary exploration of the relationship between R&D alliances and bibliometric indicators, with the emphasis on joint patenting. We have seen that joint patenting is very rare, though becoming more frequent. In the health technologies, public sector participation in patenting may explain the growth in joint patenting as universities and government laboratories carry over into patenting the collaborative instincts developed through publishing. Companies, on the other hand, seem to have a positive aversion to sharing intellectual property which they only rarely overcome, and it would be quite interesting to find out what prompts them to do so since it seems unlikely that a higher economic value to joint patenting is the motivation.

There may be some relationship between joint patenting and R&D alliances in the sense that partners for one are chosen preferentially from among those with whom the other relationship has been formed. Our dataset is however a small case study and only a much larger investigation could definitively establish this.

In general, the bibliometric indicators seem to track something slightly different from formal R&D alliances. We believe that they may track informal networking processes. The intentionally produced joint papers and patents should be the most direct indicators of this. Behind citations and references are the somewhat unintentional logical links made between organizations and so between the unpublishable resources underlying patents and papers. These may bear some relationship to potentials for networking.

None of the dimensions is likely to correlate with management's view of its networks in the same way as formal alliances do. Even the intentional dimensions of coauthorship and copatenting are probably intentional only on the part of the researchers involved and only dimly visible to upper management. We would argue that this is a strength of the bibliometric indicators, getting closer to the day-to-day work of research and development. Whether there is more substance in the formal alliances or in the bibliometric dimensions remains an open question.

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## Appendix A
## Methodological Details

The linkage data were constructed from the U.S. patent database and CHI's Science Literature Indicator's Database developed for NSF's *Science Indicators* and derived from the *Science Citation Index.* All patent data including cited patents and papers runs from 1988 to 1999. All paper data runs from 1986 to 1997. All counts are whole counts.

It was important to remove from the non-Chiron side of every citation relationship any document listing a Chiron address. This serves the obvious purpose of eliminating self-citations. It also eliminates a more subtle problem. Some of Chiron's self citations are co-authored/invented. If self-citations were not removed, institutions that, for example, co-authored with Chiron, would gain in the *Chiron pub → pub* counts from the self-cited publications. This is a form of double counting. In other words, institutions with a co-authoring relationship can seem to have an enhanced cited relationship because the cited relationship will be inflated by self-citations to the co-authored publications. With the co-authored papers removed from the other dimensions, the dimensions are truly independent.

The publishing and patenting figures come from different databases, which are in some ways incompatible at the moment. Most importantly, the paper database contains variant-unified institutional addresses for the largest publishing American institutions. The patent database contains variant-unified and parent-subsidiary unified institutional identifications for the largest 1,300 patenting international and American organizations in the U.S. patent system. A cross-database name unification was performed in which institutions were aggregated to make the institutional identifications identical with those in the patents. For example, universities patent under the name of the university system. So for example, University of California Berkeley and University of California Santa Barbara do not appear in the lists, but the University of California is by far the largest publishing institution followed US Dept. of Health and Human Services (under whose name NIH patents).

## Strategic Research Partnerships in Biotechnology

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> The drug industry, powered by the huge profits of the 1980s, had lately embraced the concept of 'strategic alliances.' Fervently in vogue, they were thought to solve a common problem: in a fractionated marketplace spanning countless diseases, an explosion in knowledge, and thousands of laboratories, no big company was big enough and no small one clever enough to go it alone.
>
> —Berry Werth, *The Billion Dollar Molecule*

### I. Introduction

Biotechnology is a sector where the growth of strategic research alliances has been truly dramatic with over 20,000 alliances formed and an annual average growth rate of 25% percent (Fisher 1996). Hagedoorn (1993) finds that biotech yields the most prolific rate of alliance formation of any sector. Until the early 1980s product development in drugs, chemicals and agriculture followed the classic in-house vertically integrated approach although academic research historically figured prominently in the initial stages of product development (Galambos 1995; Hounshell and Kenly Smith 1988; Swann 1985; Weatherall 1990). The advent of biotechnology, the commercial application of recombinant DNA and molecular genetics technology was a marked departure from the chemically-based expertise of the large firms and created the need for new collaborative research, joint ventures and new forms of cooperative. By its nature, biotech is a very knowledge-intensive industry and progress requires complementary assets that reside in different types of organizations.

There are basically three important actors in biotech research alliances, universities, small entrants and large incumbent firms. Universities and research institutes are the source of scientific knowledge and talent, potentially important breakthroughs and intellectual property and access to the large number of patients required to complete clinical trials. Universities have accepted a new mission of active technology transfer and biotechnology is important to that mission. New Biotech Firms (NBFs) are start-up firms that typically embody the commercial application of university knowledge. There are approximately 1400 NBFS in the US. They are typically small, specialized in the types of products and applications they pursue and in need of financing and expertise. Large established companies have experience in large-scale production, marketing and distribution. Most importantly, they have expertise relevant to navigating the regulatory process required to bring products to the market, and have the substantial resources necessary to complete the process.

Strategic research alliances are formed to bring these actors' complementary competencies together with the goals of advancing the technology and introducing commercial products to the market. Strategic research alliances in biotech cover every possible combination with NBFs partnering with larger firms, NBFs forming alliances between themselves, large established companies joining forces, alternatively both large and small firms partnering with universities, or three-way relationships involving the combination of large companies, NBFs and universities. This review provides an overview of strategic research partnerships in biotech, beginning by outlining the policy issues, then considering data and indicators used to study biotech alliances and concluding with a consideration of what types of data that might help inform the policy debate.

## II. Policy Issues

Strategic research alliances have many purposes and Hagedoorn (1993) concludes that biotech alliances encompass most or all of these motivations simultaneously. To the extent that strategic alliances in biotech represents a new system for commercializing science that may become a dominant model for other technically complex emerging sectors, understanding the motivations, incentives and barriers to the formation and operation of biotech strategic alliances informs restructuring towards this formation. We may ask if strategic research alliances are an efficient ways to organize resources for scientific advance. In addition, since public funding is so important in the life sciences we may seek to understand what is the role of the National Institutes of Health and other public entities and how the resulting rents that accrue to successful products are distributed.

NBFs are new entrants that serve as intermediate organizations between universities and large pharmaceutical firms. They typically form around licensees of university intellectual property and involve university researchers as either founders, members of the scientific advisory board, employees or consultants (Audretsch and Stephan 1996; Zucker, Darby and Armstrong 1998). While industry-university collaborations are often strained due to different objectives and time constraints, NBFs are able to license university technology and work with university researchers while being more attuned to commercial pressures (Bower 1992). Thus, NBFs may facilitate the commercialization of academic science and the realization of increased efficiencies. Of course, universities receive licensing fees, royalties and even equity from NBFs in exchange for their intellectual property, yet we do not have a good understanding of how these returns are distributed or if this is an efficient way to organize science and provide incentives for the generation and use of knowledge. We do not know how scientists' financial interest in companies may limit the flows of knowledge that are typically unrestricted from universities. Potentially profitable research findings may be kept confidential, remain unpublished, or be significantly delayed in order to secure proprietary rights.

The literature has documented the types of alliances that accompany biotech research. Table 1 provides an overview of academic studies with attention to the focus of the study and the data source. In general, studies focus on firms as the unit of analysis or focused on alliance agreements. While the academic literature has used existing and often proprietary databases, there is typically an emphasis on augmenting the data with data from other sources or conducting complementary case studies to add understanding to the results. Sixty-five percent of these studies used case studies.

The consensus is that firms form thick networks that involve multiple partners in a variety of alliances in order to move research forward. Studies have also either focused on alliance characteristics and the effects on participants or alternatively have looked at firm performance to assess how alliance participation affects firm outcomes such as initial public offerings and market valuation. Each of these deserves mention.

The literature generally accepts that alliances are beneficial for the participants. There appear to be great synergies between the research alliance participants that allow firms to take advantage of their competitive assets, prevent duplication of efforts and promote economic efficiencies. Specifically, NBFs gain much needed revenue and access to specialized resources. Large companies gain new products for their product development pipeline, which also helps them retain their attractiveness in the capital markets. Galambos and Sturchio (1998) find that large pharmaceutical firms are able to establish significant capabilities in new fields because of alliances with NBFs. Interestingly, Bower and Whittaker (1993) find that NBF partnerships may increase knowledge spillover potential by acting as a knowledge conduit indirectly connecting large companies.

Strategic research alliances provide pathways for knowledge spillovers; however, it is difficult to measure the benefits in terms of knowledge generation and refinement. Two important indicators are the rate of innovation and the rate of growth of the participants, measured by market valuation, revenue or employment. Evaluating the economic consequences of biotech strategic research partnerships is more difficult due to the short time frame these alliances have been in existence, the rapid changes in NBF ownership and the general volatility of the market. Some notable results include:

- Powell, Koput and Smith-Doerr (1996) find that companies, which formed alliances, experienced higher growth rates.
- Stuart, Hoang and Hybels (1999) find that strategic research alliances send a market signal that increases success of the firm's initial public offering. Alliances with well-known larger companies send an endorsement signal to the stock market.
- Zucker, Darby and Armstrong (1998) find that the number of publications in these bench-level working relationships predicted higher subsequent firm productivity in terms of products in development, products on the market and employment growth in the firm. Firms with access to leading edge scientists performed better than enterprises lacking such access.

Although the consensus in the literature is that alliances are mutually beneficial, some policy issues warrant discussion. First is the relative absence of research on alliances outside of human therapeutics and diagnostics. Most notably, research alliances in agricultural biotech appear to be different due to a market structure with fewer NBFs and greater market concentration. Second, there are concerns that NBFs may enter into partnerships due to a lack of capital—not because it is the most appropriate strategy. Third, strategic alliances that limit NBFs to be research boutiques may not be the best strategy for the long-term growth of knowledge in the industry. Fourth, there are growing concerns about the distribution of profits from research largely funded by taxpayers. Finally, we may question the degree to which the strategic research alliances in biotech represents a new model of commercializing university science that may extend to other emerging technology-intensive sectors.

Most research on biotech strategic alliances has focused on medical applications, in large part due to Wall Street investment interests, which in turn, influence the types of data that are readily availability. This focus ignores the importance of biotechnology to the other applications such as agricultural (see Kalaizandonakes and Bjornson 1997 for an exception). Biotechnology is already beginning to improve crop yields and to provide better pest control and new agricultural products, thus reducing farm input costs and benefiting the environment (Service 1998). Advances in agricultural biotechnology have potential to increase agricultural self-sufficiency and economic stability in developing countries. The United States currently leads the world agricultural biotechnology; however, other countries have aggressively moved into this application.

**Table 1: Literature Review**

| Author(s) | Unit of Analysis and Alliance Focus | Data Source |
|---|---|---|
| Arora and Gambardella (1990) | Large U.S. European and Japanese firms with other parties, particularly NBFs and universities | Primary data on the number of agreements for large pharmaceutical and chemical firms (n=81) |
| Barley, Freeman and Hybels (1993) | All organizations involved in biotech alliances | BioScan organizations (n=3056) |
| Audretsch and Stephan (1996) | University-based composition of Scientific Advisory Boards of NBFs | Primary collection of Initial Public Offering (IPO) information on NBFs |
| Baum, Calabrese and Silverman (2000) | NBFs alliances | Original data collection on the universe of 142 biotechnology firms founded in Canada from 1991 to 1996. |
| Bower and Whittaker (1993) | Research partnership of two large firms (Merck and Sandoz) with one NBF (Repligen) | Case study of the Merck-Repligen-Sandoz Network |
| Chang (1998) | Structure of R&D Intensive Firms | Case study of Chiron |
| Cockburn and Henderson (1998) | 20 largest pharmaceutical companies with public funded research | Author's compilation of development of 21 drugs; co-authorship of company researchers with university and public researchers using bibliographic citations |
| Deeds and Hill (1996) | NBFs in bio-pharmaceutical product development | BioScan (n=132 NBFs) |
| Deeds, DeCarolis and Coombs (1999) | NBFs in bio-pharmaceutical product development | BioScan (n=94 NBFs) augmented with publication records |
| Estades and Ramani (1998) | Network Structure of 20 NBFs | Case Study of twenty NBFs: ten each in Britain and France |
| Fildes (1990) | NBF collaborations with large firms and other NBFs | History of a biotechnology firm, Cetus (Fildes' company) |
| Freeman and Barley (1990) | Genentech's network of alliances | Detailed Case Study on Genentech |
| Hagedoorn and Schakenraad (1990) | Incidents of inter-firm cooperative agreements | MERIT-CATI |
| Kalaitzandonakes and Bjornson (1997) | All types of agreements in agro-biotech | Collected published data for 1600 collaborative agreements including joint ventures, mergers, acquisitions, licensing agreements and equity investments. |
| Kogut, Shan and Walker (1992) | NBFs agreements with large firms | BioScan (n=114 NBFs with cooperative agreements prior to 1989. |
| Lerner and Merges (1998) | Alliances between NBFs and pharmaceutical firms | Recombinant Capital database (n = 200 alliances) |

| Author(s) | Unit of Analysis and Alliance Focus | Data Source |
|---|---|---|
| Mang (1998) | NBFs in human therapeutics, diagnostics and vaccines | Original data collection on 81 collaborative projects involving 23 NBFs. |
| McMillan, Narin and Deeds (2000) | Publicly traded NBFs | IPO Prospectuses of 119 NBFs augmented with patent citations. |
| Peters, Groenewegen and Fiebelkorn (1998) | Projects between Public Research Institutes and Private Companies | European Community BRIDGE program joint project participation |
| Pisano (1990) | Development of R&D projects | 92 R&D projects of large pharmaceutical firms |
| Powell and Brantley (1992) | DBFs in Human Therapeutics and Diagnostics | 1990 Edition of BioScan firms (n=129) |
| Powell, Koput and Smith-Doerr (1996) | DBFs in Human Therapeutics and Diagnostics | Relational database constructed by augmenting BioScan with industry directories, and annual reports, interviews and other sources. (n=325) |
| Prevezer and Toker (1996) | Licensing, marketing, and research alliances for U.S. biotech firms | Institute for Biotechnology information database (U.S. companies to 1980) |
| Segers (1993) | New technology based firms in microelectronics and biotech in Belgium with large established firms | Case studies of two New Biotech Entities and five larger firms |
| Senker and Faulkner (1992) | Public Research Institutes and Private Companies | Seven case studies of collaboration |
| Shan, Walker, and Kogut (1994) | NBFs agreements with large firms | BioScan (n=114 NBFs with cooperative agreements prior to 1989. |
| Stuart, Hoang and Hybels (1999) | Young, venture capital-back firms specializing in human diagnostics and therapeutics. | Relational database constructed with Recombinant Capital, Micropatent Biotechnology Patent Abstracts and other published sources (n=301) |
| Zucker and Darby (1996) | World's top twenty drug-discovery firms | Alliances inferred from discovery of new biological entities, genetic sequence patents and c0-publishing. |
| Zucker and Darby (1997) | Large pharmaceutical company with universities and NBFs. | Case Study of one of the 5 largest U.S. pharmaceutical firms. Quantitative data on co-publishing. |
| Zucker, Darby and Armstrong (1998) | Universities and NBFs | Telephone census of California New Biotech Firms (NBFs). |

Agricultural biotech alliances appear to be different from the human drug and therapeutics market. First, there are relatively fewer NBFs relative to the size of the market. Most of the research alliances appear to involve large firms with universities. Second, the Institute for Biotechnology Information reports that the ag-sector has had a relatively large percentage of legal actions (18%) when compared to the pharmaceutical sector (6 %).

Greis, Dibner and Bean (1995) find that certain barriers to innovation, notably a lack of capital, motivate partnering arrangements among biotech start-ups. One policy concern is the degree to which small firms are forced into alliances due to a lack of capital, external funding opportunities or stock market volatility (Lunzer 1988). This may place the NBF in a disadvantaged bargaining position. Lerner and Merges (1998) find that the allocation of control rights in an alliance increased with the firm's financial resources; thus, financially weak firms may be relatively disadvantaged. As a point of reference, biotech alliances are a major source of revenue, generating $1.35 billion in 1997 for the top 100 NBFs ranked by number of agreements, for a compound annual growth rate of 33%.[1]

One important question raised by Pisano (1997) is that strategic alliances in which the NBF produces the idea and the larger firm undertakes scale-up or large scale production may not be the best long-run strategy due to the specific and specialized nature of the production processes. With an unproven new product, manufacturing process innovation may be critical for developing competence and long-term advantage. In contrast to strategic research partnerships that limit the scope of the NBF, the alternative strategy of becoming a fully integrated operation may be a source of commercially valuable knowledge. Gray and Parker (1997) find that the manufacturing of biotech products has occurred in geographic regions where the pharmaceutical industry has excess capacity—not near the centers where the technology was developed and where the knowledge to increase process productivity, improve product quality and augment the specialized knowledge base (Feldman and Ronzio forthcoming). Thus, strategic alliances may undermine the long-term growth potential of the biotech industry.

There are concerns that strategic alliances with universities allow drug companies to profit from research supported by taxpayers (Gerth and Stolberg 2000). Although the consensus among economists is that, the system of innovation is efficient and that private companies need profit incentives in order to develop commercial products from basic university knowledge (Nelson 1996), the allocation of the return from products developed from research that was publicly funded appears to be developing into a contentious public policy issue.

The most relevant question we may ask is if this model represents a new system for commercializing science that will become dominant for other technically complex emerging sectors. While strategic alliances have proven difficult to manage, their numbers and persistence indicates that the participants must achieve some gains and benefits. Yet, we still have a limited understanding of the most efficient governance structures, contractual terms and monitoring procedures. Increasingly the literature recognizes that the benefits of contracting and outsourcing depend on specific attributes of the technology and the inherent costs of forming and maintaining external partnerships (Hamilton, Vila and Dibner 1990, Pisano 1990, 1991, Greis, Dibner and Bean 1995; Mang 1998). When transaction costs are high, firms pursue in-house research rather than strategic alliances. Biotech start-ups' concerns about the loss of appropriability of intellectual property can limit the firm's willingness to participate in external partnerships (Zeckhauser 1996). Less is known about the contractual

[1] http://www.signalsmag.com/signalsmag.nsf/0/31D6FD00DF0E5D76882566A0007DC3DE

relationships that protect the intellectual property interests of the NBFs and universities, reduce moral hazard concerns and minimize transaction costs (Mayer and Nickerson 2000).

The next section considers publicly available data sources that have been used to investigate biotech strategic research alliances.

### III. Data and Indicators

The consensus from the literature is that firms that are active in biotech have multiple partnerships that cover the range of partnership types. Early studies of biotech alliances were based on case studies of a few companies. Work that is more recent has relied on one of three industry specific data sources: BioScan, Recombinant Capital's Biotech Alliance Database (ReCap), or the Institute for Biotechnology Information (IBI) or has used general alliance data such as MERIT-Cooperative Agreements and Technological Indicators (CATI) maintained by John Hagedoorn. Each of the industry databases will be described in turn. Hagedoorn, Link and Vonortas (2000) provide a description of the MERIT- (CATI) data as well as the U.S. CORE database.[2]

BioScan is perhaps the data source most used to investigate strategic research partnerships in the literature. The database is maintained by American Health Consultants and provides profiles of approximately 1,500 U.S. and foreign companies actively involved in biotechnology research and development. The profiles contain information on strategic alliances, mergers, product acquisitions, new products in development, licensing and R&D agreements, principal investors, financial information, and key personnel. Information available includes address, personnel, history, facilities, financial information, research interests and products in development. This proprietary data is primarily intended for purposes such as generating targeted mailing lists, locating business prospects and researching potential partners, and determining industry agreement details.[3]

Research using BioScan typically augments the data with other sources. For example, Powell, Koput and Smith-Doerr (1996) built an augmented database that filled in missing information from other industry directories, published company information and industry publications such as *Genetic Engineering News,* which tracks alliance announcements. Despite this diligence, Powell, Koput and Smith-Doerr (1996: 118), in an interview with the CEO of Centocor note that the response that the formal agreements were "the tip of the iceberg—it excludes dozens of handshake deals and informal collaborations, as well as probably hundreds of collaborations by our company's scientists with colleagues everywhere."

The Institute for Biotechnology Information (IBI) maintains a proprietary database of strategic activities, including alliances, related to the biotechnology industry. Prevezer and Toker (1996) provide an example of a study using this source. For the year 1996, IBI entered 1,368 actions into the database, ranging from marketing and licensing agreements between companies to regulatory approvals and public offerings of individual companies. IBI defines a biotechnology action in most

[2] To the author's knowledge the CORE data has not been used to investigate biotech alliances due to the difficulty of identifying biotech within the confines of the Standard Industrial Classification (SIC) code system.
[3] The website for Bioscan is http://www.ahcpub.com/ahc_root_html/products/newsletters/bsch.html. The cost of the data in either hard copy or digital form is $1395 for one year and includes six bi-monthly updates. Institutional memberships, which allow access by multiple users, are also available.

cases as an activity that involves an organization working with genetic engineering or other biotechnologies in their R&D or manufacturing activities. IBI notes the participants involved in the action as well as the type of technology and stage of development involved. Feldman and Ronzio (forthcoming) use this data to examine regional specialization in biotech product applications.

Perhaps the most promising existing publicly available database to investigate biotech research alliances is Recombinant Capital's Biotech Alliance Database (ReCap). The database focuses specifically on alliances and contains summaries of more than 7,900 alliances in biotech that have been formed since 1978. The material is gathered from the U.S. Securities and Exchange Commission (SEC) filings of biotechnology companies, as well as from press releases and other literature and company presentations made at investment conferences and other public meetings. The Alliance Database is principally concerned with alliances for which a biotechnology company partners with a major drug company (drug/biotech), with a university (university/biotech), or with another biotechnology company. In addition, the Database contains many, although by no means all, summaries of alliances of non-biotechnology alliances in the life sciences although there appears to be limited coverage on agricultural biotech. The Alliance Database is full-text indexed and searchable by company name. An example of the type of data that is available from the Alliance Database in provided in the Appendix. Lerner and Merges (1998) have analyzed these data.[4]

A related database maintained by the same company is rDNA.com. This is a very comprehensive proprietary database of alliances that offers an alliance summary (including deal press releases), the full text of the actual contract as filed with the SEC (for deals that have been filed) and contract analyses based on a synthesis of the terms of the alliance. This database would be useful for understanding the terms of the contract, the balance of power between the collaborators and ways in which agreement terms have evolved and adapted to market changes.

In order to understand biotech research alliances, researchers have used co-authorship bibliographic citations to discern the degree of collaboration (See, Cockburn and Henderson 1998). McMillan, Narin and Deeds (2000) use patent citations. The literature is developing rapidly. Our understanding of the policy issues may be facilitated with greater integration of the proprietary alliance databases with other sources of company and university data.

## IV. Developing New Indicators

Biotechnology strategic research partnerships represent new methods of conducting science and organizing innovation. In this new era, different types of public policy will become relevant. With new discoveries and development of products and processes moving rapidly, there is little room for error—a nation that waits before investing in the requisite infra-technology and infrastructure or that creates barriers to bringing these products to market will be left behind technologically, and in turn will be likely to face slower economic growth (Tassey, 2000). While the practice of strategic research partnerships began in the U.S., European firms have adopted this model and are aggressively pursuing it (Senker and Sharp 1997; Estades and Ramani 1998).

New indicators that would be developed to understand strategic research partnerships should be sensitive to what the questions and policy concerns are in biotech strategic alliances. Current publicly

[4] The company was started by one of Lerner's former students at the Harvard Business School.

available data, such as the CORE data maintained by Al Link from Federal Register announcements, does not contain information about the companies involved and the biotech sector does not fit well within the existing industrial classification scheme.

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**Strategic Research Partnerships:**
**Their Role, and Some Issues of Measuring Their Extent and Outcomes—**
**Experiences from Europe and Asia**

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## I. Introduction

Strategic Research Partnerships (SRPs), in the form of technology-based joint ventures, strategic alliances and multi-partner R&D projects, are an important feature in the generation and diffusion of technology and, by extension, industrial development. They are an important feature of the research environment and industry in most industrialized and industrializing nations. This paper examines some explanations for their formation, and some issues related to the measurement of the extent and the outcomes of SRPs.

The paper focuses particularly on East Asian and European experiences with SRPs. It argues that while there are some common motivations underlying the formation of SRPs internationally, there are broad national differences in the role they play. There is also varying capacity in government and research organizations to quantify and measure the contribution of SRPs.

As SRPs are created for a variety of purposes, and assume a range of different forms (differences that are accentuated when international comparisons are factored in) there are immense methodological problems in measuring their extent and contribution. The paper illustrates the wide range of indicators that can be used to examine specific features of SRPs. The types of analyses discussed include: science indicators and bibliometrics, international and national surveys, specific databases on alliances, network analysis and various forms of case study. There are shortcomings and deficiencies in these measures, and the value in them for policy-makers depends upon their imaginative combination in ways that address specific concerns.

In the following discussion it must be appreciated that there are major shortcomings in the collection of the various forms of information in most East Asian nations.[1]

## II. What are SRPs?

SRPs are understood here to essentially involve shared commitment of resources and risk by a number of partners to agreed complementary research aims. SRPs can occur 'vertically' throughout a value chain, from the provision of raw materials, through the design, production and assembly of parts, components and systems, to their distribution and servicing. 'Horizontal' SRPs, on the other hand, occur between partners at the same level in the value chain.

[1] This assertion is based on research visits to, and collection of available data from, Japan, India, Taiwan, Indonesia, China, Malaysia, Singapore, Vietnam, Philippines, Hong Kong, Brunei and Thailand.

SRPs between firms can take a variety of forms. They may be a joint venture, formed by two or more partners as a separate company with shared equity investments. They can be a partnership or 'strategic alliance' linking firms on the basis of continuing commitment to shared business or technological objectives without equity sharing. They may take the form of R&D contracts or technology exchange agreements whereby firms' shared objectives involve the interchange of research findings or technological know-how. Universities and public research laboratories are often partners in such R&D contracts. SRPs may take the form of 'innovation networks', combinations of firms and research organizations that share research agendas.

## III. Motivations for SRP Formation

There is a wide range of explanations for why firms and research institutes collaborate in their research activities. There are economic explanations (cost reduction and efficiencies), and those that consider the strategic competitive relationships between firms (standards creation, competitor exclusion or locking-in key players). Some address technological issues (the way the importance and role of SRPs change with the technology life-cycle), while other explanations are less instrumental and focus on qualitative issues such as organizational learning (see Dodgson, 1993a, for a discussion of these various approaches). Hagedoorn et al (2000) separate three traditions in theory that explain research partnerships: transaction costs, strategic management, and industrial organization. There is diversity within each tradition, so, for example, within the strategic management field it is possible to consider approaches that emphasize competitive forces, strategic networks, resource-based theories, dynamic capabilities and strategic options (Hagedoorn et al, 2000).

### A. Corporate perspective[2]

A firm- or institution-level perspective is required to analyze the motives for forming SRPs. In what follows a brief analysis is provided on why these partnerships are created from the perspective of the firm, where SRPs are seen as a means of improving technological competencies and learning about new markets, management practices, and strategies.

Although SRPs occur in many different forms, and may reflect different motives, a number of generalizable assumptions underpin them. First, is the belief that SRPs can lead to *positive sum gains* in internal activities. That is, partners together can obtain mutual benefits that they could not achieve independently. Such benefits may include the following.

Increased scale and scope of activities. The outcomes of SRPs may be applicable to all partners' markets, and thus may expand an individual firm's customer bases (increased scale). Synergies between firms' different technological competencies may produce better, more widely applicable products (increased scope). Increasing the scale of resources dedicated to research programs can also raise entry barriers to other firms.

Shared costs and risk. SRPs can share the often very high costs, and therefore risk, of research (although they can also, of course, share future income streams from any subsequent innovations).

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[2] This section is based on Dodgson (2000a).

Improved ability to deal with complexity. Closer strategic and technological integration between firms and research institutes is a means for dealing with the complexity of multiple sources and forms of technology. It allows, for example, the better transfer of tacit knowledge.

A second assumption regarding SRPs concerns the way they assist with *environmental uncertainty*. Increasingly sophisticated and demanding customers, growing competition in and globalization of markets, and rapidly changing and disruptive technologies place pressures on firms to exist with, and attempt to control, these uncertainties. This is believed to be more easily achieved through partnership than in isolation. Strategy is a means of dealing with uncertainty, and SRPs allow firms to observe and transfer useful lessons about strategy from partners. An important contextual factor affecting the level of uncertainty is the increasing level of scientific and technological integration occurring in various forms. Kodama (1995) discusses the increasing prevalence of 'technological fusion'. Thus 'mechatronics' involved the fusion of mechanical technology with electrical and material technologies, and 'optoelectronics' involves the fusion of glass technology with cable and electronic device technologies.

A third set of assumptions underlying SRPs concerns their *flexibility* and *efficiencies* compared to the alternatives. For example, SRPs may be an alternative to direct foreign investment, mergers, and acquisitions which are much less easily amended once entered into. As a governance structure, SRPs possess advantages over the alternatives of arms' length transactions and vertical integration. They can allow firms to keep a watching brief on external technological developments without having to invest heavily. Large firm/small firm interaction can be facilitated such that the resource advantages of the former are linked with the behavioral or creative advantages of the latter whilst maintaining their independence (Dodgson and Rothwell, 1994). Large drug companies, for example, may partner with a small biotechnology firm as a means of developing their options so that they could invest more heavily once the technology is better proven and better understood. The larger firm will have gained the opportunity to learn about the technology during the SRP.

While information and communications technologies have facilitated increased and more effective SRPs, much technological knowledge is not only tacit, but firm-specific (Pavitt, 1988). It is, therefore, difficult to transfer easily or quickly. SRPs potentially provide a mechanism whereby close linkages among different organizations enable the development of sympathetic systems, procedures, and vocabulary which may encourage the effective transfer of technology. It may also allow partners to 'unbundle' discrete technological assets for transfer (Mowery, 1988). Finally, SRPs may address the difficulty of valuing technological knowledge by providing a means of exchange that does not necessarily rely on price.

Potentially, therefore, there may be numerous advantages to be achieved through SRPs if these assumptions hold. These benefits are not only economic, but also behavioral: firms can learn about new markets, technologies and management practices through SRPs.

There are also potentially adverse aspects of such partnerships. SRPs can be anti-competitive, by excluding certain firms, or raising entry barriers, or operating in the form of cartels which anti-trust legislation prevented in the past. Also there may be strategic dangers for firms which overly rely on externally sourced rather than internally generated technology. Without internal technological competencies there can be no 'receptors' for external technology, nor capacity for building the technological competencies which provide the basis for firms' technology strategies (and which provide the basis for attracting potential partners). In addition to the positive benefits of innovation networks they also can have negative consequences. The network model of innovation may limit participating firms' access to 'complementary assets' (Hobday, 1994) and hence their ability to achieve full commercial returns to innovative activity.

### B. National differences

National variations in the extent to which SRPs occur are influenced by differences in the role of governments, industrial structures, business systems and research infrastructure within national innovation systems.

There is a great deal of similarity amongst industrialized and industrializing nations in policies towards the encouragement of SRPs. The encouragement of SRPs is a key policy focus of the European Commission, as seen in policies such as ESPRIT (a collaborative program with an IT focus) and the five Framework Programs conducted between 1984-2002 (funded collaborative research in a range of industries). In the United States, SEMATECH provides an example of government-sponsored research partnership and, in Canada, the IRAP scheme encourages collaborative research between firms and universities. A wide range of SRP-promoting policies are also found in Japan, ranging from large-scale, high technology schemes that began with the fifth Generation Computer Project to local support schemes through over 150 Regional Technology Centres. Taiwan's Industrial Technology Research Institute (ITRI) has played a central role in encouraging technological development and diffusion through collaborative projects. SRPs are supported by policy-makers internationally as a means of building the inter-firm and research networks that are essential elements of an innovative economy (Dodgson and Bessant, 1996).

There are, of course, major national differences in the policy objectives and constraints regarding SRPs in the extent to which they are driven by scientific, technological and competitive objectives. Korea's policies of supporting national champion firms through a variety of forms of SRP would be anathema to most industrial policy-makers in the West. Within the European Union, there are broad policy differences towards SRPs in accordance with different science and technology policy systems (Rothwell and Dodgson, 1990) and policy-making processes. Nevertheless, the broad policy support for SRPs, albeit with widely differing degrees of support, focus and intent, is a common motivating factor for firms and research institutes to collaborate.

The extent to which firms source research externally, both vertically and horizontally, is affected by particular national industrial structures. A commonly cited reason for the high levels of external integration in Japanese industry, for example, is the structure of industry itself; in particular the role of the *Keiretsu* and the strong vertical relationships found in Japan down the supply chain. The structure of Taiwanese industry, with its predominance of smaller firms, has encouraged the amount of collaborative research, particularly that centered around ITRI. Similarly, the large number of small and medium-sized firms in German manufacturing industry has encouraged the extensive use of industrial research associations (Rush et al, 1996).

Business systems—the ways in which firms relate to one another, to their employees, government and to financial systems—vary so significantly that different kinds of capitalism can be described (Dore, 2000). These systems affect the general propensity towards cooperation, and will influence the extent and role of SRPs. Differences between 'Anglo-Saxon', 'Rhine' or Japanese capitalism will be seen in the breadth and depth of SRP activity. This can be a reflection of the differing strategies of firms as they relate to others along a continuum of spot-trading to 'obligational contractual relations' (Sako, 1992). These differences are particularly important when consideration is made of Chinese capitalism (Redding, 1993). In addition to its ubiquity in China, Taiwan and Singapore, Chinese business practices, which are strongly family-based, are dominant in Malaysia, Indonesia and the Philippines. Chinese family businesses have a strong preference for doing business with people that are associated through kinship or geographical origins. This can have the effect of limiting options for SRPs.

The propensity to conduct SRPs is obviously affected by differing research infrastructures and the way these are integrated within national innovation systems. National science and technology capabilities, as determined by levels of R&D expenditure and employees, investment in universities, etc., vary significantly within and between Europe and East Asia. Also important is the level of integration between the different players in the innovation system. The existence of a range of strong, well-established research institutes, experienced at working with industry, such as the Fraunhofer Society institutes in Germany, are important elements of national innovation systems, and encourage SRPs. By contrast, the comparative lack of development of SRPs in China (outside of technology contracts) is caused by the historically almost complete disengagement of research institutes from industry.

Whereas most European nations enjoy access to strong national and pan-national research institutions and firms, many East Asian nations remain impoverished in this regard. Within East Asia there are massive differences in science and technology capabilities, seen particularly clearly in disparities in R&D expenditure and employment (Dodgson, 2000b). Whilst Singapore, Taiwan, Korea and Japan have developing research infrastructures, particularly in some industries, and relatively coherent national innovation systems, other East Asian countries do not possess the capacity to undertake SRPs. With countries, like Indonesia and Thailand, spending around $2 per capita annually on R&D, SRPs are only likely to be a marginal concern for the limited number of science and technology-based organizations and firms. However, whereas the sort of research partnerships found in developed economies based on 'pre-competitive' R&D is likely to be extremely rare in these countries, the more 'diffusion-orientated' partnerships are of central importance to the development of the national technology base (Dodgson, 2000b).

Policies towards, and funding for, research institutions dynamically affects the extent to which SRPs occur. In Australia, for example, the combination of budgetary constraints affecting universities, legislation mandating that the nation's largest government research organization, the CSIRO, obtain 30 per cent of its budget from industry, and initiatives such as the Cooperative Research Centers that encourage business/research links has led to historically high levels of SRPs. Such changes are common internationally, but have perhaps been seen most radically in China where, as a result of changing policies, a massive change is occurring within research institutes, and in the productive sector, in the extent and form of SRPs.

Changing policies towards research institutions not only affect the extent of SRPs, but also their intent. Seen particularly in countries like Taiwan and Korea, the national research institutions have had to adapt and change in their research activities as some industries have moved from positions of technological following to technological leadership (Kim, 1997; Dodgson, 2000b).

## IV. Measuring the Extent and Outcomes of SRPs

Measuring the scale and importance of SRPs is notoriously difficult. Data on their extent and outcomes is often piecemeal and occasionally contradictory. Furthermore, whereas the bulk of evidence suggests an increasing role for SRPs in industry, the majority of studies of their outcomes point to the considerable difficulties in gaining mutually satisfactory outcomes amongst partners in collaborative research projects (Dodgson, 1993a). These difficulties are often more apparent in horizontal partnerships as these may more often lead to disputes over ownership of their outcomes, such as intellectual property rights, or to direct competition between partners. Many of the problems of measurement relate to the ways in which the objectives of SRPs can change over time, reflecting the learning that has occurred in the partnership (Dodgson, 1993b).

However, a range of different measures does exist. As we shall see, they have varying utility in measuring the extent, conduct and outcomes of SRPs.

## V. Different Forms of Measurement

### A. Scientific indicators and bibliometrics[3]

Mapping techniques based on patent and bibliometric data are being used to analyze the structure and dynamic development of scientific and technological developments, including the growing inter-relationship or fusion of areas of science and technology. These indicators not only measure the 'context' or environment in which SRPs occur, but also directly record the SRPs of individual companies and research institutes.

Using information about the content of patents, or scientific publications, enables mapping and visualization of the cognitive structure of specific scientific or technological areas. Most recent methodological developments and highly sophisticated applications of mapping techniques can be found in Noyons (1994).

Many areas of technology are characterized by a close relationship to science, which, according to recent science and technology foresight studies, will even increase in the years to come. Analyzing those relationships is important for firms as it significantly influences the generation of new technologies. The degree of the science dependence of a certain area of technology, or the degree to which an area of technology is science based, can be measured using an indicator calculated by using the citations to scientific publications given in the official search reports of patents.

Sufficiently large samples are required to make the results meaningful (Schmoch, 1997), and that is why, generally, the indicator is used for whole areas of technology. However, the company, CHI Research, also applies this indicator at the firm level to measure the science linkage of individual firms. CHI claims that this indicator allows the identification of the high tech players in certain fields of technology and that the indicator 'has been found to be predictive of a company's stock market performance' (CHI Research, 1999). Multiplying the science linkage with the total number of patents

[3] This section is based on Dodgson and Hinze, (2000).

of a firm leads to the science strength of this company, which is seen as indicating the 'total amount of a company's science linkage activity' (CHI Research, 1999).

Having a high share of patents applied for by scientific institutions is also seen as giving an indication about close relationships between scientific and industrial activities. According to Schmoch (1997) due to the high costs of patent applications for scientific institutions it makes only sense to apply for a patent if there is an interest in the further commercial exploitation of the invention, which means that collaboration with industrial partners already exist or are intended.

Scientific publications by industrial enterprises might similarly be used as an indicator for existing relationships between science and technology. Those publications are seen as signaling scientific competence from the industrial enterprise and an interest in getting involved in scientific communication in the specific area. Direct collaboration between scientific and industrial institutions can be measured by co-publication of either publications or patents.

Cross-disciplinarity in research activities, which is one of the reasons for SRP formation, is being measured using information about the institutional affiliation of the authors in multi-authored scientific publications. Bourke and Butler (1995), for instance, showed that cross-disciplinary behaviour increased between the early eighties and the early nineties. Hinze (1999) showed that in the area of auto-immune disease research there are differences between the proportion of cross-disciplinary research depending on whether research is carried out within or across the borders of an institution within a country.

Science is increasingly internationalized, with an increasing proportion of academic publications being derived from international collaborations, particularly in basic research (Bourke and Butler, 1995). Numbers of databases measure the extent to which scientific publications are produced with foreign co-authors and patents are registered with foreign co-inventors (OECD, 1999b). There are significant international variations in these data. Around 50 per cent of scientific publications in Hungary, Portugal and Switzerland are undertaken with a foreign co-author, compared with the OECD average of 27 per cent, EU average of 18 per cent, and Japan's 14 per cent. 83 per cent of Turkey's patents are registered with foreign co-inventors, compared the OECD average of 9 per cent.

There are some dangers in using bibliometric techniques in measuring SRPs. Multiple-authorship is widely used as an indicator to measure research collaboration. The underlying assumption is that the authors involved carried out the research leading to the paper in collaboration. Results of these bibliometric analyses should, however, be interpreted with caution. Katz and Martin argue that while '...the assessment of collaboration using co-authorship is by no means perfect, it nevertheless has certain advantages' (Katz and Martin 1997: 3). According to their argument multiple-authorship should only be used as a 'partial indicator' for analyzing research collaboration because only those activities that eventually lead to a jointly authored scientific publication are taken into account and included in the investigation. Not all collaborations, however, result in publications and, conversely, a joint paper does not always mean that the results presented in the paper are based on research collaboration. At the more applied end of the R&D process collaboration may be measured using patent data in a similar manner. Basically, the same shortcomings already mentioned for publication data apply.

**B. International and national surveys**

A range of international and national surveys are conducted that contain data on SRPs, or SRP-like activities (although the paucity of research activity, and the incapacity to record that there is, in many East Asian nations must be recalled). The Annual World Competitiveness Yearbook, for example, surveys its respondents about whether technology transfer between companies and universities is sufficient, and whether technological cooperation between firms is common or lacking. Table 1 shows the results from this survey for Asian and European countries. It shows that countries like Singapore and Taiwan are assessed to do comparatively well in the effort to which firms collaborate with other firms and universities.

Statistics on the extent of various forms of SRP can be derived from compliance with government reporting requirements in a number of areas.[4] Participation in the various types of SRP promoted by the European Commission provides another obvious source of data. China, in its *Science and Technology Indicators*, records the number and value of domestic technology development contracts between buyers and sellers of technology. These increased from 34,174 contracts worth 7,000 million Yuan in 1993 to 41,019 contracts worth 11,600 Yuan in 1997 (MOST, 1998). Generally, however, government-collected statistics in East Asia do not attempt to measure the extent of SRP activity.

Firm level surveys, like the EC Community Innovation Survey (CIS), also provide information about R&D cooperation but at a rather general level. The data from CIS are derived from a survey of 33,700 enterprises, in 12 EU countries, produced by Eurostat, the Statistical Office of the European Communities. Preliminary results of the second CIS, conducted in 1996, are currently available. Eurostat advises that as the results are preliminary and that all countries are not included, a certain caution should be exercised in drawing too extensive conclusions from the comparisons between countries. The survey is mostly directed towards assessing the percentage of innovative companies (determined by reliance on new products) in the various countries. It shows that firms rarely innovate alone.

[4] Although in Europe and East Asia there is no equivalent to the formality of data reporting of a particular term of SRP in the US where, for example, 665 research joint ventures had been registered under the 1984 National Cooperative Research Act by 1996 (quoted in OECD 2000).

**Table 1: Company-University Cooperation and Company-Company Technical Cooperation, 1999**

| Company-University Cooperation | | Ranking | Technical Cooperation | |
|---|---|---|---|---|
| Finland | 6.935 | 1 | Finland | 7.0645 |
| Singapore | 6.061 | 2 | Israel | 6.1091 |
| Israel | 5.926 | 3 | Japan | 6.0661 |
| Netherlands | 5.671 | 4 | Germany | 5.8718 |
| Switzerland | 5.558 | 5 | Denmark | 5.8462 |
| Sweden | 5.540 | 6 | Singapore | 5.8182 |
| USA | 5.523 | 7 | Sweden | 5.8140 |
| Canada | 5.143 | 8 | Canada | 5.7681 |
| Ireland | 5.134 | 9 | Iceland | 5.6129 |
| Denmark | 5.128 | 10 | Taiwan | 5.5778 |
| Australia | 5.088 | 11 | Netherlands | 5.5581 |
| Taiwan | 5.022 | 12 | Switzerland | 5.5349 |
| Germany | 4.872 | 13 | USA | 5.5091 |
| Norway | 4.864 | 14 | Luxembourg | 5.1220 |
| Iceland | 4.625 | 15 | Norway | 5.0864 |
| Belgium | 4.606 | 16 | Australia | 5.0746 |
| Colombia | 4.600 | 17 | Ireland | 5.0149 |
| New Zealand | 4.549 | 18 | New Zealand | 5.0000 |
| Austria | 4.474 | 19 | Belgium | 4.8955 |
| United Kingdom | 4.300 | 20 | Austria | 4.7632 |
| Hungary | 4.213 | 21 | Malaysia | 4.7551 |
| Hong Kong | 4.179 | 22 | France | 4.7529 |
| China | 4.172 | 23 | Hong Kong | 4.5357 |
| Malaysia | 4.163 | 24 | Hungary | 4.5306 |
| South Africa | 4.063 | 25 | China | 4.4731 |
| Japan | 4.017 | 26 | United Kingdom | 4.4034 |
| France | 3.929 | 27 | Russia | 4.2920 |
| Russia | 3.809 | 28 | Spain | 4.2286 |
| Luxembourg | 3.750 | 29 | Slovenia | 4.0574 |
| Philippines | 3.667 | 30 | Poland | 4.0566 |
| Chile | 3.626 | 31 | Czech Republic | 4.0357 |
| Spain | 3.514 | 32 | Greece | 4.0282 |
| Czech Republic | 3.500 | 33 | Italy | 4.0213 |
| Greece | 3.465 | 34 | Philippines | 4.0000 |
| Brazil | 3.247 | 35 | South Africa | 3.9688 |
| Turkey | 3.219 | 36 | Brazil | 3.9529 |
| Korea | 3.196 | 37 | Chile | 3.8242 |
| Portugal | 3.034 | 38 | India | 3.7045 |
| Italy | 2.905 | 39 | Turkey | 3.5048 |
| Thailand | 2.837 | 40 | Argentina | 3.3253 |
| Poland | 2.774 | 41 | Mexico | 3.3086 |
| Argentina | 2.602 | 42 | Venezuela | 3.2609 |
| Mexico | 2.580 | 43 | Portugal | 3.2414 |
| India | 2.529 | 44 | Korea | 3.1111 |
| Indonesia | 2.508 | 45 | Thailand | 3.4065 |
| Slovenia | 2.373 | 46 | Indonesia | 2.9206 |
| Venezuela | 1.956 | 47 | Colombia | 2.8633 |

**Source:** IMD (1999). *World Competitive Handbook.* Lausanne, IMD.

Similarly the PACE and Yale surveys focus on the sources of technical knowledge of firms, and shows the importance for firms of research links with research institutes (Klevorick et al, 1996).

Some European studies have analyzed the comparative importance of international collaboration (DeBresson, 1997, Report on the Focus Group on Innovative Firm Networks, 1998, quoted in OECD, 1998). Tables 2 and 3 show these data.

**Table 2: Propensity of Innovative Firms to Engage in International Exchange of Technology (in percentages)**

| | Belgium | Denmark | France | Germany | Italy | Netherlands | Norway |
|---|---|---|---|---|---|---|---|
| Acquiring technology | 74.5 | 76.6 | 56.1 | 24.7 | 40.4 | 26.3 | 43.2 |
| Exporting technology | 82.5 | 77.3 | 52.7 | 31.7 | 49.7 | 17.8 | 28.5 |

**Source:** OECD (1994).

**Table 3: Distribution of Foreign and Domestic Collaborating Partners, 1997**

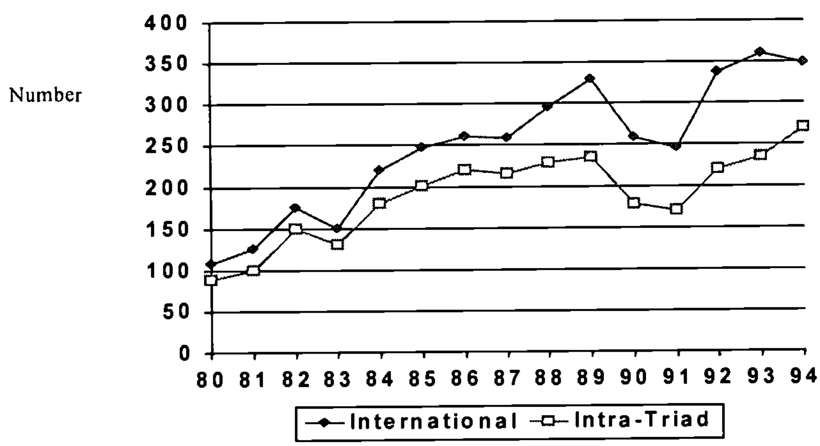
| Partner | Cooperation with domestic partners (%) | | | Cooperation with foreign partners (%) | | |
|---|---|---|---|---|---|---|
| | Austria | Denmark | Spain | Austria | Denmark | Spain |
| Customers (govermental) | n.a. | 20 | 24 | 14 | 9 | 9 |
| Customers (private) | n.a. | 62 | 41 | 37 | 41 | 29 |
| Suppliers of materials and components | n.a. | 64 | 48 | 42 | 41 | 35 |
| Suppliers of equipment | n.a. | 37 | 40 | 22 | 20 | 28 |
| Suppliers of technological services | n.a. | 39 | n.a. | 18 | 14 | n.a. |
| Other private technical consultants | n.a. | 17 | 48 | n.a. | 6 | 20 |
| Marketing and management consultants | n.a. | 30 | 28 | 7 | 8 | 6 |
| Competitors | n.a. | 9 | 9 | 11 | 5 | 6 |
| Universities and research centres | n.a. | 15 | 55 | 11 | 6 | 14 |
| Parent company or subsidiaries | n.a. | 21 | 19 | 24 | 16 | 22 |
| Others | n.a. | 32 | 4 | n.a. | 17 | 8 |

**Source:** OECD (1994).

### C. Specific databases on alliances

A number of databases measure the numbers of new international technology alliances announced in the technical press. These tend to cover high-profile, technology creating projects and under-represent more technology diffusion-oriented partnerships and those based outside non English-speaking countries. The best of these databases, the MERIT-CATI database, which includes inter-firm collaborations, shows the increase in the number of new collaborations being formed throughout the 1980s and 1990s (see Figure 1). The majority of these new collaborations occur in new technologies, particularly in IT, and are based in the United States, Japan and Europe. Although there has been an increase in partnerships outside of the Triad, primarily in technologically advanced East Asian nations, these still only account for around 20 per cent of the total recorded number (Duysters and Hagedoorn, 2000; Hagedoorn et al, 2000). The major drawback of these databases is that they rely on information that has to be reported by more or less publicly available sources and thus the proportion of unreported or confidential agreements is unknown. They may also underestimate the extent of alliance activity amongst technologically advanced East Asian and Latin American nations. Other, US based, databases include the CORE and NCRA-RJV databases (Hagedoorn et al, 2000).

**Figure 1: Number of Newly Established International Strategic Technology Alliances**




**Source:** Duysters and Hagedoorn (2000).

An example of a specific database containing information about alliances in a particular technology is provided by Recap (Recombinant Capital), which focuses on alliances in the area of biotechnology. Using Recap it is possible to differentiate between the type and origin of partners involved in an alliance (pharmaceutical firm, biotech firm, research institute, university); the type of activity of the alliance; and the stage of the innovation process, which is rather clearly defined in the area of pharmaceutical research due to special approval requirements. Data can also be analyzed for different sub-fields of biotechnology. Information included in the database is gathered from the US Securities and Exchange files where according to Recap 'over 50% of biotech agreements with major pharmaceutical companies, universities or other biotech companies are filed' due to public filing requirements (Recap 1999). Additional information is added originating from publicly available sources like press releases and the Clinical Trial Progress Database. Information in Recap can be retrieved via the internet (Dodgson and Hinze, 2000).

**D. Network analysis**

Networks of one sort or another are powerful mechanisms for communication and the transfer of complicated information and technology flows. Networks can enable the sharing of resources, for example, specialist equipment or R&D projects where the costs and risks of investment to any individual firms would be prohibitive. Definitions of network vary, but here they are considered to be an open system of interconnected firms and institutions with related interests (see Castells, 1996). Networks offer a rich web of channels, many of them informal, and have the advantage of high source credibility—experiences and ideas arising from within the network are much more likely to be believed and acted upon than those emerging from outside. They are therefore an effective mechanism for encouraging learning, an objective of SRPs. Their formation has been a major innovation policy objective around the world (Dodgson and Bessant, 1996).

The measurement of the extent and outcomes of networking activity as it applies to research is very difficult. For example, while there are data on the number of suppliers a particular firm may have, and firms know how much of their R&D is undertaken externally, there is rarely detailed information on the importance and nature of particular links with suppliers or collaborators. There is, however, some good European research into networks which shows not only the extent of networking (see Tables 2 and 3), but also begin to delineate the various types of network in the extent to which they involve equipment suppliers, users, competitors, component suppliers and government laboratories and universities (DeBresson et al, 1997, quoted in OECD, 1999a).

The most successful research project in this area is the Danish System of Innovation in a Comparative Perspective - the DISKO-project (which provided the basis for the data provided in Table 3). The central issues of this project are:
1. The importance of co-operation for innovation;
2. Co-operation inside and across borders;
3. The question of trust in establishing a co-operation.

DISKO was launched in April 1997. It surveyed 1,022 firms. The main categories of questions were:
- type of partner;
- reason for co-operation with the specific type of partner;
- duration and intensity of co-operation;
- exchange of labour during the co-operation;
- services in connection with the new products.

The major findings from the DISKO study firms showed that inter-firm co-operation in product innovation was frequent, including amongst small firms. There are distinct national variations, and variations in the propensity to cooperate depending on firm size (OECD, 1999a).

The questionnaire developed for this project, by the IKE group at the University of Aalborg, is presently being used in a broader project across a number of other nations.

## E. Case studies

### *1. Firms*

Case studies of individual firms show both the extent of SRPs and, more than any other indicator, their (often changing) focus, and outcomes. Figures 2 and 3, for example, show the reliance of Samsung Electronics on various forms of technological link with US and Japanese firms. Table 4 also shows they way in which the form of partnership changes as the company becomes more technologically self-sufficient. The focus of the partnerships progress from licensing-in to joint R&D projects (Dodgson and Kim, 1997).

**Table 4: Technology Acquisition in Consumer Electronics**

| Year | Firm | Country | Technology/Product | Type of Agreement |
|---|---|---|---|---|
| 1981 | Toshiba | Japan | MWO Production | Licensing |
| 1982 | Philips | Netherland | CTV Patent | Licensing |
| 1983 | Toshiba | Japan | Air-Conditioner Production | Licensing |
| | JVC | Japan | VCR Patent | Licensing |
| | Sony | Japan | VCR Patent | Licensing |
| | GE | USA | MWO | OEM |
| 1984 | Toshiba | Japan | Washing Machine Production | Licensing |
| 1985 | Toshiba | Japan | Air-Conditioner Production | Licensing |
| | Matshshita | Japan | Mannetron Production | Licensing |
| 1987 | UNITEK | Japan | CR Production | Licensing |
| | AMPEX | USA | VCR Production | Licensing |
| 1988 | D.V.A. | Germany | CDP Patent | Licensing |
| | Toshiba | Japan | VCR Production | Licensing |
| 1989 | Tenking | Japan | VCR Drum | Joint Development |
| | Thomson | USA | CDP Patent | Licensing |
| 1990 | TRD | Japan | Camcorder | Joint Development |
| | ITECS | Japan | CDP | Joint Development |
| | JVC | Japan | S-VHS Patent | Licensing |
| | FROG | Germany | CTV & VCR | Joint Development |

**Source:** Dodgson and Kim (1997).

**Figure 2: Technology Relationships with Japanese Firms**

samsung

**TOSHIBA**

Licences for :
- fax machines
- airconditioners
- cellular modular phones
- word processors
- washing machines
- Hi Fi, VCRs

Joint development projects in:
- Computerized typesetting
- LCD drive ICS, ASICs,
- Flash memories

**FUJITSU**

Cross licensing in LCDs

**SHIBASOKU**
**DNS**
**TOWA**
**TORAY**

**SANYO**

Licences for:
- microwave oven technology
- automatic sales machines

**MATSUSHITA**

Licenses for:
- magnetron production technology
- VCRs

Joint development of broadcasting VCRs

**MITSUBISHI**

Joint standardization of DRAM

**NEC**

Joint production of DRAMs

**SHARP**

Licences for :
- semiconductor technology
- SRAM, ROM, DRAM

**SONY**

Licenses for;
- VCRs
- broadcasting cameras

**IKEGAMI**

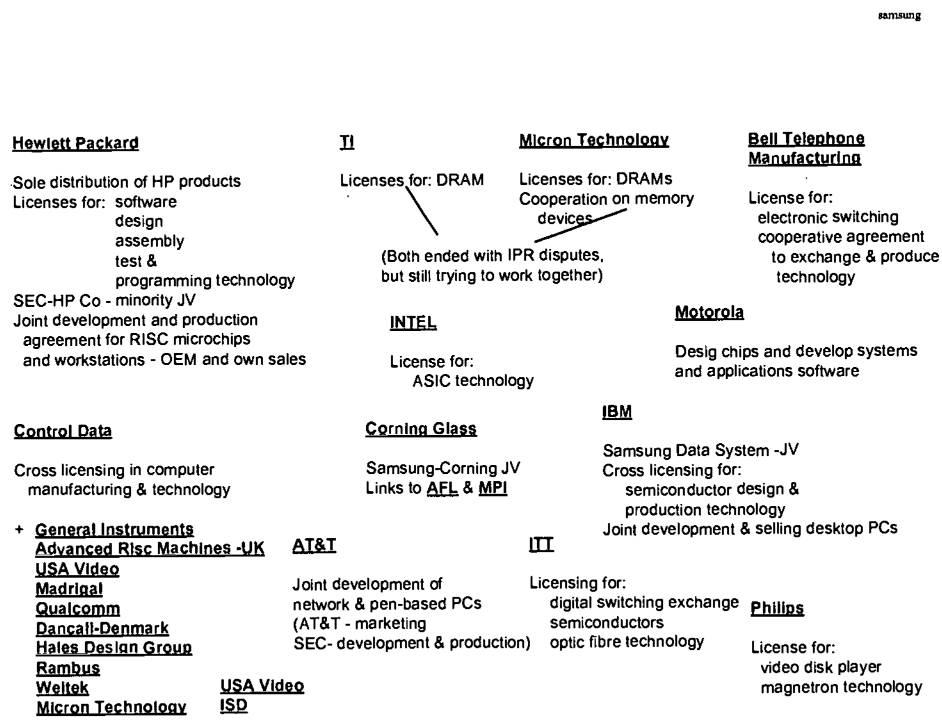
Licenses for :
- broadcasting colour monitors

**OKI**

Technology transfer and technical assistance for synchronous DRAMs

**Source:** Dodgson, M. and Y. Kim (1997).

**Figure 3: Technology Relationships with US and European Firms**




**Source:** Dodgson, M. and Y. Kim (1997).

Detailed case studies show the management problems of SRPs, with their implications for different forms of management structures and the importance of inter-partner trust (Dodgson, 1993b; Child and Faulkner, 1998).

Case studies of the management of global corporate R&D show the extent of international SRPs, and some of the major problems that need to be managed to achieve satisfactory objectives (Kuemmerle, 1997; Reger, 1997; Meyer-Krahmer and Reger, 1999).

## *2. Regions*

Analyses of particular regions can show the extent of localized SRPs and the importance of particular stimuli, such as strong research institutes or high levels of specific localized government expenditure. They can also reveal the widely different forms of the SRPs, so, for example, Saxenian's (1994) comparison of Silicon Valley and Boston's Route 128 contrasts the centrality of large firms in the latter, with the generally small firm model in the former. Although still in its development stage, Malaysia's Multimedia Super Corridor represents a very large-scale initiative to build regional research partnerships facilitated by substantial infrastructural investment.

### *3. Industries*

By conducting in-depth case studies on particular industries it is possible to delineate the most important research relationships. This is exemplified in Mathew's and Cho's (2000) analysis of the electronics industry in Figure 4.

This form of analysis has been instrumental in explaining the successful development of the IT industry in Taiwan. The networks created amongst small Taiwanese firms through their research links with research organizations and international firms have played such an important role in the success of the industry, that Mathews and Cho (2000) have described the model as a new form of economic learning.

**Figure 4: Taiwan's Strategic Alliances**

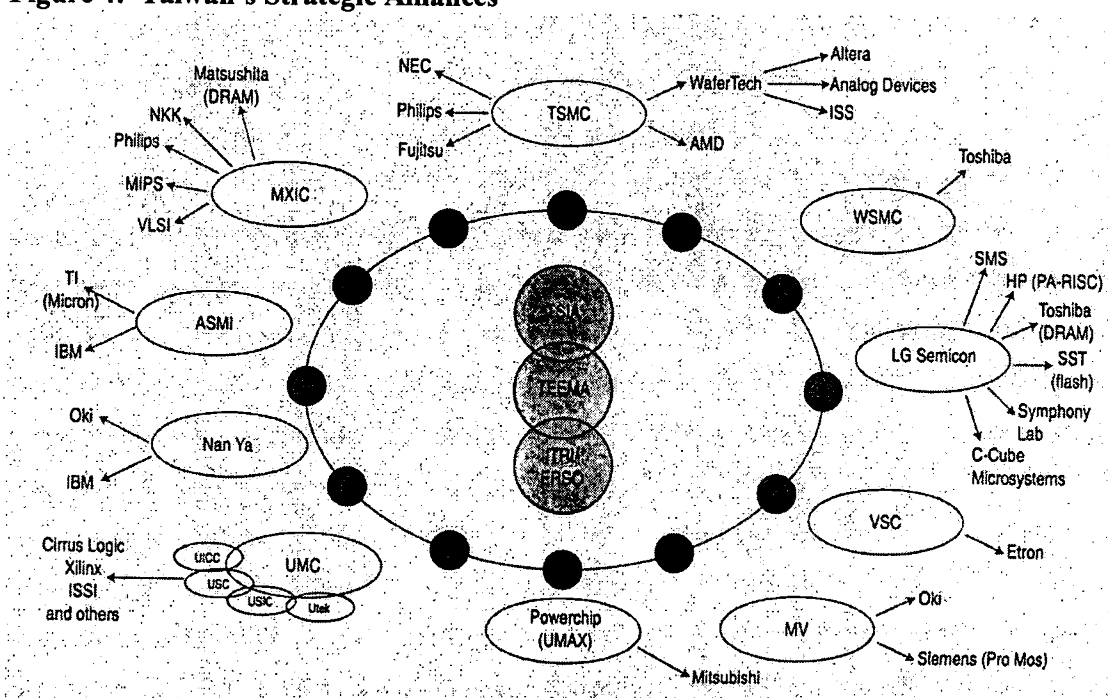



Figure 4.2 Taiwan's strategic alliances.

**Source:** Mathews and Cho (2000).

### *4. Technologies*

An exemplary case study of the role and importance of research linkages in the development of a particular technology is provided by Malo and Geuna (2000). By using a variety of techniques, their study of the development of combinatorial chemistry and biology shows the extent of the knowledge spillovers between science and technology in a research network.

### *5. Policies*

Large-scale evaluations of SRP-promoting policies can measure both the extent, motivation and outcomes of SRPs. A classic case in this regard is the evaluation of the UK Alvey Programme in Information Technology (Guy and Georghiou, 1991).

## VI. Conclusions

This paper has examined the reasons why firms and research institutions create SRPs. It has considered some methods of measuring the extent and outcomes of SRPs, particularly by reference to indicators found in Europe and East Asia. There are a number of significant methodological problems in measuring the extent and contribution of SRPs. The first of these relates to the diversity of forms which SRP's assume, and the ways in which they can change over the technology life-cycle, or in response to organizational learning. The second is allied to the motivation for forming SRPs. These motives may proceed beyond the purely economic (although economic returns can also be difficult to ascertain in, for example, assessing the relative contribution of internal and collaborative efforts), to the dynamic behavioral changes associated with learning, which is very difficult to measure. The third, is the shortage of governmental and independent academic research into SRPs, seen most particularly in East Asia.

Just as there is no unified theory explaining SRPs, there is no one particular source of data that can be relied upon to provide anything near a complete analysis of their extent, conduct and outcomes. A number of forms of measurement have been described, with varying utility for examining different aspects of SRPs. A much more complete reflection of the extent and importance of SRPs can be gained by combining a number of these different indicators for specific analytical purposes.

Science and technology indicators constructed using data on scientific publications and patents mainly cover the context in which SRPs occur, although individual firm and research institute behavior can also be recorded. Specific databases collecting data on alliances or joint ventures provide further information, which may also reveal the character of the specific SRP.

Valuable additional information, on issues such as the conduct and outcomes of SRPs, can be better tackled using indicators constructed based on firm-level survey data and case studies.

Using a larger number of indicators, from patent and bibliometric data, survey data or other specific databases, and case studies allows the construction of a more comprehensive picture of the extent, conduct and importance of SRPs. However, it will not always be necessary or feasible, due to time or financial constraints, to use all these measures. Decisions have to be made about the appropriate selection of the indicators and these will depend on the definition of the major interests of the investigation undertaken. In any case, the advantages and disadvantages or limitations of the selected set of indicators have to be made clear.

The clear advantages of bibliometric and patent data is the fact that they are easy to access, as the data is contained in publicly available databases; and the analysis of a rather long time series is possible. Innovation surveys on the other hand are carried out on a more or less irregular basis. Only recently has a periodical data collection been started in Europe, the CIS, although there appear to be delays in the conduct of the next survey.

Surveys and case studies of SRPs rarely take account of the aggregate information available from the sources described above. A greater concern to adapt questions such that the individual firm can be benchmarked against these databases would be an opportunity not only to improve the integration of the different approaches, but also to cumulatively build more detailed knowledge about the shortcomings of both approaches.

The policy challenge is not only to improve the quality and reliability of these different sources of data, but to develop metrics for their combination in response to particular policy requirements.

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## Strategic Research Partnerships in Japan: Empirical Evidence

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### I. Introduction

Strategic research partnerships (SRPs) have caught much attention from many perspectives. Firms are concerned because forming SRPs has become an important complement to their in-house R&D. It has been documented that firms increasingly rely on collaboration with other firms to conduct R&D activities (Gulati, 1995; Powell, Koput and Smith-Doerr, 1996; Osborn and Hagedoorn, 1997). Governments are concerned because they consider cooperative R&D as a tool for enhancing industry competitiveness. Japan is regarded as a forerunner in the practice of cooperative R&D. The most celebrated example is the VLSI (Very Large Scale Integrated circuit) project, designed to help Japan catch up in semiconductor technology. The project, conducted between 1975 and 1985 with a budget of 130 billion yen ($591 million) of which 22% was financed by the government, developed state-of-the-art semiconductor manufacturing technology. All of the major Japanese semiconductor producers participated in this project, and Japanese semiconductor companies gained world leadership after the project. It is widely believed that this success story is only one of many.

The perceived success of the VLSI project has motivated other countries to emulate "Japanese style" collaboration. The 1984 U.S. National Cooperative Research Act was enacted to relax antitrust regulations in order to allow the formation of research joint ventures. Major cooperative R&D projects followed. SEMATECH was established in 1987 to develop semiconductor production technology with a $1.7 billion budget as of 1996, half of which was financed by the government. The Department of Defense sponsored cooperative ventures on the development of flat-panel displays which will spend an estimated $1 billion over five years beginning in 1994. A successor bill of the 1984 law, The National Cooperative Research and Production Act, was passed in 1993 to extend the 1984 law to not just research and development, but to production of new technologies as well.

In Europe, the block exemption from Article 85 of the Treaty of Rome, which determines EEC competition rules for certain categories of R&D agreements, was introduced in 1985. Even earlier, many cooperative R&D projects were organized, including the $5.6 billion European Strategic Programme for Research and Development of Information Technology (ESPRIT) project in 1984, and the UK Alvey project in 1984, both for the development of computers and information technology. These projects were in response to another famous Japanese cooperative R&D project, the Fifth Generation Computer Project. Other European efforts include programs under the European Research Coordination Agency (EURECA) started in 1985.

In developing countries, there are similar efforts. The Korean government has launched a series of cooperative R&D projects whose scheme is very close to the Japanese one, and in Taiwan there is its own version of R&D consortia.

Given the importance of SRPs in general, and the Japanese SRPs in particular, this article focuses on SRPs in Japan. Section 2 argues the role they play in Japan, and some data are introduced. Empirical evidence is presented in Section 3. In Section 4, the strength and limitation of the data used in these empirical analyses are discussed, and the future direction of the data collection and empirical evaluation are presented.

## II. SRPs in Japan

SRPs play a very important role in Japan because of its distinctive institutional settings. First, the importance of SRP as a vehicle to share knowledge with other firms becomes more important where imperfections of factor markets are severe (Sakakibara, 1997b). The lifetime employment system prevalent among large corporations is a cause of low mobility of researchers among companies. Companies are oriented to maintain a stable number of researchers, and so even if they recognize new technological opportunities, it is hard for them to suddenly increase hiring. Also, though the situation is changing recently, we seldom observe researchers move from one company to another, especially to a competitor. Saxonhouse (1985) pointed out that the Japanese government's cooperative R&D projects are viewed as a substitute for the unusually high degree of informal interfirm communication which takes place among the more professionally oriented, potentially mobile R&D personnel in the United States. American researchers might be implicitly disclosing potentially proprietary information in order to enhance their employment prospects, and also in order to receive in exchange proprietary information of commensurable value. Without having spillover channels through recruiting, Japanese companies are motivated to use SRPs as a means of information exchange.

Second, mergers and acquisitions (M&As) as an alternative instrument to access research inputs tend to be cumbersome. Compared with the United States, M&As are still uncommon in Japan because the dominant owners of corporations are institutional shareholders—often motivated to solidify relationships not to seek immediate returns. Rules which facilitate M&As are less developed than the United States. Moreover, R&D knowledge and capability belong to individuals (von Hippel, 1988), not to firms, and so acquisitions intending to capture R&D capability can turn out to be purchases of "empty shells" due to the departure of all key personnel with the "crown jewels. " Under these circumstances, cooperation with other companies becomes a practical alternative (Sakakibara, forthcoming-a).

Third, relatively weak research capability in universities and national research laboratories, and the weak linkage between these public research organizations and corporations in Japan, make knowledge transfer among firms through SRPs important. In the United States, strong university-based efforts and university-firm linkages work as a substitute for knowledge sharing through SRPs (Sakakibara 1997b).

Fourth, firms are often motivated to form SRPs as a means of internal diversification. SRPs are directly connected with diversification in Japan because, as Porter (1992) points out, entry into new businesses is typically conducted by established firms through internal diversification. Japanese companies tend to face weaker pressure from shareholders than U.S. firms to realize short-term returns, and so a goal of them is their own perpetuation. Due to the underdevelopment of the market for corporate control, resource reallocation from mature and/or declining businesses to emerging businesses is conducted internally. Through the participation in SRPs, firms can test the possibility to diversify into new businesses. Sakakibara (forthcoming-a) empirically finds that the motives for cooperative R&D are analogous to the motives for diversification.

Because of these critical roles SRPs play, we expect to observe many SRPs in Japan. The exact number of SRPs is difficult to obtain because "pure-private" SRPs are not often announced, and so the journal-article database can be biased. Corporate executives have noted that the existence of private SRPs itself could be a signal to rival companies regarding which research direction companies try to seek.[1] This is the primary reason that the rest of the paper is based on the data of government-sponsored R&D consortia in Japan.

The promotion of cooperative R&D by the Japanese government started in 1959, when the Ministry of International Trade and Industry (MITI) and aircraft makers launched the YS-11 turboprop aircraft development project.[2] In 1961, a formal scheme to promote cooperative R&D efforts was established as the Act of the Mining and Manufacturing Industry Technological Research Association. Under the Act, which was modeled after the British Research Associations initiated in 1917 and later adopted by Germany, France and Sweden, firms can pool researchers and funds into nonprofit Mining and Manufacturing Technological Research Associations (TRAs hereinafter). The formation of TRAs was intended to promote R&D consortia as a means of coping with trade liberalization and to enhance the productivity of Japanese industries. At that time, Japan faced the task of abolishing protective policies for domestic industries following these industries' recovery from the devastation of the Second World War.

Under this scheme, participating companies enjoyed several tax benefits on their research expenses. Typical tax benefits included accelerated depreciation for expenses on machinery and equipment, instant depreciation of fixed assets for R&D, and discounts of property taxes on fixed assets used for R&D (the Council of the Mining and Industry Technology Research Association, 1991). The TRA system was introduced as a substitute for direct R&D subsidies to individual companies, which the Japanese government had to phase out as Japan prepared to join the league of developed countries and to abolish protective policies. After the scheme of TRAs was introduced, the amount of R&D subsidies to individual companies considerably declined, and in order for firms to receive significant amounts of R&D subsidies, they needed to form R&D consortia.

TRAs are not the only form of cooperative R&D in Japan. Other organizational forms for cooperative R&D include foundations and corporations. These forms are chosen by participants on the basis of each form's financial and organizational benefits (for details of different types of cooperative R&D, see Sakakibara, 1997b). It is not only MITI, but also many other ministries that are involved in the formation and operation of these consortia.

The most comprehensive data on SRPs have been collected and documented in Sakakibara (1994, 1997a,b), which include 237 government-sponsored R&D consortia which occurred between 1959 and 1992. 1171 companies participated in these consortia during this period and many were involved in multiple projects. Inclusion of these multiple projects yields a data set with 3021 company-project pairs. They cover all the identifiable government-sponsored R&D consortia during that period including all the TRAs as well as other forms of cooperation.

Figure 1 illustrates the overall trend of Japanese government-sponsored R&D consortia in terms of the budget allocated in each project, aggregated by sector. This figure illustrates that the efforts

[1] Based on the interview by the author.
[2] This section draws heavily on Sakakibara and Cho (2000).

peaked in the late 1970s and 1980s. This figure also shows that while the electronics and machinery sector caught much attention, consortia are observed in many other sectors as well.

## III. Policy Needs for Indicators

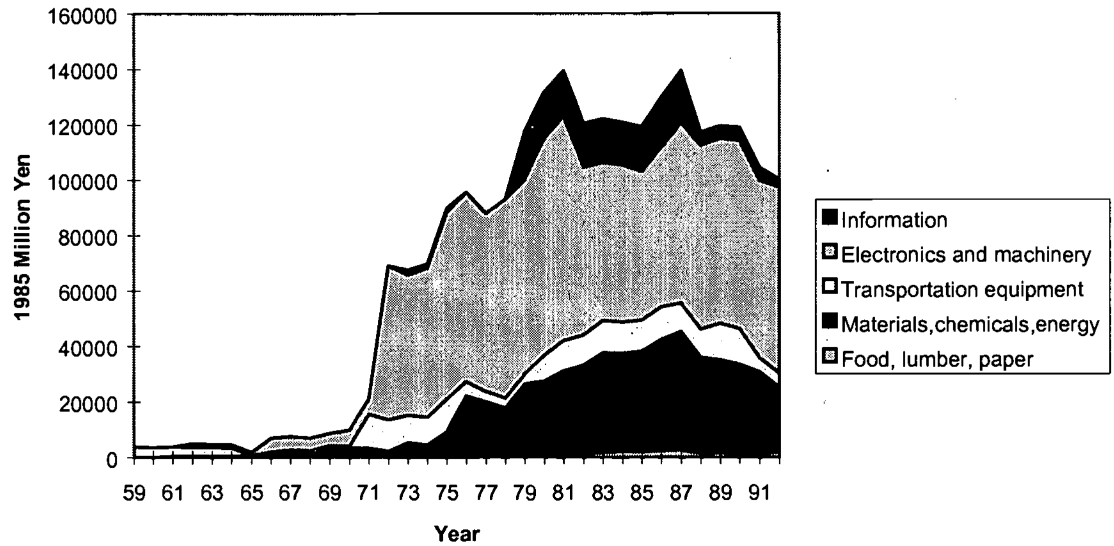
The previous section establishes a critical role SRPs play in the Japanese institutional setting. This is a necessary but not sufficient condition to call for the government's support for this particular policy instrument. If the government supports SRPs that would have been formed without government sponsorship, there is no need for government intervention. Also, if government-sponsored SRPs do not achieve intended goals to stimulate private innovative activities, the validity of their existence becomes doubtful.

In order to determine whether the government should promote SRPs, empirical examinations on the existing SRPs are informative. A natural question for policy makers is whether SRPs they promote attract the right kind of firms from a public-policy perspective, and whether the SRPs they support are an effective means to stimulate private R&D efforts rather than crowding out private spending. Also, the research productivity of SRPs is an important consideration.

Supporting SRPs is only one of many policy tools government can choose to stimulate innovative efforts. For example, public procurement, funding of research in national laboratories and universities, tax incentives, subsidies to individual firms can be chosen as a policy means. The evaluation of the effectiveness of SRPs by measuring their productivity thus gives the government a useful guidance regarding whether they should choose SRPs over other policy means.

This section focuses on three issues regarding SRPs—their formation, their effect on R&D spending of participating firms, and their productivity. Empirical studies on Japanese SRPs for these issues are limited. The paucity of empirical research is largely due to the insurmountable task of obtaining data on government-sponsored SRPs. There is no central clearing house for such data, and even within MITI, the largest sponsor of SRPs, no single place from which one can obtain the whole data of MITI-sponsored SRPs.

**Figure 1. Japanese R&D Consortia Total Budget by Sector**




**Source:** Sakakibara (1994).

## A. Formation of SRPs

In the analysis of the formation of SRPs, an important issue for policy makers is the firm- and industry-level determinants of the formation of R&D consortia.[3] At the industry level, there are two important considerations. The first is the degree of competition of the industry in which member firms of a SRP belong. The degree of industry competition will affect a firm's propensity to participate in SRPs in two opposite ways. As Katz (1986) discussed, firms in competitive industries might be more motivated to form R&D consortia to ease the subsequent product market competition. Also, SRPs allow firms to access complementary technology that enables firms to develop their R&D capabilities and improve their strategic position. These needs might be greater in competitive industries (Baum and Oliver, 1991; Eisenhardt and Schoonhoven, 1996). On the other hand, organizational economics and organizational theory document the difficulties involved in organizing cooperative ventures in general (Killing, 1983; Harrigan, 1985, 1986; Pucik, 1988; Borys and Jemison, 1989), and SRPs in particular (Doz, 1987; Hladik, 1988; Osborn and Baughn; 1990; Jorde and Teece, 1990). These studies emphasize the organization costs associated with complex ventures, including costs to monitor opportunistic behavior of participants, and to align interests among participants. If firms are in highly concentrated industries, they might find the cooperation (or collusion) easier to achieve because these difficulties can be resolved in an oligopolistic understanding among rivals.

[3] The arguments in this part draw heavily on Sakakibara (2000).

SRPs consortia can be used as vehicles to internalize the externality created through spillovers of research outcomes (Spence, 1984). Firms can agree to share the costs and outputs of an R&D project before its execution, so they can restore the incentive to conduct R&D. Cohen et al. (1998) found that, on average, intra-industry R&D spillovers are more extensive in Japan than in the United States. One major channel that facilitates spillovers is the patent system. In Japan, patent applications are automatically published 18 months after their initial filing. In the United States, in contrast, the content of the patent applications will be published only if they are granted, which is typically more than two years after the application. Under these conditions, spillovers can be major issues determining the participation in SRPs in Japan.

Firm-level factors can also influence the rate of participation in SRPs. The first factor that plays an important role is R&D capabilities of participants. Firms can use SRPs to gain access to technological capabilities of other firms to create next-generation technological competencies. This might imply that a firm that currently has disadvantageous R&D capabilities is motivated to form R&D consortia more than R&D-capable firms. However, Cohen and Levinthal (1989) demonstrated the possibility that a company's own R&D increases its learning capability from others. Firms that already invested in R&D, therefore, can benefit more from R&D consortia than less R&D-capable firms, and so they might be more motivated to learn from others.

The second factor of consideration is the experience of past participation in SRPs. The network of prior alliances provides information of new alliance opportunities, potential partners and their quality (Kogut et al., 1992). With the formation of new alliances this network updates, it is the new network that becomes influential for subsequent firm behavior (Gulati, 1999). In the case of SRPs, the experience of participation in past consortia can create technological network through which a firm can gain access to technological resources of other firms. Furthermore, Baumol (1993) argued that cheating in the cooperative R&D game can be easily detected in a repeated game situation, and punishment to exclude a cheater from the following projects is very costly for a cheater. Therefore, firms that have repeatedly participated in R&D consortia can benefit from the sustained cooperation, which further motivate them to participate.

The third factor is the encounter with other firms in product markets. The literature on networks stressed a firm's access to external networks as an important source of capabilities that the firm can draw upon (Gulati, 1999; McEvily and Zaheer, 1999). When a firm is diversified, it is likely that the firm has a better knowledge on potential partners in SRPs through contact with a large number of firms in many product markets. In other words, contact with other firms in product markets constitutes a network through which the firm can obtain superior information on future consortia. Also, when a firm is diversified into many product markets, the firm might wish to draw on outside knowledge with a greater extent by combining in-house technological competencies and external technological acquisitions to serve these markets (Gtanstrand, Patel and Pavitt, 1997). This desire further motivates the firm to form SRPs.

Sakakibara (2000) finds from an event-history analysis that both industry and company factors affect the formation of R&D consortia. It is found that a firm in an industry with weak competition and appropriability conditions has a higher rate of consortia participation. A firm's R&D capabilities, network formation through past consortia, encounter with other firms in product markets, age, and past participation in large-scale consortia also positively affect its tendency of consortia formation. This indicates that firms, which frequently participate in SRPs, are the ones that will gain most from participation and have potential for effective cooperation. Policy makers need to recognize that they need to take both industry and company factors into account when deciding the target firms. Even if they want to attract a specific type of firms to government-sponsored SRPs, it might be difficult to do so if these conditions are not met.

**B. Effect on R&D spending of participating firms**

The second issue of the interest is the effect of participation in SRPs on R&D spending of participating firms. Do SRP member firms increase or decrease their R&D spending? An answer to this question depends on the motives of participants and the organization of SRPs.

Sakakibara (1997a) makes a distinction between cost-sharing SRPs and skill-sharing SRPs. Cost-sharing SRPs refer to consortia formed to share fixed costs of R&D among participants, to realize economies of scale in R&D, and to divide tasks among members and avoid "wasteful" duplication. In contrast, objectives of skill-sharing SRPs include to learn from other participating firms. This type of SRPs can be viewed as opportunities for one partner to internalize the skills or competencies of the others to create next-generation competencies. This learning function of SRPs becomes especially important when firms try to enter a new business, to redefine their core industries, or when they respond to shifting industry boundaries.

The diversity of capabilities SRP participants possess can distinguish the different motives to participate in SRPs. In the case of skill-sharing or learning-based R&D cooperation, what is important is not only the outcome of the project, but also the process of resource accumulation, or learning in a SRP. Participants with a skill-sharing motive might find it easier to reach an agreement to cooperate without a clear end result in mind than firms whose primary motive for cooperation is cost-sharing. In addition, skill-sharing is an important means for a firm to enter a new business, implying that this motive is more likely in pre-competitive R&D where conflicts of interests are less apparent. Firms from different industries, therefore, might find it easy to cooperate when their motivation is skill-sharing. Also, the capabilities of participants in skill-sharing ventures are likely to be heterogeneous so as to best combine complementary resources and knowledge. This implies that participants are likely to come from a wide range of industries.

In contrast, cost-sharing, or scale-based R&D cooperation requires a relatively clearer understanding of the objective and configuration of a cooperative R&D project, because the benefits of cost-sharing and the realization of economies of scale has to be understood by member firms before the execution of the project. Participants in R&D consortia motivated by cost-sharing are likely to belong to a single industrial sector, because they are more likely to have similar prior knowledge, which makes the agreement easier to achieve. Their capabilities are, therefore, likely to be homogeneous.

The cost-sharing and skill-sharing motives are not necessarily mutually exclusive. An R&D consortium can pursue both motives simultaneously. The point here is that the relative importance of these motives can be distinguished by the diversity of capabilities among the consortium's participants. Sakakibara (1997a) finds that the relative importance of the cost-sharing motive in R&D consortia increases when participants' capabilities are homogeneous or projects are large, while the relative importance of the skill-sharing motive in R&D cooperation increases with heterogeneous capabilities, based on the survey data on Japanese government-sponsored SRPs.

The effects of SRPs on a participating firm's R&D spending will differ according to their motives for participation, and thus the diversity of member firms in SRPs. There are three ways that the diversity of R&D consortia participants affects the R&D expenditures of participating firms (Sakakibara, forthcoming-b). The first is the spillover effect of a firm's own R&D on others' R&D productivity. When the outcomes of SRPs are pooled and shared, firms find it best to increase their R&D efforts. The spillover effect is larger if a degree of knowledge complementarity among participants is higher, because firms can achieve better outcomes by combining their knowledge. Assuming that the diversity of participants increases the degree of knowledge complementarity, this diversity implies higher R&D expenditure.

The second effect of cooperative R&D on a firm's R&D spending is from learning, which is defined here as efforts by firms to assimilate and exploit knowledge or information generated by other firms (Cohen and Levinthal, 1989). Suppose that higher R&D expenditure facilitates better learning capability. Levin et al. (1987), for example, point out that independent in-house R&D is the most effective means to learn about rivals' technology. It is also documented that Japanese companies participating in consortia customarily set up in-house research groups to absorb and utilize the results of R&D consortia (Kodama, 1985). If there are better learning opportunities created by SRPs, the participants spend more in their R&D. Assuming that diversity of participants increases a degree of knowledge complementarity and thus learning opportunities, diversity implies higher R&D expenditure.

The third effect relates to the impact of R&D cooperation on product market competition. The more direct the product market competition among the participants, the less willing they will be to cooperate even if they own complementary knowledge. Katz (1986) argues that if higher levels of R&D make market competition more intense by lowering firms' production costs, then the resulting decline in profits will reduce their incentive to conduct R&D. Katz showed that R&D consortia could depress R&D as firms seek to lessen the severity of competition in the product market. In the case that participants are from more diverse industries (as opposed to coming from a single industry) in the product market, however, this argument implies higher R&D expenditure by consortia participants, since the market-competition effect is expected to be smaller in this case.

All three effects suggest the possibility that R&D consortia whose members have diverse backgrounds may increase participants' R&D spending, relative to consortia of single-industry participants. Note, these three effects are not necessarily mutually exclusive. The spillover effect and the learning effect are the results of technological diversity of consortia participants, while the product-market-competition effect is related with the degree of direct competition among participants in product markets. Sakakibara (forthcoming-b) finds from firm-level financial data and consortia data that when SRPs consist of firms with diverse technological knowledge, these firms offer learning opportunities and increase spillover productivity, which result in more intensified R&D efforts of participants. When R&D consortia participants have diverse business backgrounds, the expected product market competition is less intense, leading to higher R&D expenditures by participants. Sakakibara (1997a) also finds from the survey-data that when the skill-sharing motive for participating in cooperative R&D becomes relatively more important than the cost-sharing motive, a firm's R&D spending is likely to increase, consistent with results based on quantitative data.

**C. Performance evaluation of SRPs**

The third, and perhaps most important issue, is the determinant of the performance of SRPs. There are multiple levels one can approach on this issue. The first level is the overall impact of the participation in SRPs on research productivity of participating firms. As explained earlier, there are many reasons we expect a positive relationship between the participation and the increase in research productivity of participants, including the cost- and skill-sharing effects. Branstetter and Sakakibara (1998) examined the data on Japanese government-sponsored R&D consortia. They found that if a firm participates in an additional project per year, it would raise its patenting per R&D dollar (i.e., its research productivity) by between 4% and 8%.

A more disaggregated approach is to identify the characteristics of consortia that are associated with the increase of research productivity of participating firms. Branstetter and Sakakibara (forthcoming) examined the same data. They focused on two major characteristics of SRPs: spillover potential and ex-post product market competition among participating firms. Theoretical literature, Katz (1986) and others, predicts that the greater the potential levels of R&D spillovers within consortium, the greater the level of R&D by member firms. This is because when a firm can benefit more from R&D outcomes by other member firms through higher spillovers, the firm is motivated to conduct more R&D, leading to better research outcomes as SRP members. On the other hand, some of the private benefits of cooperative R&D, in terms of raising firm profits, could be dissipated through product market competition. When the level of product market competition among participating firms is not intense, a participant can appropriate all the returns R&D outcomes, motivating member firms to conduct more R&D and achieve greater outcomes. Branstetter and Sakakibara (forthcoming) measure spillover potential as technological proximity among member firms in the technological space, calculated from member firms' patent portfolio, and the level of ex-post product market competition as the product market proximity of member firms. Their outcome measure is the number of patents taken by consortia participants in technological areas targeted by consortia. They find positive association between technological proximity and consortium outcomes, and a negative relationship between product-market proximity and consortium outcomes. In addition, they employ qualitative characteristics of consortia taken from survey results by Sakakibara (1997a, b), and find that these consortia are most effective when they focus on basic research.

Sakakibara and Branstetter (2000) apply the same methodology to the data of U.S. consortia, sponsored by the Advanced Technology Program of the Department of Commerce. They find similar results in the U.S. case: There is a positive association between the intensity of participation in research consortia and the overall research productivity of participants. There is also a positive impact of consortia on the research productivity of participants in the technological areas targeted by the consortia. This positive impact of consortia is higher when the average technological proximity of participants is high. In both Japanese and U.S. SRPs, there is evidence that R&D intensive firms tend to benefit more from the participation in consortia.

Sakakibara (1997b) conducted an analysis of the performance of R&D consortia from a managerial perspective. The results show that there is no clear link between the existence of R&D consortia and industry competitiveness. This study also investigates the perceived benefits and costs of Japanese R&D consortia based on 398 responses to questionnaires distributed to high-level corporate R&D managers who have participated in R&D consortia. The perceived benefits of projects are rather intangible, such as researcher training and increased awareness of R&D in general, not the commercialization of project outcomes. The overall subjective evaluation of the typical project's success is modest, and participants do not perceive R&D consortia to be critical to the establishment of their competitive position. This finding of the positive but modest benefits of SRPs is consistent with the finding from econometric studies.

**IV. Data Issues of Evaluation Studies**

There is a fundamental issue that researchers have to cope with when they conduct evaluation studies of government-sponsored R&D. Participation in SRPs, or the selection of member firms by the government, is not a random event. To the extent that they could, governments seek to encourage firms with strong R&D programs to participate in their sponsored SRPs because they want to maximize the returns from government subsidies. As a result, if we observe good outcomes from certain types of SRPs, we cannot distinguish whether these types of SRPs are designed to yield good outcomes, or if only good firms participate in these particular SRPs. This selection problem is the single greatest limitation of past research to measure the impact of public-technology programs (Klette, Moen, and Griliches, 2000).

The data obtained by Sakakibara (1994, 1997a,b) make it possible to employ several techniques to deal with the selection problem. The data contain multiple dimensions of information (SRP, firm and time). At the SRP level, they include a description of each project, its period of operation, the total budget, the amount of government subsidy, and the names of participating firms. At the firm level, the data include all the financial information. They also contain not only input data (R&D expenditure) but also output data, measured as the number of patents taken by participating firms, both the overall patenting and patenting in the targeted area. These data are available over a long period of time; the most detailed data are available from the early 1980s to the mid 1990s. In addition to these quantitative data, qualitative evaluations of managers from participating firms are obtained through questionnaire survey.

The analyses of Branstetter and Sakakibara (1998, forthcoming), for example, demonstrate a way to address the selection problem by utilizing these data. By employing the data of patenting in the targeted technologies before, during, and after participation in a consortium by individual firms, they can control for pre-existing technological strength of a firm in the targeted technologies, which enable them to isolate an additional effect due to the participation.

Also, the data set includes observations on firms that did not participate in consortia. This dimension helps to highlight the effect of participation. Even if we observe any increase in R&D outputs by a participating firm during the period a SRP operated, we cannot conclude that increase is due to the SRP. It might be the case that technological opportunity in that field increased, or the overall economic condition was favorable. By having firms, which did not participate as a control, we can "extract" the pure-participation effect.

Finally, because we observe the same firms participating in multiple consortia, we are able to measure the marginal impact of different consortium characteristics and firm characteristics on research outcomes, controlling for consortium and firm fixed effects. A conceptual experiment this data set allows is, for example, to examine how the same firm would perform if we moved it from a consortium with a set of characteristics to one with a different set of characteristics. In a similar manner, we can estimate the impact of different firm characteristics; in other words, we can determine what kinds of firms benefit most from SRPs.

Qualitative and quantitative data offer different advantages. R&D output in this data set is measured by the number of patents generated by firms. There are limitations inherit in the patent data. For example, some innovations are not patentable. The impacts of learning by researchers in SRPs are not even codifiable. Survey data provide us with qualitative aspects of the outcomes of SRPs, and it is best, as discussed earlier, to utilize both types of data to evaluate SRPs.

Though we can learn a lot from existing data, certainly they are not perfect. First, we need multiple measures to evaluate the outcomes of SRPs. The ultimate goal of SRPs is the commercialization of research. It is very difficult to map from SRPs to the eventual commercialization of the targeted research project, however, because there is a time lag between a project and a commercialization: this time lag is project specific. Also, participating firms need to make their own efforts after the conclusion of SRPs. It is therefore difficult to quantify the exact contribution of SRPs on the eventual commercialization. Any data that help the mapping from SRPs to commercialization would be useful.

Also, it is very helpful for policy makers to obtain data of pure private SRPs. As already discussed, journal-article database might have a bias toward "hot" fields such as information technology, because they are frequently covered by media. Having data of pure private SRPs, policy makers can compare them with government-sponsored SRPs, and evaluate the marginal effect of government support. Given the increasing importance of SRPs, more data on them are helpful not only for policy makers but also for managers who consider participating in SRPs and are trying to maximize returns form participation.

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# Strategic Research Partnerships: What Have We Learned?

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## I. Introduction

An extensive knowledge has accumulated about strategic research partnerships (SRPs).[1] SRPs take many forms and have significant effects on innovative investment behavior and performance. In this short paper, I provide my perspective of what we have learned and our needs for more data. The overview is based on my understanding of the literature and on my own experience with research about R&D and technological change. My own work has focused on small pieces of the giant research puzzle about SRPs, so the task of setting out a perspective on what has been learned is especially daunting. Here are my summary thoughts, nonetheless. I shall attempt to provide short, summary answers to three questions that have been addressed in the literature. First, why, essentially, are SRPs socially useful? Second, what is the role for public policy with regard to SRPs? Third, what data initiatives are needed with regard to SRPs?

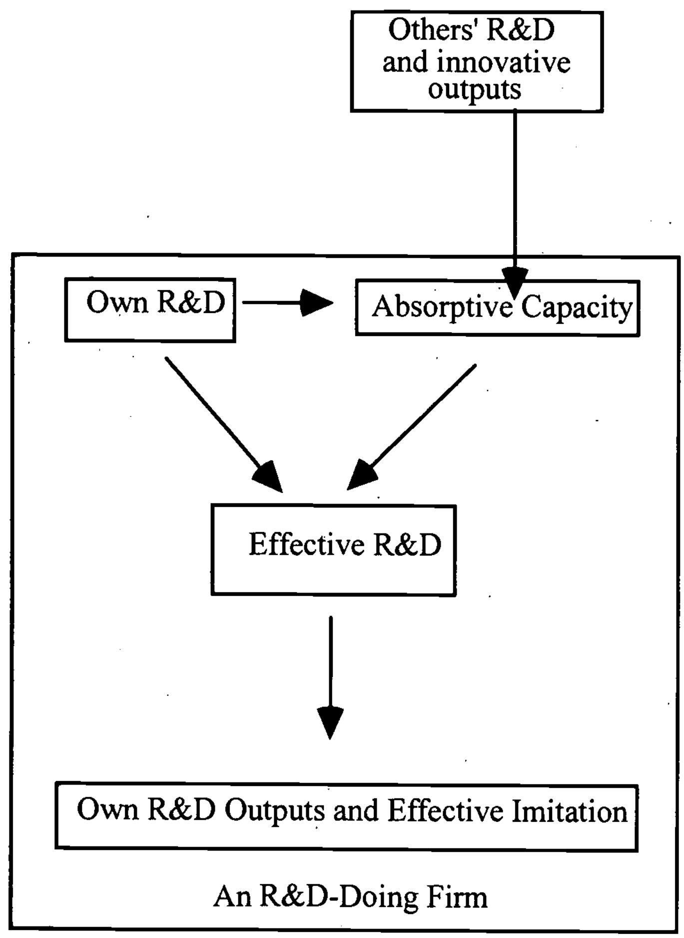
## II. Why are SRPs Socially Useful?

The literature has documented many reasons that I shall boldly combine to conclude that essentially, *SRPs are socially useful because they expand the effective R&D resources applied in innovative investment*. Why do they in effect expand the R&D resources applied? SRPs can achieve expansion of effective R&D for many reasons; Hagedoorn (2000) provides an excellent list, including, for example, that SRPs may make possible realization of economies of scale and scope in R&D. However, I shall emphasize one reason, because my own understanding of the theoretical work and the empirical work points to its great importance as a "reason behind the reasons" for the social usefulness of SRPs.

I conjecture that at the heart of much of the social benefit from SRPs is the importance of what the innovation literature has termed investment in absorptive capacity. Without a SRP, a firm must do R&D in a particular technology area to be able to benefit from the spillovers of R&D insights or innovative outputs generated by the R&D of other firms. Figure 1 illustrates the role of absorptive capacity.

[1] The background papers for the workshop where this paper was presented provide an excellent overview of the literature and the questions about data used to track the incidence and performance of SRPs. See Audretsch (2000), Bozeman and Dietz (2000), Dodgson (2000), Feldman (2000), Hagedoorn (2000), Hagedoorn, Link, and Vonortas (2000), Hansen (2000), Hicks and Narin (2000), Link and Vonortas (2000), Martin (2000), Mowery (2000), Sakakibara (2000), Siegel (2000).

**Figure 1: Absorptive Capacity for an R&D Performing Firm**



Martin (2000b) has provided an insightful review of the literature about absorptive capacity. He has also modeled noncooperative equilibria with various forms of SRPs, taking into account the need to invest in absorptive capacity along with the effects of spillovers in R&D and appropriability difficulties because of imitation of innovation (Martin, 2000a). My first point is that our learning about absorptive capacity is a key, perhaps the crucial key, for understanding social gains from SRPs.

To illustrate the importance of investment in absorptive capacity, I have used patent citations to design a test of the absorptive capacity hypothesis. Absorptive capacity is increased by active participation in the markets where research is applied and by active R&D invested in the technologies for which R&D is borrowed. Therefore, we expect the multimarket contact of two firms will increase their expected cross-citations holding constant the expected citations associated with particular market locations and other characteristics for the citing and cited firms. We expect greater multimarket contact to be associated with additional citations, other things equal, because the R&D embodied in others' patents is more useful to firms actually doing research in an area. I am assuming that the citations reflect the usefulness of the R&D embodied in the cited patents. Certainly, some citations may be for strategic reasons of protecting against potential litigation, although even then the need to use the citations for such protection suggests the usefulness of the R&D embodied in the cited patents. In any case, for the test of the absorptive capacity hypothesis, my focus is on the citations as a reflection of the usefulness of the R&D of other firms.[2]

Table 1 provides the key evidence supporting the absorptive capacity hypothesis; the evidence is taken from a model of the citations of one firm of the patents of another (Scott, 2000b). With the effects of other variables held constant, Table 1 shows the incidence rate ratios (IRRs) for citations given completely insignificant congruence (the probability of more congruence is 1.0 against the null hypothesis of random meetings) of the citing and the cited firms' operations as compared with completely significant congruence (the probability of more congruence is 0.0 given the null hypothesis). For product market contact, other things being the same the number of citations with insignificant contact are predicted to be 0.217 or 21.7 percent of the citations with significant contact. For innovation market contacts, other things being the same, the citations with insignificant contact are predicted to be 0.107 or 10.7 percent of the citations given significant contact. Both of these IRRs are estimated well, and the table shows their 95 percent confidence intervals.

These statistics use the estimates from a negative binomial model of the citations by firm i of the patents of firm j. The model controls for the firms' numbers of patents, the science linkage of their patents, their product market diversification (as indicated by the industries where they have sales), their innovation market diversification (as indicated by the product categories where they have patents), their locations in product and innovation markets, and the significance of the congruence of their product market operations and their innovation market operations.

[2] The multimarket contact occurs across a large array of innovation and product markets. Therefore, the usefulness of the R&D embodied in the cited patents can result in vertical technology flows as well as horizontal flows of the R&D results for one firm to their uses for another firm.

**Table 1: Incidence Rate Ratios for Citations Given Insignificant versus Significant Congruence of Product and Innovation Market Operations**

| Variable | IRR | Standard Error | z | Prob>\|z\| | 95% Confidence Interval |
|---|---|---|---|---|---|
| Prob(>Gprod) | 0.2168 | 0.03874 | -8.555 | 0.000 | 0.1527 to 0.3077 |
| Prob(>Gpat) | 0.1067 | 0.03919 | -6.090 | 0.000 | 0.05190 to 0.2192 |

**Source:** Scott (in *Advances in Strategic Management*, Vol. 18, forthcoming), available as Dartmouth College Working Paper 00-14, August 2000, at http://www.dartmouth.edu and then follow the links to teaching & research, social sciences, economics, and finally working papers. Details of the estimation are provided there.
**Notes:** The variable Prob(>Gprod) is the probability of a greater number of product market meetings (Gprod) for the citing and the cited firms given the null hypothesis of random diversification. Prob(>Gpat) is the probability of a greater number of meetings (Gpat) in the "innovation markets"—the categories to which patents are allocated. The z statistic is for the underlying coefficient in the negative binomial model. The IRR shows the estimated coefficient transformed to an incidence rate ratio. The standard error and the confidence interval shown here are appropriately transformed as well.

The effect of multimarket contact on citations, given controls for the product and innovation market effects in citations, is expected because the R&D of other firms is most useful to a firm when it is actively involved in the same product and innovation markets as the firms whose R&D it borrows. The model controls for the effects of the cited firm being in particular product and innovation markets, and it controls for the effects of the citing firm being in particular markets. Holding constant those effects, congruence of two firms' operations across the product and innovation markets of each is extraordinarily important for their ability to absorb each other's research and development ideas.

The importance of congruence for absorptive capacity is evidenced by the greatly increased frequency of mutual citations apart from the effects associated with particular locations in the product and innovation markets. Imagine two firms that have completely congruent operations in product markets. Then even after controlling for the effect of that congruence, and even after sweeping out the effects associated with the particular locations in product and innovation markets, with the closeness to science and size of the patent portfolios, and with the diversification in product and innovation markets, the additional effect of significant congruence in innovation markets increases the expected citations by about nine (1/.11) times.

In addition to the congruence result supporting the importance of investment in absorptive capacity, the negative binomial model of citations shows that diversification of firms across product and innovation markets increases the usability of research ideas—a possibility emphasized by Nelson (1959). Diversified firms cite other firms' research outputs more frequently, and research outputs of diversified firms are more frequently cited (Scott, 2000b).

I make two inferences based on the evidence:

- If a firm's R&D resources are actively involved in research in a technology area, the firm is more likely to find useful the R&D results from other organizations in that technology area. The evidence of the additional utility is based on additional citations, even after controlling for the other effects (such as the technology area effect itself) in citations that are the measure of usefulness here.
- Diversification of R&D effort across technology areas itself increases the usefulness of research outputs. Again, the evidence of additional utility as reflected in citations is even after control for the other effects in citations.

What then is the implication of the evidence for the social economic value of SRPs? The implication is: SRPs expand the *effective* R&D resources applied in R&D investment given *actual* scarce resources allocated to R&D. A priori, social economic value is created by SRPs because they expand the effective R&D resources applied in innovative investment. Bringing together the research resources of multiple organizations extends the range of potential research outputs.

Why would the amount of effective R&D resources devoted to innovative investment increase given the same amount of scarce resources devoted to R&D? Within a SRP, the resources of firm 1 are juxtaposed with those of firm 2, and the resources of each have the advantage of the *active* knowledge of the other's resources. As Kealey and Al-Ubaydli (2000) observe, "because science moves so fast, and because it takes personal expertise at the cutting edge to discriminate usefully between different research papers, patents and products, ... only *active* scientists have the judgement and tacit knowledge to capture others' science efficiently." Juxtaposing the active R&D resources of the partners, a SRP in effect increases the absorptive capacity of the partners given the resources that they bring together.

Figure 2 illustrates the point that SRPs expand effective R&D resources. Without a SRP, we expect just a portion (perhaps a proportion close to or equaling zero) of the effective R&D of others is appropriated. With a SRP, the active R&D of both firms, often in multiple technologies, is juxtaposed, and the effective R&D appropriated from a partner is expected to be much greater than would be the case without the SRP. Of course, the more a firm invests—apart from the investment in the SRP—in appropriate absorptive capacity, the more likely it will get additional benefits from a SRP that juxtaposes its active R&D with the active R&D of others.[3]

**Figure 2: Effective R&D Resources Applied in R&D Investment**

| | In Area A | In Area B |
|---|---|---|
| Firm 1: | $x_1 + f(x_2)$ | |
| Firm 2: | | $x_2 + g(x_1)$ |
| SRP: | $x_1 + F(x_2)$ | $x_2 + G(x_1)$ |

**Notes:** Here $x_i$ denotes the *ith* firm's R&D investment and the functions f(xj) and g(xj) denote the portion of R&D effort by firm *j* (possibly in another area of research although that need not be the case) that is appropriated by firm *i* for use in firm i's technology area in the absence of a SRP. The effect of the greater amount of resources and of their different types would be observed in the function linking inputs to the uncertain innovative outputs. That function might change given the SRP. Further, the SRP might find it optimal to change the amounts of resources $x_i$. The principal effect emphasized here is, however, the greater amount of R&D resources joined with *active* research in a given technology area and the resulting expectation that the functions F and G reflect greater effective cross-firm investments than f and g respectively.

[3] Link and Scott (2000a) find that the probability of a licensing agreement—a type of SRP—between two firms increases with their citations of each other's patents, other things being the same.

## III. What is the Role for Public Policy with Regard to SRPs?

Given appropriate legal infrastructure (for example, intellectual property law and antitrust law), and given appropriate technology infrastructure (for example, traceable standards of measurement maintained in national laboratories), will private incentives be sufficient to provide all socially optimal SRPs? In answer to this second question, I have three observations.

First, appropriability difficulties are not sufficient justification for public funding of SRPs. Even extreme cases of spillover of R&D investments and imitation of innovations are consistent with socially optimal innovative investment based on private incentives alone (Martin, 2000a; Scott, 1993, chapter 8). The reason, most fundamentally, is that each firm among rivalrous R&D competitors invests in anticipation of its own returns without regard to the cannibalization of the expected returns of its rivals. As long as there is a quality dimension (the expected quickness of the time of introduction, for example) to R&D output that increases with R&D investment so that the value of R&D increases with that investment, then a monopolist of R&D will underinvest from the social standpoint.[4] Yet rivalrous competitors "overbidding" for the innovation can offset such underinvestment, although they do so imperfectly because of a loss of optimal R&D cost structures and over-shooting or under-shooting of the socially optimal investment.[5] Nonetheless, when appropriability difficulties are severe, public policy may well be necessary to bring about the socially optimal amount of investment.

Second, partial public funding of privately performed SRPs or joint public/private SRPs will be needed to provide socially optimal SRPs when without public support the net social economic value of the SRP is positive but the net private value is negative. Following the discussion of Figure 2, I conjecture that an important reason for private underinvestment in socially valuable SRPs in the absence of public support will be the concerns of each private partner about juxtaposing its own active R&D resources with the active R&D resources of others. Those concerns would be expected when the gain from exposure to the active R&D of others exposes the partner to a potentially greater loss from opportunistic exploitation of its own active knowledge by the other partners. As Hicks and Narin (2000) explain in the context of their observation that joint patenting is rare, "Companies ... seem to have a positive aversion to sharing intellectual property which they only rarely overcome ..." (p. 11). When the active science of two firms is congruent across product and innovation markets, the R&D effort of each is more useful to the other. Public support for SRPs might be appropriate, then, if there are social gains—from juxtaposing the active R&D resources of different partners operating in different technological areas—that have not been realized given private incentives alone.

Third, the condition for public support of SRPs is more likely to be met in certain cases, including the following:

- Infrastructure technology (Link and Scott, 1998): Social economic value from scarce resources is increased by widespread use of nonproprietary infratechnologies.[6]
- Generic technology (Link and Scott, 2001): Spillovers from generic technologies increase social value beyond the value appropriated by innovators.

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[4] See Baldwin and Scott (1987), chapter 2. As explained there, exceptions are possible.
[5] See Scott (1993, chapters 8 and 14).
[6] See Tassey (1997) for careful and complete development of the importance of infratechnologies.

- New science requiring university partnerships with industry (Hall, Link, and Scott, 2000): The research problems are especially difficult, and although university involvement increases the chance of success, appropriability difficulties increase as well.
- Monitoring costs that can be reduced by a public partner (Leyden and Link, 1999): The public partner may lessen free-riding problems.
- Financial market imperfections that prevent private funding of socially valuable research (Link and Scott, 2000b; Audretsch, Link, and Scott, 2000).
- Social rather than market-based goals for research outputs (Scott, 2000a): Minority ownership or small business involvement, for example, may be social goals that would not be met by market solutions alone.

And, following the discussion about absorptive capacity in the present paper:

- High risk of opportunistic exploitation of each partner's active R&D knowledge when juxtaposition of active R&D assets for the partners will provide socially valuable extension of the application of existing R&D resources.

## IV. What Data Initiatives are Needed with Regard to SRPs?

From the literature[7], we have learned that SRPs have important effects on innovative investment behavior and performance. Further, we have learned that public policy can improve the performance of SRPs in certain cases. We also have learned that the data about SRPs are limited, not systematically gathered or coordinated, and uneven in quality. The implication for data initiatives is clear. To inform public policy, the public needs an ongoing documentation and reporting of the incidence of SRPs, their types, their research inputs and research outputs.

We have many outstanding individual efforts to assemble data about SRPs. Consider for example the data sets described in Audretsch (2000), in Dodgson (2000), in Feldman (2000), in Hagedoorn (2000), in Hagedoorn, Link and Vonortas (2000), in Link and Vonortas (2000), in Sakakibara (2000), and in Siegel (2000). However, for just one example, consider how much more understanding could be developed if the remarkable data about the incidence of SRPs over time described in Hagedoorn (2000) were augmented with good measures of the inputs and the outputs of those SRPs. As the discussion in Mowery (2000) makes clear, our data are incomplete even when we have data focused on particular types of SRPs and gathered by public institutions.

Siegel (2000) has surveyed the available and the needed data and proposed practical agenda for efficiently establishing systematic data about SRPs.[8] Bozeman and Dietz (2000) discuss the complexity of developing indicators of SRP activity, and Hansen (2000) explains the challenges of gathering information to create indicators. Based on my own first-hand experience, I add only an emphasis on the need for development of our available measures of research outputs. Multiple measures, each reflecting the particular circumstances of a type of SRP, are useful and appropriate.

[7] See the references in footnote 1 for review of the pertinent literature.

[8] Again, see the papers listed in footnote 1 above for additional survey material, with particular reference to the previous experience with technology innovation indicators as described by Hansen (2000) and to the general needs for technology indicators as described in National Research Council (1997). Siegel (2000) has undertaken the task of surveying the SRP data considerations quite generally.

I shall give four examples. First, when evaluating SRPs with significant public *performance* in partnership with industry, benefits can be quantified by asking what would have been the cost to the private sector to accomplish the same thing (or as near as possible absent the government with its unique resources, and with the shortfall measured as well) without the government as a research partner. The costs avoided (and any outcome shortfall costs) are the benefits from the public's investment in the projects (Link and Scott, 1998)—benefits that are then used to compute social rates of return to the public's investments in technology innovation.

Second, when the public does not perform research, but instead provides funding for privately performed research, to our measures of actual post-investment outcomes, we can add the *expected* rate of return at the *start* of the research project. Both the expected social and private returns can be estimated (Link and Scott, 2001), using an investment model and an interview technique to assess the extent of spillover effects from R&D investment. Of course, even when expected social rates of return exceed the hurdle rates (which in turn exceed the expected private rates of return without public support), many projects worthy of public support will not turn out well, while a select few will have extraordinarily high returns.

Output measures may of course extend beyond formal measures of the social and private rates of return from innovative investment. Useful measures may tabulate the incidence of research outcomes that are correlated with social value. Further, the tabulation may be an *estimate* based on readily available data. For a third example, then, I use the method in Link and Scott (2000a), which estimates the probability of a licensing agreement occurring between a pair of firms in specified industries. Systematic measures of the incidence of licensing agreements, an important means of technology transfer, are not available, and the method allows estimation of the incidence of licensing in the various technology areas by using readily available data about the patent portfolios of firms.

Finally, for a fourth example, research output measures based on total factor productivity can usefully measure the total factor productivity for groups of technologically close industries in addition to the traditional approach of measuring the total factor productivity for the individual industries. The effect of R&D on total factor productivity growth—the rate of return to R&D investment in the context of the model of productivity growth—is both larger and more significant statistically when the relation between R&D and total factor productivity growth is estimated across groups of industries with strong complementarities in R&D activity (Scott, 1993, pp. 128-131).

The foregoing examples from my own experience are of course a very small subset of the many types of SRPs and the many types of output measures that have been described or proposed. Our collective assessment of the literature and evidence about SRPs yields a clear answer to the third question. We need to develop systematic tracking of the incidence of the various types of SRPs, their research inputs, and their research outputs. Further, we need to develop a large number of measures of the research outputs of SRPs in order to capture and document their social benefits.

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## Constructing Indicators of Strategic Research Partnerships

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### I. Introduction

Strategic research partnerships (SRPs) have not only grown in numbers during the 1980s and 1990s (Link. 1996; Mowery, Oxley, and Silverman. 1996; Okubo and Sjoberg. 2000) but in importance in research and development (R&D) policy circles. They are widely perceived to be important to economic growth and the productivity of industrial research. But has reality kept up with perception? In fact, we have so little information about SRPs (Kleinknecht and Reijnen. 1992) that most of our assumptions about their impact on the U.S. economy are really nothing more than anecdotal or based on folk wisdom or based on research that employs diverse indicators and unclear conceptualizations (Kleinknecht and Reijnen. 1992).

Until we have a set of indicators based on a set of valid constructs, it will remain difficult to determine the importance of strategic research partnerships for the U.S. economy and the enterprise of science and technology in general. For example, absent a useful conceptualization we do not know whether SRPs are a substitute or an increment to companies' own R&D (Katsoulacos and Ulph. 1997; Mowery, Oxley, and Silverman. 1996). Without knowing more about the construct itself we really have very little idea about the extent to which formal research consortia are productive as compared to traditional informal collaborations (Faulkner and Senker. 1994; Smith, Dickson, and Smith. 1991; Freeman. 1991; Schrader. 1991) among peers at multiple sites who happen to be affiliated with multiple organizations.

The purpose of this paper is to identify characteristics of a desirable policy indicator for strategic research partnerships. Rather than reviewing the literature, we consider the analytical problems posed and the context of the general needs for any R&D policy indicator. We ask the question, "what are the specific requirements of a strategic research partnership indicator?"

### II. The Conceptual Model: What is a Strategic Research Partnership?

As is so often the case, the chief stumbling block for policy analysis is conceptual as much as empirical (Gassmann and von Zedtwitz. 1999; Katz and Martin. 1997). We can begin by asking what is the minimal requirement for a concept to even relate to the notion of strategic research partnership. We are assuming SRPs, given our interest in industrial productivity require at least one of the partners to be a commercial entity. Further, we assume that a single corporation acting alone does not constitute an SRP, nor does a corporation or firm that entails collaboration among its divisions or persons working within that firm. We take seriously the term "partnership" as implying that all of the entities involved in the social configuration of the research collaboration are in fact contributing in one manner or another. Similarly we take seriously the notion of strategic. Strategic seems to us to imply that the work that is undertaken is viewed as part of the firms' strategic directions, including product development, commercialization goals (Pisano. 1991), precompetitive R&D (Quintas and Guy. 1995; Faulkner and Senker. 1994), and so forth. Interestingly, one of the more difficult demarcations in the notion of SRPs is the very notion of research. As is well known in studies of industrial research, there are many activities that are on the borderlines of what we might call research. Some of these include process engineering, technical assistance, equipment development, and development of algorithms to be used for internal company production processes. While we are inclined to take a broad view of the notion of research, at least for present purposes, it is at least worth noting that there is that gray area of technical activity that one may or may not view as research.

Having considered some of the most elemental questions of strategic research partnerships, we move here to develop a tentative working definition that will suffice at least for the purposes of identifying a concept sufficiently sharp to permit an analysis of indicators appropriate to it. Our approach involves distilling concepts employed in the literature and borrowing from a variety of typologies that have already served some of the same analytical objectives.

At the broadest level, (Gulati. 1995) informs us that strategic interfirm alliances "encompass a variety of agreements whereby two or more firms agree to pool their resources to pursue specific market opportunities" ( p. 86). More specific to research, Hagedoorn, Link, and Vonortas (2000), define SRPs as "an innovative relationship that involves, at least partly, a significant effort in research and development..." (p. 1). This perspective places the SRP definition within the broader notion of strategic alliances and recognizes that R&D may be one element (albeit an important one) embedded within a larger strategic framework, and thus, it may be difficult or unwise in these cases to extricate the research component from the larger purpose.

A legal-based concept that grew out of the National Cooperative Research Act of 1984, was the notion of "research joint ventures." The Act defined the joint venture to be any number of activities by two or more persons for the purpose of theoretical analysis, the development of basic engineering techniques, the extension of experimental findings or theory into practical applications for experimental and demonstrative purposes, and the collection and exchange of research information.

Coursey and Bozeman (1989), in studying industry-government laboratory partnerships, defined it as "any arrangement, formal or informal, whereby at least one government laboratory and one private firm jointly develop and/or obtain technical knowledge." (Coursey and Bozeman. 1989, p. 8) And, although this definition was created to specifically examine the role of government labs, it easily comports with the SRP notion, namely collaborative R&D arrangements involving at least one industrial firm and one other organization. (For empirical data using this conceptualization see Crow and Bozeman, 1998).

But what are the relationships and collaborative arrangements that make up these partnerships? According to Coursey and Bozeman (1989), they may include:

- Joint research ventures and cooperative research agreements
- Collaborative research centers
- Research consortia
- R&D limited partnerships
- Research subcontracting

Mowery (1998), proposes a sector-based conceptualization including industry-led consortia, collaborations between universities and industry (not of the first type), and collaborations between industry and federal laboraties, often making use of formal cooperative research and development agreements (CRADAs).

As Hagedoorn, Link, and Vonortas (2000) point out, SRPs can be classified by their membership (e.g., public, private organizations) or by the organizational structure of their relationship. This latter category includes informal versus formal arrangements, and within formal, they can further be divided into equity joint ventures focusing on R&D (i.e., "research corporations") and contractual agreements they call research joint ventures. "Research corporations are created by at least two firms that combine their R&D skills and resources through equity joint ownership of a separate firm, and generally this new firm or child performs only R&D that fits within the broader context of the research agenda of the parent firms…Research joint ventures [on the other hand], such as joint R&D pacts or consortia to cover nonequity agreements, are created so that firms and other organizations can pool resources in order to undertake joint R&D activities" (Hagedoorn, Link, and Vonortas. 2000, p. 569).

Hagedoorn, Link, and Vonortas (2000) provide a useful review of the theoretical streams running through the SRP literature. Various frameworks have been applied in attempting to understand these linkages, a most prominent one in the literature being the minimization of transactions cost (Gulati. 1995; Gulati and Gargiulo. 1999); (Osborn, Hagedoorn, Denekamp, Duysters, and Baughn. 1998). Transactions cost theorists posit that the anticipated cost of a research transaction governs the form of alliance. In addition to transactions cost, Hagedoorn and colleagues (forthcoming) review strategic management and industrial organization (including tournament and non-tournament) frameworks. The strategic management literature has introduced the notion of the *strategic network* as not only a new form of organization but as a strategy. This same literature has sought to understand interfirm alliances in terms firms representing sets of *resources* (i.e., depositories of useful assets), or the *dynamic capabilities* they embody (i.e., firms as expert doers). Strategic management scholars therefore emphasize not just the minimization of transactions costs, but the ability of the firms to accomplish something altogether unlike what they would be able to accomplish otherwise.

Some examples of SRPs include: joint ventures within the Department of Commerce's Advanced Technology Program (which are focused at industrial firms but may include university and government labs), Industry University Cooperative Research Centers and the Engineering Research Centers of the National Science Foundation (which are headquartered at universities but include industrial firms), and government-initiated consortia such as Sematech and the Microelectronics Research Center. But SRPs need not be government sponsored, and, in reality, the majority are not. They need not be large and they need not be as visible as say the Semiconductor Research Alliance.

An important part of understanding the importance of SRPs is in understanding their function or their raison d'être. Mowery (1998) offers some potential benefits to SRPs: (1) to enable member firms to appropriate knowledge spillovers which would otherwise be lost, (2) to enjoy the benefit of scale economies of research, (3) to reduce duplicative R&D performed by the members, (4) to speed the commercialization of new technologies, (5) to facilitate the transfer of knowledge from universities to industry, and (6) to provide access to the unique capabilities of government labs. Hagedoorn and Schakenraad (1992) add the sharing of costs and uncertainty, access to complementary technologies, learning new tacit technologies, monitoring environmental changes, entering foreign markets, and expanding product range (See also Hagedoorn, Link, and Vonortas, 2000, for a review of SRP benefits).

March's (1991) work on organizational learning points out a potentially useful distinction for understanding SRPs. This is the difference between exploitation and exploration—the former focusing on making use of existing competencies and capabilities, the latter on the investigation of new alternatives. This categorization may be useful in understanding firms decisions to "make or buy" (i.e., look internally or externally) research. Moreover, Powell and colleagues (Powell, Koput, and Smith-Doerr. 1996) argue that when knowledge is rapidly changing, dispersed, and fragmented among different parties, the "locus of innovation" moves to interorganizational relationships.

As we can see from the literature, a variety of conceptual problems serve as barriers to the development of indicators of SRPs. Let us simply innumerate some of the leading questions that are implied by current uses of the term and in existing typologies. *First, are SRPs entirely formal research vehicles or do they also include informal collaborative research?* This question is vital and there are good arguments for including informal arguments and there are good arguments against including informal collaboration. The best argument for a more expansive definition is that may informal collaborations are extremely important and productive, whereas at least some formal collaborative arrangements are symbolic and maybe of very little value whatsoever. The chief argument for focusing only on formal collaborations is that they are much more easily identified and it is possible to set boundaries, albeit artificial boundaries, around them. The notion of informal collaboration is so difficult to set boundaries around that one has difficulty determining how to proceed to actually identify them (Powell, et al., 1996). Most people who have included informal definitions of SRPs rely almost exclusively on interview and questionnaire data. While interview and questionnaire data have obviously a great deal of utility, the construct validity for SRPs obviously poses potential problems.

*Second, when do strategic research partnerships begin and end?* This is closely related to the question of whether formal and informal strategic research partnerships are considered together. In most instances, if there is a formal document referring to the SRP it is time bounded. However, in informal relationships it is difficult to put an end boundary simply because it is quite possible that the same configuration of people and resources will come together in the future for additional research purposes. Moreover, even in the case of formal relationships it may well be true that the actual research that is accomplished has a relatively limited relationship to the documents that are proscribing the research.

*Third, how does the fact of strategic research partnership relate to its performance and intensity?* The most common approach to the measuring of SRPs is to simply count them. While this itself is not altogether a straightforward task, without some workable definition of SRPs, it is still more difficult to determine the level of intensity of the partnership. For example, if a firm has ten SRPs and another firm has a single SRP, what are we to infer from that information? It may well be the case that each of the SRPs engaged in by the firm with ten are relatively inconsequential and have little bearing on the course or the productivity of the firm. By contrast, it is at least possible that the firm with a single SRP has bet everything on that partnership and has committed the full capacity of its research and development abilities to that partnership. However, as we shall see measuring the intensity of an SRP is no easy matter. It gets worse. Even if we are able to measure the intensity of an SRP measuring its productivity (even its productivity to the firm), is not an easy matter. For example, it is quite possible that a firm can be involved in an SRP, it can commit tremendous resources to the partnership, and not only may the research not be productive, it may well be the case that it is difficult to even know whether in fact it has been productive. Here we face all of the usual difficulties of assessing R&D productivity, the most prominent of which is the fact that there are differential time horizons for the pay off of R&D and, just as important, the firm may not be able to internalize fully the pay-offs that accrue because of an inability to appropriate them.

*Fourth, what is the impact of an SRP on aggregate economic growth?* Even if one knows the productivity of a partnership that accrues to the participants, one cannot easily scale up to a knowledge of the social and economic impact of the partnerships. Once again, we encounter a wide variety of familiar problems common to assessments of R&D productivity. The most prominent of these is the ability to measure spillover effects from the firm's economic activity. Fortunately, there are a number of standard approaches to making such assessments, and it is likely that the weaknesses of these approaches are no greater (and certainly no less) for the question of SRPs than for the more general question of the contribution of technological change to economic growth.

*Fifth, to what extent does the construct of SRPs conform to various measures and methods for assessing them?* Let us assume that we have a viable construct for an SRP, an assumption that is patently optimistic but one which we hope at least will be a little more valid once we identify further conceptual problems. The existence of a satisfactory construct does not imply the existence of satisfactory measures and indicators for that construct. Thus the utility of the construct relates closely to the set of measurements of and methodological assumptions that occur with its use. Thus, for example, many studies relying on questionnaires and interviews may be of limited utility for operationalizing satisfactory constructs pertaining to SRPs (Mowery. 1998). We will return to this question at a later point when we consider specific indicators in connection with the ways in which one might go about developing satisfactory measures of those indicators.

*Sixth, how does the international and global nature of strategic research partnerships affect the appropriate conceptualization of them (*Gassmann and von Zedtwitz. 1999*)?* Clearly, many of the most important SRPs involve firms from two or more nations. However, much of the interest of policymakers has geographic boundaries. That is, policymakers are interested in the productivity of SRPs not in terms of their contribution to the gross global product but to the gross domestic product. Thus, is it useful to demarcate, even at the beginning, between SRPs that flow across boundaries of nations and ones that do not.

## III. R&D Policy Indicators: Desirable Characteristics

Many of the characteristics of R&D policy indicators should be judged by much the same criteria that one would employ in assessing any indicator or variable. Such features as policy relevance, simplicity, sensitivity, validity, stability, reliability, adequacy of index properties, etc., are as important to SRP indicators as they are to R&D (or any) indicators in general (See, for example, Bozeman and Melkers. 1993). And, thus, we do not dwell on the need for such traditional methodological and use standards. However, we do address methodological issues that seem particularly acute in a context of research and development policy indicators.

A good place to start is with a specific definition of strategic research partnerships. As we conceive it, SRPs are any arrangement, formal or informal, whereby at least one commercial enterprise and one other organization jointly develop and/or obtain technical knowledge. And, because this definition is rather broad, descriptive indicators are the logical first step in helping us to understand this phenomenon. Essentially, the question for a first set of indicators should answer the questions: What are SRPs? In what forms do they come? How common are they? And, what do they do? Generally speaking, and putting aside conceptual and methodological uncertainties for the moment, this descriptive group might include the frequency of SRPs, their structure, formality or codification, goals, life cycle, geographic location, resource investments, and R&D process indicators (See Table 1).

**Table 1. Possible Indicators of SRPs by Category and Level of Analysis.**

| Indicator Type-Indicator Category | Indicator Set | Level (unit of analysis) | Example |
|---|---|---|---|
| Descriptive | Frequency | Industry | Counts of SRPs by industry class |
| | Structure | SRP | Organizational composition/sector |
| | | | Legal structure |
| | Formalness | SRP | Legal codification |
| | Goals | SRP | Purpose of SRP |
| | | | Reasons firms entered SRP |
| | Life Cycle | SRP | Duration or planned duration of SRP |
| | Publicness | SRP | Sectoral origin of partners |
| | | | Economic/political authority |
| | Geographic Locale | SRP | Domestic, international |
| | | | Country make up |
| | | | Domestic zip code of firms |
| Input | Resources | Organization | Financial investments in SRP |
| | | | Personnel |
| Process | R&D type | Organization | R&D type (e.g., basic, applied, testing) |
| | | SRP | R&D field (e.g., biotechnology) |
| Output | R&D impacts | SRP | Publication and patents, citations |
| | | | Cross firm patent citations |
| | | | Licenses, Trademarks |
| | | | Control (access to) of intellectual property |
| | Product Development | Firm | New/improved product(s) |
| | | | New/improved process(es) |
| | | | New/improved algorithm(s) |
| | Economic | Firm | ROI, Revenues/profits |
| | | | Productivity |
| | | | Market share/penetration |
| | | | Spin-offs |
| | Technology Transfer/Diffusion | SRP | New capabilities/organizational learning |
| | | Industry | Spillovers |
| | | | Social rate of return |
| | Knowledge Value/Capacity | Any | Human capital improvements including student participation |
| | Building | | Personnel exchanges |
| | | | Collaboration/coauthorship patterns |

While indicators of these characteristics are important in understanding the SRP landscape, an important next step is in formulating indicator categories that will aid in understanding the policy relevance and importance of SRPs as compared with other R&D and business practices. This objective in indicators development suggests that performance indicators such as measures of SRP outcomes may be desirable. Again, leaving aside conceptual and methodological murkiness, this category might include measures of R&D impacts, economic performance, product development, technology transfer, and capacity building (See Table 1).

These indicators categories, perhaps, raise as many questions as they answer—for few of these categories are simple to put in practice. Some of these questions include:

- *To what degree does the research conducted under an SRP substitute or complement existing research internal to the member organizations?*

This question is vital in understanding the role of SRPs as a mechanism to minimize transactions costs versus their role of permitting firms to pursue strategic directions and new capabilities that would otherwise be unavailable to them (or at least prohibitively difficult to pursue). The key methodological problem in pursuing indicators of substitutability is in their reliance upon counterfactual propositions and their requisite validity and reliability problems. Would a firm have pursued an SRP mission on its own anyway had there been no SRP? This is an exceedingly difficult question to answer for both questionnaire respondents about specific SRPs and policymakers about aggregate trends in SRPs.

- *What kind of research is conducted as part of the SRP? Is it more or less fundamental, strategic, applied compared to the other research of the member organizations?*

This question is, in some ways, related to the first one, and one can think of the composition of the research as one way SRPs may substitute or complement what R&D organizations are pursuing on their own. The difficulty, here, is two-fold: in identifying the proper categorization of research that is meaningful to the SRP member organizations, and in how to deal with the overall make-up of the research versus what individual researchers are themselves engaged in. It is quite possible that a group of academic researchers may characterize their research (rightly) as fundamental, while others (e.g., industrial researchers) may be working on more applied or developmental aspects of the project.

- *What would constitute indicators of success to the organizations who are part of an SRP?*

Perhaps one of the best strategies in dealing with unexplored areas of policy is to ask the participants themselves how they would define and measure success. This certainly would be an important pursuit for any exploratory or pilot studies that might lead to indicators development.

- *What would constitute indicators of "social" or societal success of an SRP?*

This question is particularly relevant to SRPs that are funded by the government. Is societal or social success the same as business success? In some instances, such as in industries that face intense international competition, it might be. But in many cases, business success does not seem entirely satisfactory as a rationale for the investment of public resources. One typical measure of social return involves the extent to which R&D findings reside in the public domain or "spill over" to other organizations. But, it seems that intellectual property issues would be particularly knotty in the area of SRP policymaking.

- *What is the morphology of SRP arrangements? Why would the taxonomy of organization structures of SRPs be important?*

It certainly may reveal much about what kinds of organizational structures and compositions seem to have relative advantages and disadvantages under various circumstances. Many federal and state programs now require partnering arrangements including those that involve universities (e.g., Engineering Research Centers of NSF) as well as those that do not (Advanced Technology Program of NIST). In fact, in 1997 Secretary of Commerce, William M. Daley, announced increased emphasis on a mix of companies, universities, and other organizations in the ATP joint ventures. Currently those policy mandates are justified based on mostly anecdotal or common sense rationales, and understanding SRP morphology is a step in the right direction.

- *How do or should indicators of SRPs relate to international partnerships and the research arrangements of multinational enterprises?*

Aside from knowing the prevalence of internationally-based companies partnering with domestically-based ones, what else needs to be known about the international dimension of SRPs? Clearly, there is a strong international trend that runs parallel to or is perhaps directly tied to the growth of SRPs in recent decades. And, of course, there are myriad difficulties in defining what is an international SRP versus a domestic one. For example, do foreign subsidiaries count as true partners or are they more akin to subdivisions within a firm. And, finally, what does globalization mean to a domestic policymaker?

- *What role do SRPs play in capacity building within member organizations, including the differential effects of firms, government labs, and universities working together?*

This is perhaps the area that has been most ignored in the literature on SRPs. It surfaces in the literature most often in the form of "organizational learning" (see, for example, Powell, et al., 1996; Cullinan. 1994). But is there something unique or important about SRPs in terms of their impacts on organizational capabilities and the human and social capital endowments of the people who work in them? Put differently, what are the implications of this mixing of organizational roles, objectives, cultures, and the different forms of human capital they possess? What impacts do SRPs have on the educational opportunities of graduate and undergraduate students? Do they effect the curriculum? The difficulty here is in deciding where to "set the trap"—that is, knowing what to measure and how to measure it successfully.

In a concluding section we provide our recommendations to consider a few needed "first step" in developing SRP indicators.

## IV. Conclusion

We have raised many questions and provided few answers. But at this point it may be premature to do much more than that. In the first place, despite the fact that many of our questions seem to us quite basic, few have yet received much attention. Second, there is no need to reinvent the wheel. The NSF and many other agencies have accumulated a great wealth of experience and craft in developing indicators. We have tried to focus on issues specific to SRP indicators, but the SRP indicators have much in common with most science and technology indicators issues. So, a good question to begin with (one answered more easily by others) is "in developing indicators that have been the backbone of *Science and Engineering Indicators*, what has been learned and how can we apply it?" We have not taken that important step, but it needs to be taken.

In our judgment, the first priority for developing SRP indicators is to settle on a acceptable operationalization. In all likelihood, the best approach is to focus on formal SRP's because an approach based on informal interaction renders already difficult measurement problems virtually impossible. Nevertheless, it is important to recognize that many SRP's are more symbolic than real and any system of indicators must be able to distinguish between the two.

After settling on an acceptable operationalization, the next step in developing indicators is to pursue simple descriptive information about the population of SRP's. Not much can be done until the SRP's have been satisfactorily identified.

In choosing among the many possible conceptualizations and indicators of SRP, a framing question should be: "what is the public stake?" To be sure, much of science and technology policy (not to mention tax policy and economic development policy) proceeds on the assumption that private benefit translates into public benefit via economic growth. In many instances this is an entirely plausible argument, at least to a point. However, public investment in science and technology is most often rationalized in terms of market failure or public domain benefits. Arguably, the fact that SRP activity has great economic import (still an open question) does not imply an equivalent government or public policy importance. This seems to imply, then, that SRP indicators should focus on such factors as the composition of R&D (e.g., do they shift the balance in available public domain research), impacts of labor and human resources, tax implications (e.g., use of tax credits, foregone revenue and its impacts), and, especially, public-private partnerships (e.g., how are government-sponsored or -brokered SRP's different from others?).

Having suggested that the sphere of indicators be limited, we nonetheless emphasize the need to move forward in examining SRP's and developing valid, reliable indicators. Despite the fact that we still do not have enough knowledge to assess the impacts and effects of SRP's we do know, if only from anecdotes and casual empiricism, that their activities are too important to the U.S. research capability for us to rely entirely on anecdotes and casual empiricism.

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# Technology Innovation Indicator Surveys

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## I. Background

This paper summarizes work that has occurred over the last three decades that is geared toward the development of new indicators of technological product and process innovation in the private sector of the economy. In addition to surveying the indicator development work that has occurred in Europe and North America, it is also intended to frame the issues that will confront a new effort to construct innovation indicators for the United States. The research that underlies this paper was originally performed under contract with SRI, International on behalf of the United States National Science Foundation. These efforts were not designed to focus exclusively (or even primarily) on Strategic Research Partnerships (SRP's). While a number of the innovation surveys described below do ask questions that are related to inter-firm relationships more broadly, and while these surveys have occasionally contained questions about "R&D Limited Partnerships" or "R&D Joint ventures," these topics played bit parts rather than starring roles in their respective surveys. Instead, the purpose of this paper is to provide an historical context within which current and future innovation surveys may be viewed. Over the past two decades much has been learned about how to usefully structure and administer innovation surveys. That information may be of use to those contemplating future surveys concerning related topics.

### A. The nature of indicators

The importance of the development of technologically new products or production processes has been widely appreciated since at least as early as the industrial revolution. Writing in 1776, Adam Smith felt that this concept was so self evident that "It is unnecessary to give any example."[1] In the ensuing two centuries the pace of technological change has quickened dramatically. Government policies with regard to innovation have sometimes played the role of promoter, sometimes regulator, and sometimes referee between competing private interests. To support these functions a substantial effort has been made to understand the nature of technological innovation and to measure various facets of technological development.

Technological innovation is a concept that is sufficiently complex and multi-dimensional that it is impossible to measure directly. In this sense it is a bit like measuring the health of a human being. There is no single measure of human health, so we must rely on a range of indicators, such as body temperature, skin color, level of pain or discomfort, the levels of various different components of the blood, dark and light areas on x-rays, and so forth. Each of these indicators is based on our fundamental understanding of how the various biological systems in humans work. As our understanding of human physiology improves, so does our capacity to develop better indicators of

[1] Smith, Adam, *The Wealth of Nations*, (New York: The Modern Library, 1937, 1965) p. 9.

human health. The underlying system is sufficiently complex and multi-faceted that it is reasonable to conclude that no single measure of human health will ever be developed.

So it is with innovation. Technological innovation is a process that involves the interaction of many different resources within and among firms. It also results in a wide variety of outputs that cannot be measured along any single-dimensioned scale. As a result, innovation can never be measured directly. Instead, indicators of innovation provide information on various facets of the innovation process, helping us to understand the phenomenon better and assisting those (both in the public and private sectors) who must formulate innovation policies.

## B. Theoretical foundations for innovation indicator development

Changes in our understanding of the innovation process over time have resulted in substantial changes in indicators of innovation. Decades ago, innovation was perceived as a process that took place almost entirely within individual firms. Innovation was viewed as a procedure that often started with basic research and then moved in a linear fashion through applied research, development, trial production runs and continued through to the market introduction and diffusion of new products or products produced by new production processes. At each stage, inputs such as R&D expenditures, scientific and engineering employment, etc. could be monitored and intermediate outputs such as patents and professional literature citations could be gauged. Much less attention was paid to developing indicators of innovation *outputs*. There were occasional efforts to assess output directly, and a considerable amount of effort was devoted to understanding and measuring productivity changes (as an indicator of process innovation). However, it was usually an unstated, but implicit assumption that differences in innovation outputs among firms or between time periods could be understood by viewing differences in innovation inputs. Thus, measures of innovation inputs could reasonably serve as indicators of innovation outputs.

The early work that was done developing innovation input indicators was extremely valuable and has provided, together with productivity data and patent data, the only long term time series data related to innovation in the U.S. However, because of its focus on inputs, and the implicit relationship of inputs to a linear model of innovation that largely neglected inter-firm linkages, it also distorted our understanding of innovation. For example, since a relatively small number of large firms in the U.S. economy accounted for the vast majority of R&D expenditures, it was assumed that they were also responsible for almost all technological innovation. Thus, if you believed these data, innovation policy could be usefully directed at large R&D based firms, and small and medium-sized firms, which generally had no central R&D lab, could safely be ignored. In the heyday of the large corporate R&D lab this was an easy enough mistake to make, but it became harder to justify this view in the face of the extremely rapid growth of small, technology-based enterprises in the past two decades. Thus, many felt it was essential to look beyond indicators based on innovation inputs, toward indicators that were then described as being "downstream" from research and development.

At the same time advances were being made in our understanding of the innovation process itself. For example, innovation was no longer perceived as being a linear process within each firm. Some innovations occurred without any traditional "research" at all. Others began at a stage that had previously been thought of as downstream from research, but then required scientific and engineering expertise later, to solve problems related to the commercialization of a new product or process. This view of innovation, popularized by Kline and Rosenberg as the "chain-link model" of innovation, serves a key foundation for most of the recent innovation indicator development.[2]

Innovation is also not an activity that occurs wholly within firms. Studies in many countries have confirmed that a significant portion of firms that introduce new products or new production processes have no formal R&D process at all. In many cases this is because they rely on technologies developed elsewhere. Their role in innovating consists of adapting these technologies or combining technologies developed elsewhere to produce improved or completely new products or production techniques. The importance of backward linkages with supplier firms, at least in some industries, has been understood for a very long time. In the 1970s, largely based upon the work of Eric von Hippel, considerable attention was focused on the role of users and customers in the innovation process as well. More recently Chris DeBresson has argued that the relationships between firms involved in innovation really consist of complex networks with an array of communications and interactions among firms.[3]

The conclusion from all of this is that without a better understanding of the nature of interactions among firms (whether they be customers, suppliers, or more complex relationships) any examination of the linkage between innovation (as measured by older indicators) and economic performance may be tenuous at best. For example, correlations between firm performance measures such as sales growth or profitability and R&D expenditures have always been difficult because it was nearly impossible to specify the lag structure between innovation investment and improved performance. But if the underlying R&D that serves as a basis for sales growth due to new products or processes isn't even made by the firm that introduced the innovation, then documenting this relationship with traditional innovation indicators will be impossible. Furthermore, policies that rely on traditional measures to indicate where innovation is occurring may be fundamentally flawed.

The newer indicators of innovation were designed to paint a more detailed picture of innovation by more directly examining innovative outputs, by collecting data on the structure of innovative activities within firms and by tracing the linkages between firms that give rise to innovation. While development work on these indicators has been going on for at least two decades, they are "new" in the sense that their collection is only now becoming regularized, and they are not being regularly collected at all in the U.S. Thus, they are the focus of this chapter. This is not to imply that data collection of innovation input data (R&D expenditures, technical employment) or patent or bibliometric data is not continuing to improve, only that they are beyond the scope of this chapter.

[2] Kline, S.J., and Rosenberg, N., "An Overview of Innovation," in Landau, R. and Rosenberg, N. (eds.) *The Positive Sum Strategy. Harnessing Technology for Economics Growth* (Washington: National Academy Press, 1986).

[3] DeBresson, Christian, *Economic Interdependence and Innovation: An Input-Output Analysis* (London: Edward Alger, 1996).

## II. Early Work on New Innovation Indicators

### A. Object-based studies

Two fundamentally different approaches have been used to collect data for new indicators of technological innovation.[4] The earliest work took the innovation itself as the unit of analysis and attempted to collect data on the number of innovations produced, expenditures on their development, their rate of diffusion and their significance. This approach has sometimes been referred to as *innovation-based* and is called the *object approach* by the latest version of the Oslo Manual.[5] Studies of this type were undertaken in Britain, the United States, and Canada.[6] The usual method for this type of data collection project is to develop a list of significant innovations through literature searches or panels of experts, identify the firms that introduced the innovations, and then send questionnaires to those firms about the specific innovations. A variation on this approach is to send a questionnaire to firms that asks them to identify their most significant innovation or innovations and then answer a series of questions about the specific development project that let to that innovation.

This approach however, has not been the one favored by most data collection projects sponsored by or performed by government agencies. There are a number of reasons for this. First, firms have a very difficult time responding to detailed questions about innovation activities that are related to specific innovations. They simply don't retain this type of data. Secondly, the innovation-based approach only collects data about successful innovations. When studies are limited to successes, it is more difficult to use the data to distinguish factors that relate to successful innovative outcomes. Finally, government statistical agencies are generally geared toward collecting contemporaneous data for relatively brief periods not exceeding a few years. Studies based on literature searches or expert identification of innovations are inherently historical in perspective and generally cover rather long time periods. More recently some government innovation surveys (notably Canada) have included questions asking firms to identify their most important innovation. But this approach adopts the firm's view of which innovations are important and generally limits firms to identifying only one or two representative innovations.

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[4] For a more detailed discussion of surveys conducted during this period see: Hansen, J., "Innovation Indicators: Summary of an International Survey." OECD Workshop on Innovation Statistics (OECD/DESTI/IP/86.8), 1986. In addition to those surveys discussed above, early surveys were also conducted in France, the Netherlands, and Canada.

[5] OECD, *OSLO Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data* (Paris: OECD, 1997).

[6] In Britain: Townsend, J. et al., "Science Innovations in Britain since 1945." SPRU Occasional Paper Series N. 16. (Brighton, SPRU, 1981). Pavit, Keith, "Characteristics of Innovation Activities in British Industry." *OMEGA*, 1983, vol. 11, no.2, pp. 113-130. Pavitt, K., M. Robson, and J. Townsend, "The Size Distribution of Innovating Firms in the U.K. 1945-1983." (Brighton, SPRU, 1985).

In the United States: Gellman Research Associates, "Indicators of International Trends in Technological Innovation." (Gellman Research Associates, 1976).

In Canada: DeBresson, Chris and Brent Murray, "Innovation in Canada. A Retrospective Survey: 1945-1978." (New Westminster, B.C.: Cooperative Research Unit on Science and Technology, 1984).

**B. Subject-based studies**

The second approach is to collect data from firms about the totality of their innovation efforts, not merely those that are associated with specific innovations. In this approach, firms are asked to provide information on expenditures for various innovation-related activities, information about the structure of these activities within their firms, information on their innovation-based relations with other firms and institutions and information about the firm's view of its innovation goals, policies and the obstacles it faces. This approach is sometimes referred to as a *firm-based* approach and is described by the Oslo Manual as *subject-based.*

Before 1992, a number of subject-based surveys were conducted in a variety of countries, mostly in Western Europe. One of the earliest of these was undertaken by Lothar Scholz at the IFO Institute in Germany.[7] Conceptualized in 1977-78, this survey was first conducted in 1979, and performed annually thereafter. The centerpiece of this survey is its request for data on innovation expenses by category: research, experimental development, construction and design, patents and licenses, production preparation for new products, production process innovation, and administrative process innovation. This survey is noteworthy in that it is one of the few that has been successful in obtaining answers from firms on innovation expenditure by function over a significant period of time. This is partly due to the fact that the survey is repeated annually (so firms can refer to their previous year's responses). In addition, the IFO Institute works fairly closely with respondent firms, and respondents are provided with reports of the resulting data disaggregated by industrial sector, which they find very useful. This survey also asked a range of questions about the number and types of innovations introduced, the sources of ideas and barriers to innovation, and the technologies that underlay the innovations.

The largest innovation indicators survey undertaken during this period was performed in Italy by the National Research Council and the Central Statistical Office.[8] This was an incredibly ambitious project that began with a fairly brief survey sent to every manufacturing company in Italy with more than 20 employees (about 35,000 firms in all). This was the first large-scale survey to demonstrate that innovation was a pervasive phenomenon. While the percentage of innovators did increase with firm size, the Italian survey showed that even among the very smallest firms, almost two thirds had introduced new products or production processes. Thus the Italian survey clearly showed that innovation was a much more widespread phenomenon than in-house R&D.

The initial Italian survey was followed by a more detailed questionnaire administered to all those firms that had reported some innovation activity in the initial comprehensive survey. Questions were asked about the number and types of innovations, their costs, the types of technologies involved, sources of information, obstacles to innovation, their impact on sales and future technological

[7] Scholz, Lothar and Heinz Schmalholz, "IFO – Innovation Survey. Efforts to Inform Decision-Makers of Innovation Activities in the Federal Republic of Germany." Paper prepared for the OECD Workshop on Pentent and Innovation Statistics, June, 1982.

Schmalholz, Heinz and Lothar Scholz. "Innovation in der Industrie: Struktur und Entwicklung der Innovationsaktivitaten, 1979-1982." IFO studien zur industriewirtschaft, 28.

[8] Avveduto, S. and Sirilli, G., "The Survey on Technological Innovation in Italian Manufacturing Industry: Problems and Perspectives." OECD workshop on Innovations Statistics, 1986. Archibugi, D., Cesaratto, S. and Sirilli, G., "Sources of Innovation Activities and Industrial Organization in Italy", *Research Policy*, 20, 1991, pp. 299-314.

opportunities. Many of these questions serve as the basis for items included in the first edition of the Oslo Manual.

In the United States, early subject-based innovation surveys were sponsored by the U.S. National Science Foundation and conducted at MIT's Center for Policy Alternatives and Boston University's Center for Technology and Policy beginning in 1981.[9] The goal of this series of projects was to develop workable new indicators of innovation that would relate either to innovation outputs or to significant factors in a firm's environment that affected the innovation process. It is interesting to note that at the time this work was going on the investigators were completely unaware of the European firm-based studies, yet developed questions that were strikingly similar to those used in Germany and Italy.

## III. The First Oslo Manual and the First Community Innovation Survey

### A. The first Oslo Manual

In the late 70s and mid-1980s the Organization for Economic Cooperation and Development (OECD) held a series of workshops to bring together individuals who were working on new indicators of technological innovation to compare notes. At this point new indicator technology was maturing to the point that the policy community was beginning to seriously evaluate the need for standards in data collection that would facilitate international comparisons, in much the same way that the OECD's Frascati Manual provided standard for the collection of innovation input data.[10]

In 1988 the first multinational study that collected data for new innovation indicators was undertaken in Scandinavia, under the aegis of the Nordic Fund for Industrial Development.[11] The questions on this group of surveys revolved around many of the same themes that were pursued in the earlier surveys in Europe and the United States. From the beginning, however, it was anticipated that the surveys would be constructed in such a way that international comparisons of the results between the participating countries (Norway, Denmark, Finland, and Sweden) would be possible.

About the same time the Nordic Industrial Fund also sponsored a series of workshops to move toward a standardized approach to innovation indicator data collection. The initial intent was to provide some input for the ongoing Nordic Survey. The keynote paper for the first set of meetings, developed by Keith Smith of the Resource Policy Group in Oslo, referenced only the Nordic Survey,[12] but from the beginning the group, which comprised most of the individuals who had developed extant survey instruments,[13] framed the discussion more generally in terms that could be

9 Hill, C.T., Hansen, J.A., and Maxwell, J.H, "Assessing the Feasibility of New Science and Technology Indicators." (Cambridge, MA: MIT Center for Policy Alternatives, 1982) CPA 82-4. Hansen, J.A., Stein, J.I., and Moore, T.S., "Industrial Innovation in the United States: A Survey of Six Hundred Companies." (Boston: BU Center for Technology and Policy, 1984) Report 84-1.

10 OECD, *The Measurement of Scientific and Technical Activities: Frascati Manual.* (Paris, OECD, 1980).

11 Nordic Industrial Fund, *Innovation Activities in the Nordic Countries* (Oslo: Nordic Industrial Fund, 1991).

12 Smith, Keith, "The Nordic Innovation Indicators Project: Issues for Innovation Analysis and Technology Policy." (Oslo: Gruppen for Ressursstudier, April, 1989).

13 Including Sirilli from Italy, Scholz from Germany, DeBresson from Canada, Hansen from the United States, Mikael Akerblom from Finland, Alfred Kleinknecht from the Netherlands, Pari Patel from Britain, and Andre Piatier from France, as well as representatives from the Nordic Countries and the OECD.

applied across the OECD. An additional workshop was held the following year and the general framework for a guide to collecting innovation indicator data was in place. Drafting of what came (at the suggestion of Alfred Kleinknecht) to be known as "The Oslo Manual" was left to Keith Smith and Mikael Akerblom. The first revision of the Manual, was adopted and published by the OECD in 1992.[14]

The first Oslo Manual did not contain specific questions that were recommended to be included on innovation surveys. Instead it laid a conceptual framework for developing innovation indicators and discussed the general areas in which data had been collected by various existing surveys. Then specific topic areas were recommended for inclusion in future national surveys. The principal topic areas were:

1. Firm objectives in undertaking innovation. This included the firm's technological strategies such as developing radically new products, imitation of market leaders, adapting technologies developed elsewhere, etc. It also discussed the firm's specific strategies with respect to product innovation (replace existing products, open up new markets, etc.) and process innovation (lowering production costs, increasing production flexibility, etc.).
2. Sources of innovative ideas. This included cooperation with customers, suppliers, subcontractors, research institutes, government facilities and universities. It also included the acquisition of embodied or disembodied technology, and ideas from the scientific, technical, or commercial literature, trade fairs, exhibitions etc.
3. Factors that hamper innovation. These included high risk, expense, lack of information, lack of technological opportunities, resistance to change within the firm, regulatory barriers, etc.
4. The proportion of sales and exports due to new products. This was a measure of the importance of new products to the firm. Products were deemed to be "new" during their first three years on the market.
5. The structure of R&D. This included a collection of issues concerning whether firms have a central R&D facility, the proportion of their R&D budget that is spent in such a facility, and the degree to which they have cooperative R&D relationships with other firms or research organizations.
6. The acquisition and sale of technology. This included the degree to which firms rely on patents or other mechanisms for the protection of intellectual property and the degree to which they have licensing arrangements with other firms.
7. Innovation costs by activity. This item dealt with total expenditures related to new product and process development disaggregated by type of activity, for example, internal and external R&D, acquisition of disembodied technology, expenditures for tooling up, engineering and manufacturing start-up and marketing.

**B. Statistical units for data collection**

A key issue that has been a source of some frustration for innovation indicator researchers concerns the proper statistical unit at which to collect the data. If data is collected at the corporate or *enterprise* level, it is fairly easy to merge it with other data collected at this level including data on R&D. This has been an approach that has been attractive to many national statistical offices because they are already collecting other data at this level. Also, the technology strategies of firms are sometimes developed at this level and collecting data at a lower level of aggregation may make it difficult to

[14] OECD, *OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data: Oslo Manual* (Paris: OECD, 1992).

pursue these issues. On the other hand, much more data, and often better quality data, can be collected at the *establishment* level, where most innovation activities actually occur. However, it is often impossible to reaggregate data that is collected at the establishment level to provide information about the enterprise as a whole.

This topic will be treated in more detail in section VII.A below. At this point it is worth noting that for most of the early European studies this was less of an issue than in the United States. In the early 80s, when asked about this question, one European data collector said that for most firms that he had dealt with there was very little difference between the enterprise and the establishment. Each of the half dozen firms in his country that was large enough to create a problem was treated as a special case.

In the United States, however, the difference is enormous. All of the NSF-sponsored U.S. studies up to this point have used the enterprise as the unit of analysis, in order to be consistent with NSF's other data collection procedures. Sometimes exceptions were made in individual cases where the enterprises were essentially holding companies or where the firms themselves asked that the survey be sent to establishments. In instances where inconsistent procedures were used, it created significant data analysis problems.

The original Oslo Manual treats this issue fairly ambiguously. Initially it says that the unit of analysis is the "enterprise-type" unit, by which it means the smallest possible separate legal entity. However, it also approves of the use of a smaller unit (a division or establishment) in cases where the firm is engaged in many different types of activities. It then says that the "enterprise group" should not be used unless its activities are relatively homogeneous.

## C. The first Community Innovation Survey (CIS-1)

In the early 90s the European Community sought to design a common questionnaire that would be based on the Oslo Manual and could be administered in all of the EU countries. This project was implemented as a joint venture of Eurostat and the SPRINT / European Innovation Modeling System (EIMS) program of DGXIII. In 1991-92 there was a small-scale pretest of the survey in five countries. The survey instrument was revised in early 1992, and in 1992/93 data collection was completed in Belgium, Germany, Denmark, France, Greece, Italy, Ireland, Luxembourg, the Netherlands, Portugal, the United Kingdom, and Norway. Over 40,000 firms were surveyed in the course of this project.[15]

The goal of attaining comparability between nations was not fully achieved for a number of reasons. First, the survey instrument itself differed between countries. Each country was free to modify the survey as they saw fit and indeed some did, either by adding, deleting, or making alterations in the CIS core questions. Sometimes these alterations were subtle. For example, an identical question that asks for categorical responses but provides different response categories may make comparisons

[15] Evangelista, R., Sandven, T., Sirilli, G. and Smith, K. "Measuring the Cost of Innovation in European Industry" presented at the International Conference on Innovation Measurement and Policies, May, 1996.

impossible. As Arundel, et al. noted "even minor differences such as a change in layout or a change in scale can have substantial effects on the comparability of the results."[16]

Secondly, sampling and follow up procedures varied substantially between countries. In some countries surveys were conducted, others conducted a census. In some cases the population was taken to be all manufacturing firms, in others the questionnaire was targeted toward firms believed to be innovators. Some surveys were conducted by mail, others were based on interviews. In some countries firms were legally mandated to respond, in others they were not. The guidelines for filling out the survey that were provided to firms also differed substantially between countries. In part these differences occurred because of different legal and institutional requirements of the different countries, in part they occurred because countries wished to make their surveys comparable with previous surveys they had done, and in part they occurred because in some areas there were no recommended procedures for the EU as a whole. The Commission was reluctant to provide detailed procedures on data collection because they felt it would presumptuous given that they are only empowered to make recommendations, not promulgate requirements.

After the first Community Innovation Survey was completed substantial revisions were made both to the survey instrument and the Oslo Manual that served as the basis for the instrument. Since CIS-1 has largely been superceded, it will not be considered in detail here.

## IV. The Second Oslo Manual and the Second Community Innovation Survey

### A. Overview

A revised version of the Oslo Manual was published in 1997 (hereafter Oslo-2). The revisions to the Manual were in part based upon the field survey experience of CIS-1, but were also driven by fundamental changes in the economy itself. In particular, for the first time an attempt was made to draft innovation indicator data collection recommendations that would apply to service industries as well as manufacturing industries. Just as the first version of the Oslo Manual served as a basis for the first CIS survey, the second version of the Manual laid the underpinnings for the second CIS survey.

### B. Definitions and basic concepts

In Oslo-2, technological innovation is divided into two categories: Technological Product Innovation and Technological Process Innovation. Product innovations are further subdivided into new products and improved products. Oslo-2 recommends that when surveys ask firms whether they have made any innovations during the relevant survey period, that they be asked about each of these three categories separately. The definitions for the three types of innovation are provided as follows:

*A technologically new product is a product whose technological characteristics or intended uses differ significantly from those of previously produced products. Such innovations can involve radically new technologies, can be based on combining existing technologies in new uses, or can be derived from the use of new knowledge.*

[16] Arundel, Anthony, with Keith Smith, Pari Patel, and Georgio Sirilli. "The Future of Innovation Measurement in Europe: Concepts, Problems and Practical Directions." IDEA Paper Number 3, The STEP Group, 1998. All of the IDEA papers referenced in this report can be conveniently downloaded from: http://www.step.no/Projectarea/IDEA/papers.htm

*A technologically improved product is an existing product whose performance has been significantly enhanced or upgraded. A simple product may be improved (in terms of better performance or lower costs) through use of higher-performance components or materials, or a complex product which consists of a number of integrated technical sub-systems may be improved by partial changes to one of the sub-systems.*

*Technological process innovation is the adoption of technologically new or significantly improved production methods, including methods of product delivery. These methods may involve changes in equipment, or production organization, or a combination of these changes, and may be derived from the use of new knowledge. The methods may be intended to produce or deliver technologically new or improved products, which cannot be produced or delivered using conventional production methods, or essentially to increase the production or delivery efficiency of existing products.*[17]

Definitions for concepts that are as amorphous as technologically new products and processes are very difficult to develop. One way to be clearer about them is to provide lots of examples of the types of things that should be included and should not be included within the definition in the hope that respondents would be able to draw analogies between the product and process examples mentioned in the definition and their own products and processes. The problem with this approach is that it leads to relatively lengthy definitions. Experience has shown that if the definitions become so lengthy that a separate sheet containing definitions must be included with the questionnaire, many, if not most, of the respondents will not read the definitions section at all. Therefore an effort was been made in Oslo-2 to be clear, but also to be brief in providing definitions.

Not only is it difficult for firms to determine what is "new" but it is also difficult for them to determine the difference between "new" and "improved" consistently. When deciding whether a product is wholly new or simply improved, they are most likely to take their own company's history as their frame of reference. As a result, a wholly new product produced by a company that manufactures household cleaners may have less technological innovation content than a product that is classified as merely improved by a manufacturer of embedded microcontrollers.

Oslo-2 provides a brief discussion of some of the problems that arise when attempting to apply these definitions directly to the service sector. In particular, in service industries the distinction between the product and production process becomes blurred because the product is generally intangible and consumption occurs simultaneously with production. While the Manual does offer a wide range of examples of service sector innovations, it provides little guidance for separating them into product and process innovation categories. For a more detailed discussion of options with regard to the service sector see section 7.3, below.

**C. Degree of novelty**

Another problem that must be addressed by innovation indicator data collection efforts is the specification of the degree of novelty required in order for a product or process to be considered truly "new." To take two extremes, an innovation might be considered new only if it was being introduced

[17] OECD, *OSLO Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data* (Paris: OECD, 1997) pp. 48-49.

for the first time anywhere in the world in any industry. Alternatively, it might be considered new if it were simply being used for the first time by the "innovating firm" even if it had been previously widely used in other firms in the same industry.

Oslo-2 refers to these two extremes as "world-wide technological product or process (TPP) innovation" and "firm-only TPP innovation," respectively. They are defined as follows:

*Worldwide TPP innovation occurs the very first time a new or improved product or process is implemented. Firm-only TPP innovation occurs when a firm implements a new or improved product or process which is technologically novel for the unit concerned but is already implemented in other firms and industries.*[18]

While it may be reasonably argued that every application of existing technology in a different setting requires a degree of adaptation and, thus, innovation, it is also clear that the adoption of existing technology that is widely used elsewhere involves a substantially reduced degree of innovation relative to the creation and first use of new technology. After all, the introduction of a production process that is "new to the firm" might simply occur because the firm was expanding its product line into a new area which required different equipment based on existing (and possibly quite ancient) technologies.

On the other hand, firms generally know when a product or production process is new to their firm. Often they do not know whether it is also new to their industry, new to their country or region, or new to the world. In fact, in DeBresson's object-based study of innovation in Canada, he found that a rather large number of firms claimed to have developed world first innovations.[19] In fact, in a number of cases more than one Canadian firm claimed to have been the first in the world to develop a particular innovation.

It is generally the case in innovation indicator research that there is a tension between the data that would be most helpful from a policy perspective and the data that firms are readily able to provide. Survey design is often something of a balancing act. The more the survey focuses on obtaining the best possible data, the less able and willing firms are to supply that data and the lower the response rate. However, by moving too far in the other direction and asking firms only questions that they can easily answer, high response rates can be achieved, but the resulting information may be uninteresting. One of the most important reasons for pretesting a new survey vehicle is to determine whether a proper balance has been achieved between minimizing respondent burden and maximizing the usefulness of information obtained.

Oslo-2 takes the position that any TPP that was new to a firm was to be classified as an innovation. It also recommended asking firms about their world-first innovations and perhaps also about some intermediate degrees of novelty, such as TPPs that were new to the country or new to the region.

[18] *ibid.*, p. 52.
[19] DeBresson, Chris and Brent Murray, "Innovation in Canada. A Retrospective Survey: 1945-1978" (New Westminster, B.C.: Cooperative Research Unit on Science and Technology, 1984).

**D. Statistical unit of analysis revisited**

The 1997 Oslo Manual revisited the issue of which level within the firm should provide data and noted a distinction between the reporting unit (which is the part of the firm that was asked to provide the data) and the statistical unit (which is the part of the firm that the data is collected about). Oslo-2 notes that if the reporting unit is larger than the statistical unit, it may be difficult to determine how to distribute the data gathered among the various portions of the firm that comprise the different statistical units. Suppose, for instance, that there is a large enterprise with a number of different production divisions. If the reporting unit is the enterprise, but the statistical unit is the production division, it may be difficult to allocate data reported by the enterprise among the various divisions. In asking questions about the objectives of innovation, for example, if the enterprise prioritizes its objectives, it is unclear whether these priorities are the same for all divisions or whether they reflect the priorities of the largest, or most profitable, or most innovative divisions. Or they might reflect some sort of weighted average of the objectives of the various divisions.

Oslo-2 does not explore the implications of the statistical unit being larger than the reporting unit, but the problems are similar. Suppose that the reporting unit is the production division but the statistical unit is the enterprise. If data is collected from the various production divisions it may be difficult or impossible to reaggregate this data back to the level of the enterprise. This is clearly the case if a survey is taken rather than a census or if some divisions are among the non-responders. This is because sampling is generally taken from the population of establishments as a whole, not on an enterprise by enterprise basis. Furthermore, even if all divisions are surveyed and all divisions respond it may not be possible to reaggregate data. In this case reaggregation of quantitative data would be possible, of course. One could simply add up the R&D expenditures for all divisions to obtain a total R&D expenditure for the firm. But on qualitative questions such as the strategic objectives of the firm's innovation activities, if two divisions report one objective and three divisions report another, it is not clear how these would be aggregated to get an overall firm objective.

The principle difference between the treatment of the statistical unit in the first and second Oslo Manuals is that Oslo-2 seems to have a much greater recognition of the problems involved in selecting any one unit of analysis. Its basic recommendation is the same: that the enterprise-type unit generally be used, but it makes this recommendation "Taking into account how innovation activities are usually organized." It also recommends that when enterprises are involved in several industries, a smaller unit like the kind-of-activity unit (KAU) "an enterprise or part of an enterprise which engages in one kind of economic activity without being restricted to the geographic area in which that activity is carried out"[20] may be more appropriate.[21]

[20] From OECD, 1997, *op. cit.*, p. 121: The kind-of-activity unit (KAU) groups all the parts of an enterprise contributing to the performance of an activity at class level (four digits) of NACE Rev. 1 and corresponds to one or more operational subdivisions of the enterprise. The enterprise's information system must be capable of indicating or calculating for each KAU at least the value of production, intermediate consumption, manpower costs, the operating surplus and employment and gross fixed capital formation." (Council Regulation (EEC) No 696/93 of 15 March 1993 on the statistical units for the observation and analysis of the production system in the Community, OJ No. L 76, p. I, Section III/F of the Annex).
[21] OECD, 1997, *op. cit.*, pp. 63-65.

Oslo-2 also recognizes the problems that will arise from attempting to evaluate innovation within multinational companies. Specific recommendations for dealing with the problems of attempting to calculate national data in the face multinational corporations are not included.

**E. Topics covered in Oslo-2**

As with the first Manual, Oslo-2 does not recommend the wording of specific questions that might be included in the survey. It does, however, go into substantial detail about what should be included in the questions, occasionally to the point where the wording of the questions can be derived fairly directly from the text of the Manual. The major topic areas covered in Oslo-2 are:

- Whether the firm has had any innovation activities within the past three years.
- Whether the firm has introduced any innovations within the past three years.[22]
- General data on the firm: sales, R&D expenditures, R&D employment, exports, employment, operating margin.[23]
- The firm's innovation objectives.
- Sources of information for firm innovations.
- Factors that hamper firm innovation.
- The percentage of firm sales, over the past three years, subdivided by the proportion that stem from:
  1. Technologically new products.
  2. Technologically improved products.[24]
  3. Products that are technologically unchanged but produced with changed production methods.
  4. Products that are technologically unchanged and are produced with unchanged production methods.
- The average length of the firm's product lifecycle.[25]
- The degree to which firms are engaged in "custom" production.[26]
- The impact of innovation on production inputs: employment, materials consumption, energy usage, and use of fixed capital.
- If innovation has resulted in a reduction in production costs, to what degree has the average cost of production been reduced.
- The main sectors of economic activity of the users of a firm's technologically new or improved products, by sales, in percentage terms.
- Evaluation of the effectiveness of various means for protecting intellectual property rights including patents, design registration, secrecy, complexity of design and lead time.
- Information on purchases and sales of technology subdivided by domestic and foreign firms.
- Expenditures on innovation activities by type of activity.

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[22] Note that the difference between these first two items is that a firm may have engaged in innovation activities that were either aborted before the introduction of a new product or process or have not yet come to fruition.
[23] If not already available from other surveys.
[24] In the case of the first two items, it is also recommended that they be broken down into products that are new to the market and products that are new only to the firm.
[25] Some concern is expressed in the Manual that firms with short product lifecycles would naturally have a higher percentage of sales from new products and that it might be useful to separate the effect of large new product sales due to short lifecycles from large new product sales due to other factors.
[26] As in the previous item, it is useful to be able to account separately for those firms who engage primarily in custom production (where virtually everything is new).

Note that there are no questions here devoted directly to research relationships among firms. More broadly, connections between firms are explored in the questions that concern the sources of information for innovations (where other firms are a possible source) and purchases and sales of new technology.

A substantial amount of time and effort has been spent attempting to develop innovation survey questions that measure the resources devoted to the wide range of innovation activities within firms. Almost all of these efforts have resulted in data of questionable value. The biggest problem stems from attempts to separate the part of each category of expenditure that is related to new and improved products and processes from the part that relates to routine activities. For example, research and development expenditures are relatively easy to collect because almost all R&D expenditures are directly related to the development of new products or processes. However, even R&D expenditures may not be trivial to calculate because many firm's research personnel spend a portion of their time working on products that reflect style variations which are not properly viewed as technologically new products. Interviews with the individuals in these firms who are responsible for reporting R&D expenditures reveal that they are only partially successful in separating out R&D expenditures related to technologically new products from those which are not.

As data is collected about firm activities that are closer to the market introduction of new products, it becomes much more difficult to collect data that solely relates to expenditures for technologically new products and processes. Expenditures for plant and equipment, for example, often can not be segregated into expenditures for new products (to say nothing of expenditures for technologically new products) and expenditures for expansion of the production of existing products. The same thing is true for marketing expenditures. Most survey response analysis has shown that the questions on innovation expenditures are the most difficult for respondents, have the lowest response rates, and produce results of questionable value.

Oslo-2 recognizes many of these problems and devotes a substantial section to attempting to hone the definitions to be clear about which items should be included and which should not. Despite this, Oslo-2 clearly sees the problem as "not which data to collect, but how to collect reliable data on innovation expenditures other than R&D expenditures."[27] To try to improve the situation, Oslo-2 recommends that surveys ask firms to indicate whether the data provided in this area are fairly accurate or are rough estimates only. The Manual notes that this may result in more firms simply doing rough estimates, but it might also raise response rates.[28] In this context it is worth noting that high response rates are not always desirable. If the alternatives are high response rates but poor quality data or low response rates but carefully answered questions, the latter may, in fact, be preferable.

Oslo-2 also includes a very useful section on survey implementation, imputation of data from non-respondents, and tabulation of the results. The latter issue needs substantially more attention. In a comparison of the data obtained from six countries, Hansen found that even when the questions asked were essentially identical and even when the responses were gathered in a similar way, the results of the various national surveys might not be comparable if the results are not reported using the same

[27] OECD, 1997, *op. cit.*, p. 89.
[28] *ibid.*

protocol. This occurs because the results are published in aggregate form and if the same aggregation procedures are not used, useful comparisons between the data sets will not be possible.[29]

## F. The second Community Innovation Survey (CIS-2)

The most recent EC survey is the second Community Innovation Survey (CIS-2). As with the first CIS, the EC developed a model or "harmonized" set of questions for the second round of surveying. Individual countries were then free to modify, add or delete questions as they saw fit. The questionnaire was developed in early 1997. By the end of 1998, fourteen of the European Union countries and Norway had implemented this survey. Many of these countries had submitted the resulting data to Eurostat and that data is in the process of being cleaned and analyzed as this paper is being written.

The second Community Innovation Survey is actually two surveys, one that is designed to cover manufacturing industries and one for the service sector. The inclusion of the service sector represents a major step forward since each year services account for a larger fraction of most national economies. Service sector industries that are covered by CIS-2 include electricity, gas and water supply (NACE 40-41), wholesale trade (51), transportation (60-62), telecommunications (64.2), financial intermediation (65-67), computer and related activities (72) and engineering services (74.2 in part). Notably absent is the health care sector.

The changes made to the CIS manufacturing questionnaire to adapt it to the service sector are actually relatively minor. So, instead of treating the two questionnaires separately, they will be discussed at the same time, but the adaptations made for the service sector will be noted along the way. The service sector questions were pre-tested in Germany and the Netherlands. In addition, an early larger scale test was conducted in Italy. A more complete discussion of the nature and status of innovation indicators in the service sector will be found in section VII.C, below.

The survey begins with a list of questions about the nature of the firm and its activities including employment, sales, and exports. These questions are rather routine and probably presented few response difficulties for firms. In many countries this data may be known ahead of time and therefore could be deleted from the survey.

The definitions for new products and processes are included with the questions about whether firms introduced any innovations, rather than on a separate sheet. Technological innovation is defined as "technologically new products and processes and significant technological improvements in products and processes." By new, the survey means new to the enterprise. The manufacturing questionnaire asks separately about new products and new production processes. With regard to products, it asks firms to specify the percentage of sales during the period 1994-96 that were generated by new products, improved products and unchanged products. It also asks firms about the percentage of sales that were generated by products that were not only new to the firm, but new to the market as well. Note the distinction here between the CIS survey and the Oslo Manual. The Oslo Manual specifically refers to "world-wide TPP innovation," while the CIS survey asks about products that are new to the firm's market. These are not necessarily the same thing. A firm could view its market as being regional or national. If a product existed in other national or regional markets but was being

[29] Hansen, J. A. "New Indicators of Industrial Innovation in Six Countries: A Comparative Analysis." Final Report to the National Science Foundation, June 22, 1992.

introduced to the firm's market for the first time, it might count it as new. In fact there is substantial ambiguity here since different firms in the same market may view the concept of a "market" differently. The survey provides no guidance for interpretation of this term.

In the service sector survey, no distinction is drawn between product and process innovation. Instead firms are asked whether they introduced "any new or significantly improved services or methods to produce or deliver services." This was done because of the problems of segregating innovations into product and process innovations when production and consumption occur simultaneously. In addition, the question on the percentage of sales due to new products was dropped from the service questionnaire because it was found that firms in the service sector had much more difficulty answering it than firms in manufacturing.

One key distinction between the first and second CIS questionnaires is that the first one refers to innovations that were "developed or introduced" in the relevant period while the second refers to innovations that were "introduced onto the market" or "used within a production process." Arundel, et al., argue that this leads to a confusion of the technology creation process with the diffusion process and suggest rewording this question so that it asks separately about the introduction of innovations that were developed within the firm and the introduction of innovations developed elsewhere.[30] This approach, it is argued, would clarify the interpretation of many of the remaining questions, which seem to apply mostly to the creators of new products rather than those who diffuse the technology.

CIS-2 contains a significant section asking firms to disaggregate 1996 innovation costs between the following categories of expenditure:

- Research and experimental development within the enterprise
- Acquisition of R&D services
- Acquisition of machinery and equipment linked to product and process innovations
- Acquisition of other external technology linked to product and process innovations
- Industrial design, other production preparations for technological new or improved products
- Training directly linked to technological innovations
- Market introduction of technological innovations.

One paragraph definitions are included for each of these areas. The service sector question differs slightly in that it refers to "technological innovations" rather than "product and process innovations." It also refers to "software and other external technology" rather than just "other external technology." Finally, it omits the "industrial design" category and in its place has "preparations to introduce new or significantly improved services or methods to produce or deliver them."

This section also asks four additional questions concerning the resources devoted to innovation. Firms are asked about R&D employment (again assuming the data is not available from other surveys). They are also asked whether they preformed R&D continuously, occasionally, or not at all. They were also asked for a categorical (yes/no) response as to whether they received government financial support for innovation activities. These included subsidized loans and grants, but there is no

[30] Arundel, Anthony, with Keith Smith, Pari Patel, and Georgio Sirilli. "The Future of Innovation Measurement in Europe: Concepts, Problems and Practical Directions." Idea Paper Number 3, The Step Group, 1998. pp. C-IV to C-VI.

reference to provisions of the tax code that might have in effect provided subsidies. Finally, they were asked whether they had applied for any patents in any country during the 1994-96 period.

CIS-2 asked for categorical responses regarding the objectives of firm's innovation activities during the period 1994-96. Firms were not asked to rank order their objectives, rather, for each of the listed objectives they were asked to specify whether the objective was not relevant or was slightly important, moderately important or very important. The list of objectives provided was virtually the same for the service sector as for manufacturing (the word "service" replaced the word "product"):

- Replace products being phased out
- Improving product quality
- Extend product range
- Open up new markets or increase market share
- Fulfilling regulations, standards, etc.
- Improve production flexibility
- Reduce labor costs
- Reduce materials consumption
- Reduce energy consumption
- Reduce environmental damage.

Firms were also asked to specify the main source of information for innovations during the 1994-96 period. The same scale was used as in the objectives question and the question was identical on the services and manufacturing questionnaire. The sources included were:

- Sources within the enterprise
- Other enterprises within the enterprise group
- Competitors
- Clients or customers
- Consultancy enterprises
- Suppliers of equipment, materials, components, or software
- Universities and other higher education institutes
- Government or private non-profit research institutes
- Patent disclosures
- Computer based information networks
- Fairs, exhibitions.

Note here that the wording of this question tends to exclude SRP's, although almost every other form of inter-firm relationship (customer, supplier, competitor) is included. In an additional question, however, firms were asked to specify whether they had been involved with any joint R&D or other innovation projects during the 1994-96 time frame. If so, they were asked to specify whether their partners were located in the same country, in Europe, the United States, Japan, or elsewhere. The types of partners specified was identical to the sources of information list, except for the obvious deletions of the enterprise itself, patents, information networks and fairs.

Finally, firms were asked if they had had at least one innovation project seriously delayed, abolished or aborted before it was started. If so they were given a list of possible reasons that this could occur and asked whether the reason resulted in delay, abolition, or not having been started. Possible "hampering factors" include:

- Excessive perceived economic risk
- Innovation costs too high
- Lack of appropriate sources of finance
- Organizational rigidities
- Lack of qualified personnel
- Lack of information on technology
- Lack of information on markets
- Fulfilling regulations, standards
- Lack of customer responsiveness to new products.

This question was identical on the manufacturing and service sector surveys. The value of this question will be considered in detail below. It is worth noting, however, that the survey provided no guidance to firms concerning how to separate the twin issues of economic risk and innovation costs. Nor did it ask firms whether having innovation hampered by factors like a lack of finance and the need to meet standards was a good thing or a bad thing from the standpoint of the firm. Rather, there seems to be an underlying assumption in this question that all things that hamper innovation are undesirable.

In a footnote, CIS-2 recommends that the national surveys also ask firms to describe the most important technologically new or improved product or process. There are no recommendations on the core survey for the wording of such a question nor is there any guidance about which types of questions should be asked about the most important improved product or process. In addition, there is no discussion of this question in the guidelines for submitting the data Eurostat. One is left with the impression that Eurostat feels the question is important, but is unsure of the best way to implement the question or to collect and present the results.

Currently, Eurostat is gearing up for the third iteration of the Community Innovation Survey. It is hoped that the questionnaire will be finalized by the end of 2000 so that can be administered in 2001. There may well be a more detailed exploration of the relationships between firms on this questionnaire, though the direction this exploration might take has yet to be determined.

## V. Other Recent Innovation Surveys Outside the United States

### A. Canadian innovation surveys

The Science and Technology Redesign Project of Statistics Canada has been most directly responsible for the collection of innovation indicator data in that country. Canada is worth treating separately here because in addition to conducting surveys that stem from questions in the Oslo Manual, they have also expanded that design toward drawing connections between technology developers and technology users. In addition, they have performed significant development work in service sector innovation surveys, and have also conducted a couple of industry-specific surveys that generate useful information for future innovation indicator development. The discussion below is not intended to provide a comprehensive review of the Canadian surveys; rather it will focus on those areas where the Canadian questions were significantly different than those used elsewhere.

In 1993, Statistics Canada conducted an Oslo-style survey of innovation in Canadian manufacturing industries. A similar methodology was applied in a 1997 survey (1996 data) of the communications, financial services and technical business services industries. Little, if anything about this survey is service sector specific; most of its questions are general enough that they could be applied to both the manufacturing and service sectors of the economy.

The Canadian surveys are significantly longer than those contemplated in either of the Oslo Manuals. In part this is because completion of the survey is mandated by Canadian law. This permits the Canadians to survey on a wider range of topics than in other countries. Canadians have the additional advantage of having a single statistical data collection agency for the country. As a result, routine questions about the firm that might have to be duplicated on multiple surveys in other countries can simply be obtained in Canada by linking data sets based on a tax identification number.

Questions that have been added to the survey by the Canadians include the usage of employee development and training programs, employee access to the Internet, and the firm's use of the Internet for selling its products. In addition, there is a rather detailed section on the qualitative impacts of innovation activities on the firm, including its impact on productivity, the quality of service, the range of products offered, the size of the geographic market, and the firm's impact on the environment. Firms are also asked the degree to which new products replaced products that the firm previously offered. In addition to asking questions about the impact of new and improved products on firm sales and exports, firms are also asked a question about the frequency with which new products are introduced.

As in most Oslo-based surveys, firms are asked about their objectives in pursuing innovation development programs. The Canadian survey uses a threshold question (whether the objective relevant at all) followed by a five point scale for rating how important the objective is to the firm. The Canadian survey lists potential innovation objectives in more detail than most other surveys. So, for example, while CIS-2 lists "open up markets or increase market share" as a possible objective, the Canadian survey subdivides this into two categories ("open up" and "increase share") and further subdivides the increase share category by geographic region (domestic, European, USA, Japan, other Pacific rim, and other).

Aggregating this data in such a way that it will be comparable with the results of the CIS-2 survey will be difficult or impossible for three reasons. First, the CIS survey uses a 3 point scale rather than a 6 point scale. Second, because the data is not quantitative, it cannot be simply added up among the finer categories of the Canadian study to create the coarser categories of the CIS survey. Finally, the wording and design of the question itself may impact the comparability of the two surveys.

The same situation extends to questions on sources of information for firm innovation and barriers to innovation as well. In each case the Canadian survey presents a substantially finer subdivision of categories for firm responses. The implication here is not that the Canadian survey is either better or worse than the CIS version. Rather, it simply points up the importance of explicitly deciding whether or not to conform one's national survey design to those used elsewhere. There is clearly a trade off here between gaining more information about the domestic economy and obtaining results that are comparable with other nations.

As noted above, CIS-2 recommends that surveys ask firms to specify their most important technologically new or improved product or process. The Canadian survey takes up this issue and pursues it in some detail. Firms are asked to describe the most important innovation and are provided with a list of novel attributes and asked to specify all of them that apply to this innovation. These potentially novel attributes are:

- Use of new materials
- Use of new intermediate products
- New functional parts
- Use of radically new technology
- Fundamental new functions
- New production techniques
- New organizational innovations with regard to the introduction of new technologies
- New professional software developed by or specifically for you
- Other.

The principal reason the Canadians have focused on the firm's most important innovation is that the Canadian theoretical framework looks at innovation as having three parts: the generation of knowledge, the diffusion of knowledge and the use of knowledge. Very often these three functions do not occur in the same firm. The direction this theory is moving is to look at clusters of firms which may have complex relationships and information flows. As a result, it is important to pursue, in some detail, the linkages between technology developers and technology users. So, for example, they ask firms to specify the industry or industries and country or countries that were the main suppliers of ideas for the specified innovation as well as the ones who were the main customers for the new product. The idea here is to move beyond questions that, for example, might ask firms to specify the percentage of new ideas obtained from customers, and instead begin to identify networks of firms and industries that produce and use new technology. Note that this concept of "clusters" or "networks" of firms may be substantially less formal than that which is implied by SRP's. In particular, these clusters may have little in the way of a contractual foundation and may be more ephemeral in nature, appearing and disappearing as the firms see fit.

In addition firms are asked whether the innovation was a world first, a first for Canada, or simply a first for a local market. If it was not a world first, firms were asked where it was developed first and the length of time between its initial development and adoption by the responding firm. Firms are also asked about the effect of this innovation on firm employment and on the skill requirements of the firm's workers.

The Canadians devote a substantial section of their questionnaire to intellectual property rights. They ask both how frequently various mechanisms were used over a three year period in categorical brackets (none, 1 to 5 times, 6 to 20 times, 21 to 100 times, more than 100 times) and how effective they were in protecting intellectual property (using a threshold question and a five point scale). In this question they specifically ask about copyrights, patents, industrial designs, trade secrets, trademarks, integrated circuit designs, and plant breeders rights. They also ask firms about the effectiveness of two additional strategies: being the first to market, and having a complex product design.

Finally firms are asked to rate the importance of various factors to their overall competitive strategy and to the overall success of their firm. This permits one to assess in a more general way the role of innovation in the firm. A fairly detailed list of factors that might contribute to firm success is included under general areas such as technology and R&D, management, production, markets, financing and human resources. The factors that might contribute to a firm's competitive strategy include such items as price, quality, and customer service in addition to introducing new or improved products. In each case firms are not asked to compare the importance of these factors, they are merely asked to rate the importance of each on a five point scale (or as not applicable at all).

The Canadian Survey of Innovation was repeated in the fall of 1999, collecting data covering the 1997–1999 period. The questionnaire was similar to that used previously, though some changes were made in the order in which the questions were asked to attempt to minimize respondent misinterpretation. In addition, a new statistical unit was introduced called the "provincial enterprise". This unit consisted of all establishments of a multi-provincial firm that are located in a particular province. The idea was to develop a database with regional data. However the survey was sent to each company's national head office. Some problems of double-counting resulted when the head office attributed a single innovation to each statistical unit. [31]

In addition to the more general innovation surveys, Canada has conducted surveys on biotechnology in 1997 and 1999 and has recently completed a survey of the Canadian construction industry. The biotechnology survey was conducted in two parts, one of which surveyed biotechnology companies themselves and the other which surveyed firms that were in industries that were likely to be users of biotechnology-based products. While these surveys do not have a great deal of relevance to more general innovation indicator surveys, in a couple of cases they resulted in the creation of interesting new survey questions that may have some broader relevance. In particular, in addition to asking questions about whether intellectual property had been purchased or sold during the survey period, the biotechnology survey also asked whether firms had ever been forced to abandon a project because further work was blocked because of intellectual property that was held by another firm. They also asked the number of times in the past year that the firm had been involved in patent litigation.

Canadian analysts report that firms had considerable difficulty answering the questions about education of employees, whether an innovation was new to the world or just new to the local market, and the amount of time that elapsed between the introduction of an innovation by another firm and the its adopting by the responding firm. In addition, the Canadian survey contained a question asking firms to allocate the costs of innovation among categories and it found that Canadian firms had a great deal of trouble doing so.

The biotechnology survey also has an interesting variation on the barriers to innovation question. Instead of asking directly about barriers to innovation it asks firms to check the three most important "problems" to successful commercialization:

- Access to capital
- Access to smart capital (money plus management expertise)
- Access to technology
- Skilled human resources
- Consumer acceptance
- Lack of information about markets
- Regulations
- Labeling
- Limited international harmonization
- IP protection

[31] Information for this section was provided by Daood Hamdani of Statistics Canada.

- Cost of gaining regulatory approval
- Time required to gain regulatory approval.

This provides a potential alternative to the usual problems with separating out the effects of risk and cost in assessing innovation barriers.

**B. Other European surveys**

A number of other European countries (both within and outside the EU) have built upon the basic structure of the CIS and other reported surveys, adding questions on issues of concern to them. In addition to the EU countries, surveys have been carried out in at least the following countries: Switzerland, Norway, Poland, the Slovak Republic, Russia, Japan and Australia. These will not be considered in detail here, but will be taken up to the extent that they offer questions that are significantly different than those discussed above.

The Italian survey, for example, asks about the impact of innovation on firm employment, and also adds opinion questions about the impact of innovation on firm performance and about the firm's innovation plans for the future.

Like the Canadian survey, the Polish and Slovak Republic surveys ask questions about the purchase and transfer of new technologies.

The Swiss survey explores a number of interesting new areas. Firms are asked to evaluate, on a 1-5 scale, the technological opportunities available in their industry. The questionnaire also asks firms to evaluate the level of competition (with separate questions for price competition and other kinds of competition) using the same 1-5 scale. Firms are asked to characterize their products as standardized, differentiated, and/or custom built, though the survey does not ask firms to specify the percentage of products that fall in each category. In addition, firms are asked to rate the contribution of external information to the effectiveness of internal innovation development.

Switzerland also conducted a separate survey on the diffusion of basic technology in industry, focusing mainly on the conditions surrounding the adoption of computer-assisted production and the diffusion of microelectronic-based technologies. This raises an interesting question of whether it is advisable to bundle special surveys on multiple topics together if they are targeted at the same respondents. On the one hand, it no doubt reduces the cost of administering the survey and causes basic questions about the firm to not have to be repeated on both surveys. On the other hand, it also may cause the survey to become so large that response rates are adversely affected. The Swiss survey, including the computer assisted production and microelectronics special topics ran to sixteen pages of fairly small type.

In the second round of the CIS, most countries implemented the core CIS-2 questionnaire with relatively few changes. Exceptions include the United Kingdom and Germany, which both implemented significantly more detailed surveys. The UK survey asks an interesting question about the degree to which firms have implemented technologically-oriented management or organizational changes. They ask specifically about electronic data interchange, just in time (or similar) planning systems, electronic mail, use of the Internet, investments in people, quality management systems or standards (such as ISO9000), and benchmarking performance against other firms.

Under the topic of information sources, the UK survey asks the usual question about external sources of information that provide ideas for new or improved products or production processes, but it also goes on to ask which sources of information were used to actually carry out innovation projects as opposed to just suggesting ideas.

## VI. Innovation Surveys in the United States

Efforts to collect innovation indicator data (other than input indicators) in the United States have been on going for at least twenty-five years. In the mid-70s, NSF sponsored a group of pilot studies that were geared toward measuring the resources devoted to innovation on a project by project basis.[32] These studies encountered significant problems because it was determined that firms rarely kept records of this sort that attributed specific costs to specific development projects.

### A. NSF-sponsored innovation indicator surveys

In the early 1980s the focus shifted to collecting data about firms rather than collecting data about specific innovation projects. Christopher Hill, et al. explored the feasibility of a very wide range of potential innovation indicators. These indicators were developed through an exhaustive search of the extant literature on innovation theory and tested by conducting in-depth interviews with potential respondents using a series of trial innovation questionnaires.[33] Some of the questions in CIS-1 and CIS-2 can trace their roots to this indicator development project. This project culminated in the survey of 600 manufacturing firms in 1983-84 (collecting 1982 data).[34] The topics covered in this survey were:

- The number and sources of new products and proportion of firm sales due to them.
- The degree to which R&D was performed centrally in firms or in product divisions.
- The degree to which firms made grants or contracts to universities for research.
- The extent to which firms were involved in various kinds of internal and external technological ventures including venture capital investments and R&D limited partnerships.
- Expenditures for new plant and equipment, production start-up, and marketing for new products and production processes.
- The degree to which firms relied on patents and trade secrets.
- The amount of royalty and license fees from domestic and foreign firms and the number of firms from which such payments were received.

This survey achieved a response rate in excess of fifty percent. The completion rate for individual questions on the returned surveys was in excess of ninety percent. The survey was repeated in 1986 (collecting 1985 data) by Audits and Surveys, Incorporated. Roughly two thousand firms were

[32] Fabricant, S., et al. *Accounting by Business Firms for Investment in Research and Development* (New York: New York Univ. Dept of Economics, 1975) NSF/RDA 73-191.

Posner, L. and Rosenberg, L. *The Feasibility of Monitoring Expenditures for Technological Innovation* (Washington: Practical Concepts Inc., 1974).

Roberts, R.E., et al. *Investment in Innovation* prepared by Midwest Research Institute for the National R&D Assessment Program, National Science Foundation, 1974.

Hildred, W., and Bengstom, L. *Surveying Investment in Innovation* (Denver: Denver Research Institute, 1974) NSF/RDA 73-21.

[33] Hill, Hansen, and Maxwell, 1982, *op. cit.*

[34] Hansen, Stein, and Moore, 1984, *op. cit.*

involved in this latter study, but the response rate was substantially lower than with the previous survey. Almost 100 firms were respondents to both surveys. While minor changes were made to a few of the questions, for the most part the data collected were the same in both surveys. In some cases the same individual answered both questionnaires while in others, the questionnaire was answered by two different individuals within the same firm. One effort to assess the quality of the data consisted of analyzing whether the differences between the survey responses were greater when a different person responded than when the same person completed both surveys.[35]

In 1994 the U.S. Census Bureau conducted another pilot survey to develop innovation indicators in the U.S covering the 1990-1992 period. In this project 1000 firms were surveyed with a questionnaire that contained many of the same topics as the Eurostat surveys. Questions were included on issues such as:

- The incidence of product and process innovation.
- The objectives of innovation
- The sources of information for innovation
- Channels used to obtain new technology and channels for the transfer technology out of firms
- R&D or innovation partnerships with external entities
- Target technologies for R&D (such as new materials, flexible manufacturing systems, software, etc.).

The response rate obtained from this survey was 57%. One hundred thirty of the firms were the subject of intensive follow-up and for these firms a response in excess of 80 percent was achieved.

One of the most interesting results of this survey was the finding that of those firms introducing innovations, 84% also were R&D performers.[36] This is a stark contrast with most the European studies, which found a very large number of innovating firms that performed no R&D at all.

**B. The Yale/CMU surveys**

In the 1980's Levin, et al. conducted a survey designed to elicit information concerning the ability of firms to appropriate the results of their own technology development programs.[37] This survey, which came to be known as the Yale survey was later adopted and expanded by Wes Cohen, et al. at Carnegie Mellon University.[38] The second survey (hereafter CMU) is the focus of this section. It is significant for a number of reasons. Most importantly, the reporting unit for this survey is the business unit, rather than the enterprise. As a result, significantly more detailed questions could be asked.

[35] Hansen, J. A. "New Innovation Indicator Data Validation." Final Report to the National Science Foundation. 1991.
[36] Rausch, Lawrence, "R&D Continues to be an Important Part of the Innovation Process." NSF Data Brief, vol 1996, no. 7, August 7, 1996.
[37] Levin, R., Klevorick, A., Nelson, R. and Winter, S. "Appropriating the Returns from Industrial R&D," *Brookings Papers on Economic Activity* (1987) pp. 783-820.
[38] Cohen, W., Nelson, R., and Walsh, J. "Appropriability Conditions and Why Firms Patent and Why They do not in the American Manufacturing Sector." Mimeo, Carnegie Mellon University.

The sampling frame for this survey was constructed from the Directory of American Research and Technology[39] as supplemented by Standard and Poor's Compustat database. The sample was thus limited to R&D labs or units within firms that actually conducted R&D. The focus on firms that perform R&D was driven by the fact that the survey principally concerned the R&D function within the firm rather than the broader range of innovation activities, thus a firm that did not perform R&D would have found little on the survey that pertained to them. The CMU survey did not, however, focus primarily on measuring R&D inputs, but rather looked carefully at research objectives, information sources, and the structure of the environment in which R&D occurred within the firm. As a result, many of the questions are similar to those found on the CIS and MIT questionnaires. In addition, the CMU questionnaire also asked about the competitive environment in which the firm operated and the mechanisms that were used to protect intellectual property rights.

It is useful to focus on those areas of CMU survey that asked questions that were wholly different than those incorporated on previous surveys. For example, in attempting to pin down characteristics of the R&D environment in firms, questions were asked about how frequently R&D personnel interacted face to face with personnel in the firm's marketing and production units or in other R&D units. This is an example of the type of question that would be impossible to explore on the enterprise level, but certainly makes sense at the establishment level and seems to work at the business unit level as well. Firms were also asked questions about the relationships between R&D and other firm functions, such as whether personnel were rotated across units or whether teams were constructed drawing on various cross-functional units. They were also asked to specify the percentage of R&D projects that were started at the request of another unit within the firm. All of these questions stem from a more complex, non-linear model of innovation within firms.

While a number of other studies ask about the importance of firm interactions with universities and government labs, the CMU questionnaire was able to ask for more information about the nature of these relationships. For example, in each of three categories (research findings, prototypes and new instruments and techniques) it asked the percentage of R&D projects that used research results from universities or government labs. It also presented a series of scientific fields (Biology, Chemistry, Electrical Engineering, etc.) and asked on a four-point scale what the significance of university or government research was to the firm's R&D activities.

The CMU survey also included a section that asked about the relationship between the firm and its competitors. Firms were asked to name the most innovative firms in their industry and to assess their own level of innovation (disaggregated by product and process innovation) relative to other firms in the industry. Then firms were asked to assess the overall rate of product and process innovation in the industry as a whole. Firms were asked questions aimed at assessing how early in the innovation process they became aware of their competitor's innovations and what percentage of their innovations projects have the same technical goals as their competitors. Finally, firms were asked to estimate the number of competitors they have by region of the world, and how many were able to introduce competing innovations in time to effectively diminish the profitability of the firm's own innovations.

A significant section of the CMU questionnaire is devoted to assessing the firms ability to capture the returns from innovation using various mechanisms (patents, trade secrets, etc.). First firms were asked to specify the percentage of their innovations (disaggregated by product innovations and process innovations) that were effectively protected by:

[39] Bowker Press, *Directory of American Research and Technology* (New York: Bowker Press, 1984).

- Secrecy
- Patent protection
- Other legal mechanisms (such as design registration or copyright)
- Being first to market
- Complementary sales/service
- Complementary manufacturing facilities and know-how
- Product complexity
- Other.

A number of additional questions were asked about the firm's patenting behavior, including the number of patents applied for, the reason that patent applications are made (prevent copying by other firms, measure researcher performance, obtain revenue, etc.) and the reasons the firm might specifically decide not to patent a new discovery (information disclosure, cost of patent application, difficulty in demonstrating novelty, etc.). In addition firms were asked how long it took competitors to introduce similar alternatives both in cases where patents had been obtained and in cases where they had not. This question was asked separately for product and process innovations.

### C. Other innovation indicator studies in the United States

There has been a range of other studies in the United States that have attempted to develop innovation indictors. As was noted in the introductory section, the NSF sponsored a number of these projects in the 1970s. In addition over the past couple of decades the U.S. Small Business Administration has developed a database of U.S. introduced innovations, with a focus on those developed by small businesses.[40] This database assigned each innovation to a 4 digit SIC category and also contained information on the geographical area where the innovating establishment was located and a ranking that reflected the significance of the innovation. This database is limited to product innovations. In 1993, Gelman Research Associates attempted to sample from this database and obtain data about the timing of key events in innovation development, the sources and uses of funds, the markets served and commercial impacts of innovations and the innovations degree of novelty. The study was marred by extremely low response rates and was eventually limited only to participation by small firms.[41]

One other survey that is worthy of note is an R&D survey conducted by the Industrial Research Institute and Center for Innovation Management Studies. In addition to asking about R&D spending, it also asked about the organization of R&D within firms (notably the degree of centralization), the sources of R&D funds and the percentage of sales attributable to new or improved products.[42]

[40] The Futures Group, *Characterization of Innovations Introduced on the U.S. Market in 1982.* Study prepared for the U.S. Small Business Administration, 1984.
[41] Gelman Research Associates, *A Survey of Innovative Activity* (Jenkintown, PA: Gelman Research Associates, 1993). Final Report Prepared for the U.S. Small Business Administration.
[42] Bean, A., Russo, M, and Whitely, R. *Benchmarking your R&D: Results form IRI/CIMS Annual R&D Survey for FY '96.* Cited in Cooper, R. and Merril, S. "Trends in U.S. Industrial Innovation: An Assessment of National Data Sources and Information Gaps." Forthcoming.

## VII. Issues for U.S. Innovation Indicator Development

As the previous section demonstrated, a number of efforts to develop innovation indicator surveys have been undertaken in the United States, sponsored both by governmental and non-governmental agencies. We have learned a considerable amount from the experience. Most importantly, we have learned that useful data can be collected, though achieving acceptable response rates is rather difficult. We have also leaned that the United States has some unique characteristics that confront data collectors with a different set of challenges than are faced elsewhere.

Two of these characteristics are especially important. First the United States has no single central statistical office. Thus, developing linkages between innovation data and other economic data is inherently more difficult. Secondly, the United States has an extremely rich variety of organizational forms among its firms. Hence, while the Europeans might take the view that it was reasonable to collect data at the enterprise level and then handle any firms for which this presented difficulties as individual special cases, this will probably not work in the United States. These two characteristics combine to create an even more difficult problem. If it were possible for the National Science Foundation to determine the optimal statistical unit of analysis for innovation surveys, it could determine that innovation survey data would be collected at that level. However, it cannot determine the statistical unit of analysis for other government agencies that collect data from firms. Thus it must take into account both the theoretically preferable manner in which to collect data and a desire to have the data linked to other data sets when determining the statistical unit.

This section focuses on issues that need to be addressed before a new innovation indicator survey could be mounted in the United States. The topics here include the content of the survey instrument itself, the reporting unit, coverage of service sector firms, and procedures to maximize the response rate.

### A. The reporting unit

The Oslo Manual draws a distinction between the *reporting unit* and the *statistical unit*. The reporting unit within a firm is the level of the organization that actually receives the questionnaire and is asked to fill it out. The statistical unit within a firm is the level of the organization that the data is actually collected about. These need not be identical. For example, it is possible to ask that the firm as a whole report the percentage of sales from new products for each of its establishments. In this instance the reporting unit would be the enterprise, but the statistical unit would be the establishment. The Oslo Manual suggests, however, that whenever possible, the reporting unit and the statistical unit should be the same.

The content of the survey depends in part on the reporting unit selected. Detailed questions, especially concerning various types of innovation expenditure, cannot be collected at the enterprise level because the data simply are not known at that level. On the other hand, questions concerning firm strategy, such as those revolving around the firm's innovation objectives, may be developed at the enterprise level, making it difficult to collect these data at the establishment level. Thus it is important to make a decision about the level at which data will be collected before making final decisions about what data to collect.

While the issue of the reporting unit has often been framed in terms of the alternatives of the enterprise or the establishment, Archibugi, et al. point out that there are really a number of different candidates for the reporting unit:

*The legally defined enterprise* is a unit which has legal status in a given country. It might have one or several establishments, one or several business units. In several cases, it corresponds to the unit registered for tax purposes. According to this definition, establishments or business units located outside the borders of the nation should not be considered.

*The economically defined enterprise* is classified according to the ownership or control. It includes all establishments or business units which are owned or controlled by the enterprise, located in the same or in a different country than the enterprise's headquarters. Often, large economically defined enterprises are subdivided even within one country, into several legally defined enterprises.

*The business unit* is part of the enterprise, although several enterprises are composed by a single business unit. A business unit may have one or more establishments. [note: this unit is intended to be similar to the "line of business" concept in the U.S.]

*The establishment* is a geographically specific production unit. Several enterprises, especially among those of smaller size, have a single establishment only.[43]

Given the importance of developing national data on innovation, the economically defined enterprise is unlikely to be adopted as the reporting unit. As a result, we will focus on the other three candidates, which will be concisely referred to at the enterprise, the business unit, and the establishment.

Most ongoing innovation indicator studies use the enterprise as the reporting unit (and the statistical unit of analysis). The Oslo Manual specifically makes this recommendation, but adds that diversified firms may be subdivided according to the type of economic activity that they engage in. To date all of the U.S. National Science Foundation innovation indicator data has been collected from enterprises as well. In the first round of CIS surveys, only two countries used something other than the enterprise as the basis for their survey. The second CIS survey instructions clearly indicate a strong preference for using the enterprise as the statistical unit:

> The statistical unit for CIS 2 should be the enterprise, as defined in the Council Regulation on statistical units or as defined in the statistical business register. If the enterprise for some exceptional reasons is not feasible as statistical unit other units like divisions of enterprise groups or kind of activity units could be used. These exceptional units should be indicated in the database. Some adjustments for these might be needed in the processing of data.[44]

[43] Archibugi, Daniele, Cohendet, Patrick, Kirstensen, Arne, and Schaffer, Karl-August. "Evaluation of Community Innovation Survey (CIS)–Phase I" European Innovation Monitoring System (EIMS) Publication No 11. 1995.

[44] Eurostat, "The Second Community Innovation Survey: Annex II.3: Methodological Recommendations," 1997.

One key reason for relying on the enterprise as the reporting and statistical unit is pragmatic. Other data, (notably R&D expenditures) are collected with the enterprise as the reporting unit. Thus data collectors both have a great deal more experience collecting data from enterprises and have other historical data series that are collected on an enterprise basis.

Policy makers have traditionally wanted firm-level innovation data so that they could link it to other firm-level data sets and so that they could address questions that were inherently firm-level questions, such as the distribution of innovation activities by firm size. It is notable that virtually every innovation indicator study has attempted to collect data and report results disaggregated by firm size. Without firm-level data this is impossible.

If having firm-level data is important, the only practical way to obtain it is to collect data at the enterprise level. This may be observed by considering the methodology that would be required to collect firm level data at a lower level within the firm. In principle, if the data collected were purely quantitative, it should be possible to collect the data from each of the firm's establishments or business units and then re-aggregate it back to the level of the firm as a whole. This would be possible if either a census was taken of all of the firm's establishments or business units or if some method were established for imputing values for the missing components of the firm. Even if a census were used, it is likely that there would be some non-respondents among the firm's establishments, requiring imputation of some missing values in any case. This technique would probably require that each firm be treated as a "special case" so that the analyst has a list of each of the units within the firm and is able to keep track of which units responded and which did not. The analyst would have to be sufficiently well informed about the firms operations that he or she could intelligently estimate the missing values.

In the case of qualitative data, it is likely to be impossible to reconstruct firm data from data provided by the various establishments or business units. For example consider the following question from CIS-2:

*Between 1994-96 has your firm introduced any technologically new or improved processes? If yes, who developed these processes?*

| | |
|---|---|
| *Mainly other enterprises or institutes* | O |
| *Your enterprise and other enterprises or institutes* | O |
| *Mainly your enterprise* | O |

Suppose a firm has four establishments or business units. Three of them indicate the first response (mainly other enterprises or institutes) and one indicates the third (mainly your enterprise). How should we re-aggregate this data to the firm level? Should we assume that since this work is done both within and outside the firm the appropriate response for the firm as a whole is item 2 (even though no entity has checked it)? Should we conclude that the answer should be the first response because three of the four units checked it? Should we weight the responses by sales or R&D expenditure to come up with an average response?

On the other hand, suppose the one establishment that indicated the third choice also contains the firm's central R&D lab. Ought we not to conclude from this that the establishment with the central R&D lab is fundamentally different than the rest of the firm and that no single answer to this question will adequately describe the firm's behavior? The raises a fundamental problem with collecting data at the enterprise level. If it is not possible for the data collector to construct a reasonable answer to the question based on information obtained from the various firm establishments (or business units) this may be because a single reasonable answer for the firm as a whole does not exist.

Another problem with collecting data at the enterprise level is that it makes sector-level analyses rather difficult. Many, if not most, enterprises span more than one industrial sector. The Oslo Manual recommends using International Standard Industrial Classification (ISIC) codes or NACE codes to classify enterprises by sector. The recommended divisions are only to the two digit classification level, so the categories tend to be fairly broad.[45] Even at the two digit level, however, it is extremely difficult to classify even moderately diversified firms. Oslo-2 recommends classification by *principal* area of economic activity. Thus for a firm in more than one two digit category, all of its activities will be attributable to its principal category. This creates problems at the two digit level, but classification of enterprises at any finer level of stratification than two digits is virtually impossible.

If we come to the conclusion that the only practical way to collect data about the enterprise as a whole is to survey at the enterprise level rather than the establishment or business unit level, it has a substantial effect on the type of data that can be collected for two reasons. First, enterprises know less about the activities going on in the business units than the units themselves do, so they are less able to answer detailed questions (especially in areas such as innovation costs) than are business units or establishments. Thus, surveys of enterprises rely heavily on either qualitative data or on rough estimates of quantitative data. Secondly, asking for qualitative data at the enterprise level does not eliminate the aggregation problem described above, it merely causes it to be dealt with by the firm itself rather than by the data collector. It is still necessary for someone to look at the various behaviors of the business units within the firm and make a judgment about what data should be reported for the firm as a whole. While it is arguable that individuals inside the firm are in a better position to make judgments about how to aggregate qualitative data from disparate business units, it does not mean that it will be possible to report meaningful summary data in situations where no meaningful summary data actually exist.

If it were possible to do without data aggregated on an enterprise-wide basis, it would be possible to collect the data on either the establishment or business unit basis. An establishment represents an entity that is limited to a single geographic area. As a result, respondents at this level generally tend to have more detailed information available than do respondents at the enterprise level. Another advantage of collecting at the establishment level is that it is the only mechanism that will permit analysis of data disaggregated by geographic region. Neither enterprise-level data nor business unit data permit tracking the geographic location of innovation activities.

There are a number of problems with the establishment approach, however. First, there is a much larger population of establishments than of firms. This would represent a very significant increase in cost for those surveys that attempt to conduct a census rather than select a sample. Even for those researchers who only wish to survey a sample of establishments, significant problems will arise in identifying the population from which the sample is to be drawn.

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[45] It is interesting to note that the initial Yale study found that a two digit sector analysis was sufficient to elucidate most of the important inter-industry differences see Levin, et al., 1987. *op. cit.*

There are particular problems associated with achieving high response rates when surveying establishments. At the enterprise level, there is generally someone whose job it is to be concerned with innovation within the firm. This person may have a title such as Vice President for Research and Development, Chief Technical Officer, or Director of Technology. This person is likely to have at least some sympathy for the goals of the innovation indicator data collection project and some interest in the underlying concepts. In doing surveys of this type we have found that many of these individuals have a great deal of enthusiasm for the innovation indicators project and have launched their own ongoing internal innovation data collect efforts. It is far less likely that a similar individual will exist at the establishment level. At the establishment level potential respondents are more likely to find the survey purely an inconvenience that interferes with the flow of their work. Previous studies have found that one thing that contributes to increasing response rates is that the survey be addressed to an individual within the firm by name. This involves identifying the name of the person within the firm that is the most appropriate individual to fill out the questionnaire. Because establishments generally do not have offices or individuals who are specifically responsible for innovation within the firm, respondent identification will be substantially more difficult than it is for enterprises.

At the establishment level response rates may also be hampered if potential respondents do not believe that they have the authority to complete and return the questionnaire. In these cases respondents may forward the questionnaire back to the enterprise level rather than completing it themselves.

The third alternative is to collect data at the level of the business unit. A business unit consists of all establishments within an enterprise that are in the same line of business. While the activities of individual establishments may span multiple NACE code categories, all of the activities of an establishment would be attributable to its principal NACE category. Because the activities of establishments are substantially more homogeneous than the activities of enterprises, this problem is significantly less serious than in the case of establishments. As a result, line of business reporting can generally be successfully achieved at a more disaggregated sectoral level than enterprise-based reporting.

There are a number of advantages to this approach. To the extent that it is desirable to analyze innovation on a sector basis, the business unit approach provides data that will most clearly facilitate this analysis. Companies themselves often view business units as natural divisions for record keeping and strategic planning, so it would be easier for them to provide data at this level. However, it is worth noting that there is no particular reason that companies would view the boundaries between business units as being the same as those that were called for by the various standard industrial classification systems.

In addition, since the data are designed to summarize firm behavior, it makes sense to collect this data at a level where the data within each reporting unit is relatively homogeneous and the differences between reporting units are greatest. Because the line of business often dictates the type of technology developed and used and the way it is applied, these categories occur most naturally when the statistical unit is based on business units.

Some of the problems identified in conjunction with collecting data at the establishment level also exist in the case of business unit reporting. Obtaining a population of business units from which to sample (or to conduct a census) is likely to be even more difficult than obtaining a list of establishments. This is because establishments at least have a relatively unambiguous identifying characteristic (a distinct geographical address) whereas the identifying characteristic of business units is more amorphous. Identifying the appropriate individual within the company to respond to the survey will also be more difficult, but since lines of business are generally a higher level of aggregation within a firm than establishments, there is a better chance that someone is specifically responsible for innovation.

The degree of difficulty posed by these considerations depends on how the firm is organized. If firms are already organized along business unit lines (for example, with divisions that correspond to NACE business units) then locating someone to provide the data and obtaining the data will be relatively easy. If, however, the firm is not internally divided along business unit lines, simply trying to explain to a potential respondent (who may never have heard of SIC, ISIC or NACE codes) what data is being requested will pose a daunting task. It might be useful to discuss this issue in some detail with representatives of the Federal Trade Commission who attempted to collect data along business unit lines in the 1980s. Their perspective on the level of difficulty associated with requesting data from firms might provide some guidance as to whether it is reasonable to expect acceptable response rates if data is collected in this fashion.

The focus up until now on collecting data from enterprises is based on the view that innovation is an activity that is firm-centric. That is, information flows and new product and process development are activities that occur mostly within firms. As we have begun to understand the degree to which linkages with customers, suppliers and others are important to the innovation process, these linkages have been dealt with as exceptions... important exceptions, it is true, but exceptions nonetheless. Thus it was considered reasonable to argue that collecting data on an establishment level was problematic, because central R&D labs, which would be treated as separate establishments, report R&D but no sales. However, if the R&D that underlay a new product innovation was conducted in a completely different firm (either because of an SRP or some other arrangement) for some reason this wasn't viewed as a reason for abandoning enterprise-based data collection. The situation is made worse because the reporting unit has generally been the legally defined enterprise, not the economically defined enterprise. Thus R&D that is performed within the firm, but in a subsidiary that is in a different country, is not counted either.

Recent research results from Statistics Canada cause one to wonder if the problem isn't even more serious. In a recent data collection effort on the construction industry in Canada, researchers found that the very concept of a "firm" was beginning to disappear. On some construction projects "firms" as we think of them have no persistence. The firm is essentially a joint venture of contractors (*not* working as subcontractors for a general contractor) which come together to form a "firm" for the life of a single construction project. It is argued that this results in economies in the design process and also reduces litigation costs if something goes wrong.

Similar behavior can be seen in other industries as well. Engineering expertise is being contracted out by firms on a project by project basis. In some cases these relationships are with engineering consulting firms, while in others independent contractors are hired. Some of these relationships will persist for long periods of time while others will relate to just one project. The research capacity of firms using this technique is thus extremely fluid. Perhaps most interesting is the fact that the firms that are consumers of these engineering services are often firms that have almost no internal development capacity of their own. They may regularly introduce new products or new production processes, but have done essentially no development themselves. This model has been observed for quite some time in computer software, where firms with no in-house software development capability would hire outside consultants or firms to create custom software packages, and in the process substantially alter their production processes. However, the approach has been picked up in a number of other industries, and is now quite common, for example, in the development of custom embedded microprocessor applications and even such traditionally less technological industries as toys.

### B. The composition of the questionnaire

A great deal of time has been spent over the past two decades on the development of specific questions that might be included on innovation indicator surveys. It is important to design these surveys so that the results will be comparable with previous surveys and with surveys that are conducted in other countries. Thus it is useful to begin by considering questions that have been included on previous surveys both in the United States and elsewhere. However, since the field is not likely to stand still, it is also important to not ignore on-going theoretical developments that may result in productive new areas of inquiry.

CIS-2 asks for innovation data in six basic areas: The scope and importance of innovation activities, the resources devoted to innovation activities, the objectives of innovation, the sources of information, cooperative innovation ventures, and factors hampering innovation.

Questions on the scope and importance of innovation activities ask whether the firm is involved in the introduction of new products and processes and the extent to which these activities have contributed to firm sales. These questions have now been tested in quite a number of countries over a substantial period of time. All indications are that firms are able to answer them and that the data produced are reliable.[46]

The remaining issue with regard to these questions is one of scope. Arundel, et al., argue that questions of this type should be careful to include asking about the *development* of new technological products and processes (TPPs) as well as their introduction on the market.[47] Some surveys have asked for firms to differentiate between sales that are attributable to new products and those that are attributable to improved products. In the United States, when these data were collected at the enterprise level, most firms answer with "educated guesses" rather than calculations based on the firm's financial records.[48] In this case the question of whether to ask for a further subdivision is partly psychological. Firms are often reluctant to provide responses when there is no hard data to support the answers given. The more questions that are included that firms feel uncomfortable answering, the more likely they are to not respond to the survey at all. Asking for more detailed breakdowns of items where the respondent has little confidence in the accuracy (except in general terms) of the aggregate estimate, may result in a lower response rate.

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[46] Hansen, J. A. "New Innovation Indicator Data Validation" Final Report prepared for the U.S. National Science Foundation, 1991.
Archibugi, et al., 1995. *op. cit.*, chapter 5.

[47] Arundel, et al., 1998, *op. cit.*, appendix C.

[48] Hill, C. Hansen, J., and Maxwell, J. *Assessing the Feasibility of New Science and Technology Indicators* (Cambridge: MIT Center for Policy Alternatives, 1982).
This was not the case with all firms. Some had collected data themselves and used it for strategic planning. A few even included it in the firm's annual report.

Questions on the resources devoted to innovation have caused significant problems for most studies in which they have been included. Oslo-2 concedes that "Not many enterprises keep separate records of other [non-R&D] TPP innovation expenditures," but nevertheless concludes that "experience has shown that it is quite possible for them to give acceptable estimates of the non-R&D portion."[49] Later though, the Manual notes that most studies that have attempted to collect this data have found that firms simply don't have it.[50]

Some work has been done to assess the validity of this indicator. For example, comparisons of data collected in the U.S. in 1982 and 1985 found large unexplainable differences in the responses to this question. It also found that the percentage of total innovation expense accounted for by R&D was much higher than was indicated by previous studies. For example, in 1985, firms reported that on average expenditures for new plant and equipment related to the introduction of new products was only twice as high as their expenditures on R&D. Just three years earlier an admittedly smaller sample of firms reported that it was 21 times higher.[51] Other studies have reported similar anomalies. For example, in a survey conducted in the Nordic Countries that was sponsored by the Nordic Industrial Fund, it was found that R&D accounted on average for more than two thirds of all innovation expenditures in Norway.[52]

This is not to say that this question has never worked. In a series of annual studies of innovation expenditures in Germany, Lothar Scholz found that this data could be collected in a meaningful way. However, it required a substantial amount of close work with the companies involved in the survey. When the survey was first begun, response rates were rather poor. However as the survey continued over time and firms themselves began to see the value in it, response rates improved as did the apparent quality of the data. The firms believed the survey had value because as participants in the survey, they received a sector report that summarized the collected data for their specific industry. Scholz believed that firms became more skilled at preparing these estimates as they became more experienced with them. He also suggested that experienced firms used a procedure of estimating the change from the preceding survey rather than constructing a wholly new estimate for each year's survey.

Questions on the firm's objectives for innovation, sources of information, and cooperative arrangements with others are relatively easily answered. As discussed above, it is sometimes difficult to know how to interpret the answers to these questions when the response is from an enterprise with many disparate business units. With regard to all survey questions that ask simply whether a firm has a particular activity, relationship or goal, the larger and more diversified the enterprise the more likely it is to answer "yes." Diversified firms simply do more different kinds of things than smaller, less diversified firms. If the activity, relationship or goal exists in any of the diversified firm's various units, the answer to the question for the enterprise as a whole will be in the affirmative. However, the total amount of innovation produced by a large firm that does a wide range of things is not necessarily more than the innovation produced by a group of small firms which, if taken together, would have the same range of activities.

[49] OECD, 1997, *op. cit.*, p. 81.
[50] *ibid.* p. 89.
[51] Hansen, 1991, *op. cit.*, p. 23.
[52] Nordic Industrial Fund, *Innovation Activities in the Nordic Countries* (Oslo: Nordic Industrial Fund, 1991). p. 56.

In some areas, CIS-2 asks firms to specify whether each item is not relevant, slightly important, moderately important, or very important. In a highly diversified firm, if an item is critically important, but only to a single business, it is unclear whether they will answer very important, because it is critical to the one unit, or some lower level of importance because it only affects one unit. Firms are offered no guidance on this issue on the survey itself.

One additional difficulty that has come up with regard to the objectives of innovation question is that unless the question is very carefully worded, firms may answer from the perspective of whether each of the goals on the list is an objective of the firm's competitive strategy in general, rather than a goal of the firm's innovation strategy.

The final area on CIS-2 concerned factors that hamper innovation. Questions of this type have appeared on a large number of surveys over the years either as factors that hamper innovation or as obstacles to innovation. The importance of this subject stems from a desire on the part of policy makers to promote innovation in the economy. Policy maker's concerns over the level of innovation stem from two sources. First early economic studies pointed out both theoretically and empirically that there is a divergence between the private and social returns to investment in innovation. As an innovation becomes diffused through the economy, the firm that introduced it will only be able to capture a portion of the benefits that accrue from that innovation. As a result, the incentive to develop innovations in the first place is less than it would be if firms could capture all of the benefits that they produce.

Second, the government necessarily has a role in the innovation process. For example it determines the rules and regulations surrounding firms' use of patents and technology licensing. It finances a significant amount of research either directly through grants and contracts or indirectly through its purchases of goods and services that have new technologies embedded in them. It also establishes environmental (and other) regulations that affect technological development. As a result, it is concerned about the degree to which these policies promote or hamper innovation in private firms.

While recognizing that assessing the degree to which firm innovation is hampered by various factors is important, it may not be that the best way to do this is to ask firms directly. There are a number of reasons for this. First, it is not clear that firms (or anyone else for that matter) can usefully disagregate hampering factors that are inherently intertwined. For example, CIS-2 asks firms whether they are hampered by "excessive perceived economic risks," by "innovation costs [being] too high," or by a "lack of appropriate sources of finance." The decision to invest in new product or process development stems from an analysis (albeit sometimes an informal analysis) of the likely return on the investment, adjusted for the perceived risk, and the cost of the investment. Lower risks or higher returns will justify innovation investments with higher costs. It is difficult to see how a firm could look at these three factors one at a time, rather than considering them as a group.

Even when it is possible to disentangle the various hampering factors, it is not clear that the firms actually know the answer to this question. We can find out from a survey how important they perceive these factors to be (or at least what they report this importance to), but it is quite possible that one of the most significant factors hampering innovation is that firms don't have a good understanding of what obstacles they actually face. It is also possible that on a government questionnaire asking whether government regulations or standards hamper innovation, firms may view the survey is an opportunity to alter government policies in this area.

Finally, there is a substantial bias built into most of the questions of this type. The words used in the question are almost always pejorative. Firms are asked if they are "hampered" by "obstacles" or "barriers." They aren't asked if they are restrained from making unwise and unprofitable investments in products or processes that have little market potential.

Aside from those questions specifically included on the CIS-2 survey, there are some areas where it might be useful to considering making additions. One area that deserves consideration is the collection of data that will help trace the relationships that are part of an innovation production/diffusion network. The "sources of information" question is designed to move in that direction, but it collects data concerning only one kind of interaction (information exchange) and looks only at very broad categories of firms (customers, suppliers, competitors).

Another approach is that taken by Canada and a few other countries, where firms are asked to identify specifically their most important innovation. Follow up questions can then be asked about other firms that were involved in either the development or diffusion of this innovation. This provides much more detailed information about the inter-relationships of various firms' innovation activities.

A key problem with this approach is that it generally asks about only one innovation. The firm's "most important" innovation may not be a typical innovation. It may stand out in the mind of a respondent precisely because it was so unusual. On the other hand, it would be rather difficult to ask firms to name a "typical" innovation, since these are likely to be relatively routine and unmemorable. In any case, this may be the type of question that is best addressed at the enterprise or business unit level, since large, diversified firms are likely to have trouble answering it at all.

An alternative approach has been at least partially explored in the CMU study. Instead of only asking about the importance of sources of information by various categories of firms, the CMU study disaggregates the sources of information question by type of technology (at least when asking about university or government contributions). For example, it asked whether university or government research yielded significant results to the firm in the area of biology, or physics, or chemistry. It is possible to envision extending this to the questions about sources of information from customers and suppliers as well, asking firms to specify the industries that had some relationship to their innovation efforts. This might facilitate identifying the clusters of firm-types that are responsible for innovation.

The Oslo Manual offers one other suggestion along these lines. It proposes "asking firms to indicate the proportion of sales due to technologically new or improved projects by the sector of main economic activity of their main client(s) for those technological product innovations."[53] Particularly at the enterprise level, this type of data may be difficult or impossible to obtain.

While it is mentioned in the current Oslo Manual, the latest CIS questionnaire does not ask for any information about mechanisms the firm might use to appropriate the benefits of its technology developments. At a minimum, it may be worth considering whether a question or two about the relative importance of various forms of intellectual property protection ought to be included. Such

[53] OECD, *OSLO Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data* (Paris: OECD, 1997). p. 76.

information is, of course, useful on its own, particularly since the legal environment created by government policies has a significant impact on firm's strategic decisions with regard to protecting intellectual property. However, since patents themselves have often been the subject of data collection efforts as intermediate outputs of the innovation process, understanding how firms view the importance of patents relative to other forms of protection is critical to interpreting the patent data itself.

A range of questions have also been asked on surveys about the structure of R&D within firms. These include such items as asking the percentage of R&D that is spent in a central research facility as opposed to production divisions, whether R&D is conducted in a central facility that is financed outside the facility (either from production division budgets or outside the firm), and the amount of time that R&D personnel spend on a range of activities including meeting with people from marketing or production, attending conferences, receiving additional education, etc. Other questions of this type included on many surveys include the degree of contracting out of R&D or participation in joint R&D relationships with universities, government laboratories, or other firms. In reviewing many of the concerns cited by the recent NRC report on industrial innovation in the U.S., many of them revolve around issues of the structure of R&D within firms.[54] These include questions concerning the alleged "hollowing out" of firm's research capabilities. Questions of this type could be structured to gather information about these concerns.

One concern raised by a number of analysts is that often qualitative questions are not anchored to any reference that is shared between firms.[55] Firms are asked, for example, whether an innovation objective is slightly important, important, or very important. As responses are collected, it is reasonable to think that various respondents will have very different ideas of what "important" means. Thus two identical firms with identical sets of objects might provide different answers as one rate an objective "important" while another said "very important." One way around this is to ask firms to identify the most important factors, rather than evaluating the importance of each one separately.

### C. Sector coverage

The service sector of the economy continues to grow relative to manufacturing and now accounts for well over half of all employment. However, until now, innovation indicators in the United States have focused exclusively on manufacturing. Partly the reason for this was pragmatic; it was deemed to be more difficult to collect meaningful data from the service sector. It was also partly policy driven. Evangelista, et al., point out that innovation policy is almost exclusively directed toward the manufacturing and university sectors,[56] hence the need for innovation data for policy purposes was limited to those sectors. However, not only has the service sector become a large portion of our economy, it is also major contributor to technological innovation. In OECD countries, the service sector accounted for nearly a quarter of all business R&D in 1991.[57] As the importance of the service

[54] Cooper, R., and Merrill, S., *op. cit.*
[55] See for example, Arundel, et al. "The Future of Innovation Measurement in Europe" IDEA Paper No. 3, The STEP Group, 1998. Appendix A, pages IV-V.
[56] Evangelista, R., Sirilli, G. and Smith, K., "Measuring Innovation in Services" IDEA Paper No. 6, The STEP Group, 1998.
[57] Evangelista, R., and Sirilli, G. "Innovation in the Service Sector: Results from the Italian Survey" IDEA Paper No. 7, The STEP Group, 1998. p. 1.

sector of our economy grows, it is difficult to imagine that the collection of innovation indicator data could be limited to the industrial sector for much longer.

If the decision is made to include service sector firms in innovation indicator data collection projects, it is reasonable to ask what, if anything, about these firms causes them to require any different treatment than manufacturing enterprises. While there are a number of distinctions, the key element cited in most studies is that in the service sector production and consumption occur simultaneously.[58] The reason for this is that in services there is no tangible product that can be stored or inventoried. From an indicators standpoint, this leads to a general concern about whether it would be possible to treat product and process innovations separately, since the process by which the service is produced is generally also the product. An example of this sort of problem can be found in the introduction of the automatic teller machine (ATM) in the banking industry. The ATM is a production process because it is the mechanism by which banking services are delivered to consumers. Consumers, however, view the ATM as the product. A clear distinction here is probably impossible.

Eurostat approached this problem by sponsoring a series of pilot studies of service industry innovation. Initially twenty interviews were conducted in Germany and the Netherlands (10 in each country) to determine whether the definitions in the Oslo Manual would have to be changed to accommodate the service sector. Note that the assumption was made that the questionnaire would be pretty much the same for the service sector as for the manufacturing industries, but some changes might be required in the definitions of "new products," "new processes," etc.

A number of significant changes in the definitions were recommended as a result of the pretest. Most importantly, separate definitions for product and process innovation are not included. Instead the final version of CIS-2 is clear that both types of innovation need to be included, but does not ask firms to attempt to separate them.

A new or improved service is considered to be a *technological innovation* when its characteristics and ways of use are either completely new or significantly improved qualitatively or in terms of performance and technologies used. The adoption of a production or delivery method which is characterized by significantly improved performance is also a technological innovation. Such adoption may involve change of equipment, organization of production or both and may be intended to produce or deliver new or significantly improved services which cannot be produced or delivered using existing production methods or to improve the production of delivery efficiency of existing services.

The introduction of a new or significantly improved service or production or delivery method can require the use of radically new technologies or a new combination of existing technologies or new knowledge. The technologies involved are often embedded in new or improved machinery, equipment, or software. The new knowledge involved could be the result of research, acquisition or utilization of specific skills and competencies.[59]

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[58] See for example, Miles, I., *Services Innovation, Statistical and Conceptual Issues*, Working Group on Innovation and Technology Policy, OECD (DEST/EAS/STP/NESTI/ (95)12).
[59] OECD, "The Second Community Innovation Survey," Core Questionnaire: Service Sector, 1997.

Another early effort to develop innovation indicators for the service sector was undertaken in 1995 in Italy. The survey was limited to in person interviews with nine companies. Here the researchers were careful to focus on innovation that was "technological" rather than also allowing for innovation that was based on "new knowledge," but they also preserved the definitional distinction between product and process innovation. The Italians found that initially firms exhibited a great deal of confusion about whether innovations were product or process innovations, but since the research was based on in-person interviews, the interviewers were able to explore means of clarifying this distinction. They found that if they explained that a process innovation was one that was aimed at increasing the overall efficiency of the firm while a product innovation involved the introduction of a new or improved service, firms were able to distinguish between them.[60]

Another major change that came about as a result of the pretest was that questions that attempted to assess the significant of innovation by asking about their contribution to sales were dropped. The reason is that firms have trouble identifying the sales that result from a product addition or change. In these industries, services are often bundled together and sold a package. Often this sales method is dictated by the product itself.. Returning to the example of ATM machines, the services provided by these machines are most often packaged with a range of other bank account services. It might be possible to calculate the amount paid by consumers (in fees and foregone interest) for the services associated with a particular type of account (though even this is questionable), but it is impossible to isolate the component of the fee that is related to ATM services.

The inability to develop data for the new product sales indicator is disappointing because in manufacturing, firms have generally been able to provide this data. It is perhaps the only quantitative measure we have that provides information on diffusion. Its value as an indicator is demonstrated in part by the quantity and range of surveys on which it has been used.

As yet, few efforts have been made to develop any new indicators of innovation in the service sector that do not have counterparts in the manufacturing sector. It may be that there simply are none. However, when the current crop of indicators was developed, the researchers who developed them clearly had manufacturing in mind. Had they focused on the service sector instead, it is not clear that this same group of indicators would have emerged. As a result, it might be worth considering devoting some resources to taking a fresh look at the service sector from this perspective.

One other item is worth mentioning. None of the work that has been done to assess the feasibility of applying these indicators to the service sector has been performed in the healthcare industry. In fact, this sector is not mentioned in the classification list of service sector enterprises in the Oslo Manual, nor was it treated in the Canadian service sector survey. The reason for this is that in these countries the healthcare industry is generally viewed as a part of the public sector of the economy rather than the private sector. This raises two interesting issues. First, should health care be included in a U.S. survey of innovation in the service sector? Second, should public sector service providers in the U.S. (the U.S. Postal Service, for example, or public universities, as education providers, not R&D providers) be included? As long as innovation data collection was related solely to manufacturing, this issue didn't arise, since there is very little public sector manufacturing. As the focus shifts to the service sector, however, it must be addressed.

[60] Evangelista, Sirilli, and Smith, *op. cit.*, p.20. This is something of an oversimplification. Firms were also given a number of examples.

**D. Response rate maximization**

A key concern for future U.S. innovation indicator data collection projects is achieving a high response rate. To date, voluntary surveys on innovation activities that are as detailed as those contemplated by either Oslo-2 or CIS-2 have rarely achieved response rates in excess of 60 percent. This is true both in the United States and in European countries. Previously-sponsored NSF innovation indicator studies have achieved response rates that range from below 30 percent to almost 60 percent. Surveying at the establishment level (as in the Yale/CMU studies) resulted in similar response rates. The initial Yale study obtained a response rate of just over 40 percent. All of these rates are significantly lower than NSF and other government agencies are accustomed to obtaining on other surveys.

Response rates do matter. If the characteristics of non-responders are fundamentally different than those of responders, substantial doubt is cast on the quality of the information obtained by the survey. In recognition of this, many innovation surveys have carried out studies that attempted to compare the characteristics of those who responded to the survey and those who did not. In many instances, this consisted of collecting publicly available data about responders and non-responders to determine whether there were any systematic differences between them. For example, Hansen, et al. performed an analysis of the size and industry classification of respondents and non-respondents for a NSF-sponsored survey of 600 companies in 1982. They found that there was a higher response rate from larger firms than smaller firms, especially in mature industries, such as food, primary metals, paper and stone, glass, clay and concrete. [61]

CIS-2 requires that any country that attains a response rate to the initial survey of less than 70 percent must conduct a follow-up non-respondent analysis. This analysis goes beyond simply collecting data from public sources and instead attempts to gather information from a sample of the non-respondents themselves. The goal of this second round of surveying, a 100 percent response rate from this sample of non-respondents, may be ambitious given that the sampling frame is a group of firms that have previously declined to participate in the survey. Preliminary indications are that the level of innovation among non-responders is actually higher than it is among those who responded to the survey. These results would seem to be consistent with those of the Hansen study.

There are a number of things that can be done to maximize the response rate. Questionnaire length and organization are key considerations, since excessively long questionnaires that are difficult to follow are more likely to be discarded. Some argue that the more difficult questions should be reserved until the end of the questionnaire since once respondents have invested time in filling out the easier questions, they are more likely to continue until the end. Difficult questions up front result in the survey being discarded before the respondent has invested any time in it.

Follow-up is also crucial. Initial surveying is unlikely to produce a response rate higher than 25 percent. Follow-up by telephone can easily double this. The 1994 NSF-sponsored study of 1000 firms clearly demonstrates how effective this type of follow-up can be when pursued aggressively. The survey team selected 130 firms who had not responded to the survey for intensive follow-up. Ultimately it was able to obtain responses from 80 percent of these firms.[62]

[61] Hansen, Stein, and Moore, 1984, *op. cit.*, pp. 57-59.
[62] Rausch, *op. cit.*

One factor that is often neglected is the tendency for response rates to rise over time in the case of surveys that are repeated on a regular basis. Lothar Scholz found that this was the case even when the survey was intended to collect data on innovation expenditures by category; a subject that is among the most difficult for firms. There are a number of reasons for this. First, response rates will be higher if it is possible to determine before the survey is mailed the name of the most appropriate individual within the firm to receive it. While this can be done on a one time survey, it is difficult and expensive. However when a survey is repeated, a database of previous respondents exists which can be drawn upon to target appropriate individuals.

In addition, respondents have an easier time completing a survey if they have previously answered similar questions. Less time is required for reading definitions and developing an understanding of the survey's basic concepts. In addition, if the agency collecting the data has been careful to publish summary data from the previous round of surveys in a form that is useful to the respondents (notably, disaggregated by industrial sector) and has made certain that respondents have ready access to those summaries, it can have a substantial positive impact on response rates as well. This is one factor that Scholz cites as being essential to his relatively high response rates in Germany.

Finally, repeated surveys containing identical data requests may affect firm's views about what data is important for them to collect in assessing their own level of innovation. Previous work in the United States found that many firms were searching for a metric of innovation within their own organizations and some adopted questions from the U.S. survey on an ongoing basis for internal use.[63] If a survey is repeated over time, and the results are regularly published, firms may come to collect this data for their own purposes.

These factors lead to a general conclusion that in beginning innovation indicator data collection efforts it is important to not be too discouraged about response rates that are somewhat below those obtained in other studies that are conducted on a regular basis.

[63] Hansen, Stein, and Moore, 1984, *op. cit.*, p. 153.

## Workshop Participants

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