Estimating the benefits from collaboration: The case of SEMATECH

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Abstract:

SEMATECH (SEmiconductor MAnufacturing TECHnology) was established in 1987 as a not-for-profit research consortium with an original mission to provide a pilot manufacturing facility where member companies could improve their semiconductor manufacturing process technology. Since its inception, SEMATECH's mission has become more general. This paper presents the findings from a quantitative case-based analysis of the returns to member companies from their investments in SEMATECH. The findings suggest that SEMATECH has provided an organizational structure in which important processes and technologies have been advanced which could not have been justified on economic grounds outside of a collaborative research arrangement.

Keywords: SEMATECH | collaborative research | internal rate of return

Article:

I. Introduction

SEMATECH (SEmiconductor MAnufacturing TECHnology) was established in 1987 as a not-for-profit research consortium with an original mission to provide a pilot manufacturing facility where member companies could improve their semiconductor manufacturing process technology.[1] Since its inception, SEMATECH's stated mission has evolved and become more general. The consortium currently defines its mission around solving the technical challenges

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[1] See Public Law 100-180, section 272, December 4, 1987.

presented by sustaining a leadership position for the United States in the global semiconductor industry.[2]

SEMATECH had fourteen founding semiconductor company members; but at present it has eleven: AT&T, AMD, Digital Equipment Corporation, HewlettPackard, IBM, Intel, Motorola, NCR, National Semiconductor, Rockwell, and Texas Instruments.[3] These eleven member companies fund approximately one-half of SEMATECH's annual $200 million operating budget.[4] The Defense Advanced Research Projects Agency (DARPA, now ARPA) matches annual company contributions, but SEMATECH has requested FY 1997 as the last year to receive government funds.[5] SEMATECH's operating revenues not only support research at its headquarters in Austin, Texas; but also they support related research at member companies, supplier sites, and universities.[6]

SEMATECH's budget for projects has grown from $3 million in 1988 to $141 million in 1993- the last full year before this study was begun. Cumulative research spending over this time period has been nearly $500 million. The purpose of this paper is to report the returns to member companies from their investments in SEMATECH.

In Section II, the qualifications and limitations of the study are discussed. In Sections III and IV, the methodology used in the study is described in detail. In Section V, member company returns are estimated in terms of an internal rate of return and a benefit-to-cost ratio. The implications of the findings are discussed in Section VI in terms of SEMATECH, in particular, and collaborative research relationships in general.

II. Qualifications and Limitations of the Study

It is important to understand the scope of SEMATECH benefits in order to put the benefit analysis presented in this paper in context. First, there are four organizational groups linked to SEMATECH, all of which receive benefits. These groups include: (i) member companies, (ii) ARPA as a funding source, (iii). U.S.-headquartered semiconductor equipment and materials vendors, and (iv) other outside groups engaged in silicon-related research (e.g., universities and national laboratories). Interface organizations, such as the Technical Advisory Board (TAB) (between SEMATECH and the member companies), SEMI/SEMATECH (between SEMATECH and the U.S. semiconductor equipment and materials industry), and the SRC (between SEMATECH and universities and national laboratories) help to define SEMATECH's activities and to distribute results from SEMATECH's activities. Because of the magnitude and diversity

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[2] It is important to distinguish between SEMATECH and the U.S. semiconductor industry because not all members of the industry are members of SEMATECH.

[3] Harris, LSI Logic, and Micron Technologies has left the organization after their initial five-year commitment.

[4] Company contributions are determined by a revenue-based formula.

[5] Originally, it was the intent of SEMATECH to become self-supporting. The political realities are that continued government funding is doubtful even if SEMATECH desired such support. The government is viewed by SEMATECH as imposing undesirable regulations on the direction of SEMATECH's research.

[6] University research is supported through SEMATECH's ongoing funding of the Semiconductor Research Corporation (SRC) in Research Triangle Park, North Carolina. University research is also supported through numerous projects that draw upon specific university research outside of SRC's operation.

of these organizational linkages, this study focuses on only one group of stakeholders, namely member companies.

Member companies are, after all, the constituency group that is most directly targeted by SEMATECH. Moreover, because the member companies financially support SEMATECH, it is important to quantify their returns for obvious internal managerial reasons.

The scope of this study is also limited as to the types of benefits measured. Generally speaking, SEMATECH benefits to each stakeholder group can be dichotomized into tangible and intangible benefits. Tangible (meaning quantifiable) and intangible benefits can flow either directly (e.g., from SEMATECH to the member company via the TAB) or indirectly (e.g., from SEMATECH to the member company from spillovers from another stakeholder group) to the benefit recipient. Only tangible direct benefits accruing to member companies, transferred through the TAB channel, were considered in this study.

Potential tangible benefits can be grouped into three general categories: (i) research management, (ii) research integration, and (iii) research results. The benefits from research management are important in that SEMATECH provides value to members by lowering the transaction costs associated with acquiring research results, improving the match of research capabilities to requirements, prioritizing the research agenda, and accelerating the delivery of research. The benefits from research integration are important because SEMATECH defines for its members a long-term research strategy that can lower the risk of advanced research and rationalize additional research funding by member companies. Furthermore, the benefits from research results are important because they embody the technical knowledge accumulated from specific research projects undertaken by SEMATECH. The benefits associated with research results were selected for this study.

During interviews with SEMATECH officials, it was clear that the benefits to member companies from research management and research integration, as well as the indirect benefits from spillovers, were more important than the tangible direct benefits flowing directly from research results. Interviews with TAB members and other individuals inside member companies reinforced this view. In other words, the benefit area focused on in this study is the smallest of all of the benefits areas defined above. Still, it was recognized that this effort to quantify the direct returns from research results to member companies, albeit limited, is nonetheless important to member companies and was manageable from a research perspective. As a result, the estimates presented here clearly understate the total returns to members, and certainly to the semiconductor industry as a whole, from SEMATECH.

III. General Methodology

1. PROJECT-BASED APPROACH

SEMATECH's research agenda is implemented on the basis of specific projects, formulated within the SEMATECH Roadmap.[7] Each year, SEMATECH's Board decides which projects, from a large number of proposed projects, will be initiated in that year. By the end of 1993, SEMATECH had completed 84 projects and 94 were underway. In 1994, 72 new projects were started.

The approach taken to evaluate the direct returns to member companies was based on a sample of SEMATECH projects. By studying a representative sample of projects in detail, it was believed that inferences about the overall direct returns could be made. The sample selected contained eleven projects, as described later in the paper.

To capture the project-specific returns to member companies, those individuals within each company who were knowledgeable about each project that was selected for the study were interviewed. With the assistance of the relevant SEMATECH project leaders, project-specific survey instruments were designed.

The survey instruments were distributed to the member companies through SEMATECH's Director of Technology Transfer, who wrote to the appropriate individual within each company for each project studied and (i) introduced the study, (ii) explained the importance of the study from SEMATECH's perspective, and (iii) asked that each project survey be distributed to the most knowledgeable individual within the organization.[8]

2. COLLECTION OF INFORMATION

In order to gain the full cooperation of the member companies, each was assured that its individual responses would remain strictly confidential.[9] Survey responses were collected either directly from the identified project-specific individual(s) within each company or from each member company's representative on the SEMATECH Technology Transfer Council. Each member company was assured that project-specific survey responses would neither be distributed to SEMATECH nor published. The survey responses were aggregated across projects within each company, and then across companies, as discussed below. Only aggregate values are discussed herein.[10]

3. ANALYSIS OF THE DATA

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[7] The Roadmap is a resource for planning. It provides a consensus view of how semiconductor technology will develop over the next ten to fifteen years and of the technology challenges that must be met for this schedule to be realized. See also Teece (1994).

[8] To facilitate this last step, SEMATECH project leaders prepared a list of individuals within each company who had previously been involved with each of the projects studied.

[9] Confidentiality agreements were signed with the three companies that so requested.

[10] It should be noted that one of the leading-edge producers refused to attempt to quantify any benefits to their company from any project, although its SEMATECH assignees represent that the company did receive significant benefits from many, if not all, of the projects. This company was the only company that refused to participate at this level of reporting. Accordingly, the benefits realized by this company were estimated to equal the average benefits realized by the other companies reporting benefit values.

On the cost side, there are three separate issues to consider. The first issue related to the scope of the cost data that were obtained from SEMATECH's budget data. Second, because SEMATECH is partially funded from federal funds, there is an issue related to allocating the government's share to individual projects. The third issue relates to costs not included in SEMATECH budgets, but that should be considered in the analysis because they support research.

SEMATECH's accounting system is the only source available to obtain information on project-specific costs for each of the eleven sample projects. To be consistent, project costs were defined to include: (i) payments to third-party suppliers that participated in development and improvements projects; (ii) costs for equipment purchased by SEMATECH for specific projects; and, (iii) payments for miscellaneous other project-related services.[11] In order to allocate other project-specific costs (such as SEMATECH labor; the use of SEMATECH's facilities, equipment and consumables; and non-project-specific indirect costs) to the projects in the sample, SEMATECH's total budget information was used to calculate, from historical experiences, a factor with which to burden direct project costs.

With respect to the government's share of the project costs, no distinction was made between the federal and member company funds spent on each project. Thus, since one-half of the research budget is funded by the government, reported costs are viewed as 50 percent government funded. Non-project-specific costs are also assumed to be 50 percent government funded, with minor exceptions.[12]

The final issue to be addressed is that of costs not captured in SEMATECH's accounting system. First, as may be the case with most if not all research consortia, traditional cost accounting procedures do not capture all relevant costs associated with a particular research project. Separate from costs incurred at SEMATECH, member companies incur costs above their annual SEMATECH dues. For example, each Technology Transfer Council representative devotes member company time and resources to SEMATECH-related activities.

Second, the costs captured by the SEMATECH's accounting system are conceptually "push" costs-the costs related to "pushing" SEMATECH research results to member companies. However, pushing the results out to member companies is not sufficient for effective technology transfer. Member companies must also invest in "pulling" the research results into their organization. That is, they must invest in the acquisition and absorption of the technology generated by SEMATECH in order to internalize and adapt the results for their individual purposes. These research-pull costs are likely to vary across member companies. Although the absolute magnitude of the pull costs associated with the projects studied are not known, an attempt was made to account for them by asking each company to net these costs against reported benefits.

On the benefit side, the eleven projects were used to estimate the annual project-specific benefits to member companies from their investments in SEMATECH. Unlike SEMATECH's project-

[11] These cost classifications came from GAO (1992), p. 29.
[12] For example, government funds cannot be used to support the operation of SEMATECH's Washington, D.C. office. This represents only a very minor share of the total budget, however.

specific cost data, benefit data from the member companies were not tracked or recorded by the companies in any formal manner.

Project-specific surveys were developed after having discussions about each project's characteristics with SEMATECH project leaders.[13] A different survey instrument was developed for each project. Project-specific survey questions were accordingly tailored to each member company through follow-up telephone interviews with at least one individual in every participating company. The purpose of these follow-up interviews was to encourage participants' elaboration or clarification of their survey responses. This process allows diverse company-specific benefits from a particular project to be captured in a consistent manner.[14]

An inspection of the survey responses reveals that a variety of benefits were considered by the company respondents. Many companies either reported a range of benefits or noted that there were significant benefits that could not be accurately estimated.[15] When a range of benefits was reported, the mean of the range was used for aggregate quantitative purposes. When a company noted that there were benefits, but that they could not be estimated, a $0 benefit value was assigned to that company for that project. Because of this, the reported benefits to member companies from SEMATECH research is understated.

IV. Sample of Projects Selected

1. POPULATION OF SEMATECH PROJECTS

As of April 1993, when the quantitative analysis was conducted, there were 76 completed research projects (totalling $137.2 million in expenditures) and 82 open or active projects (totalling $356.1 million, including estimated 1993 expenditures) at SEMATECH. However, only a subset of this population of 158 projects was used to define the population for this analysis. Fifty-six of the 158 projects lacked completed background files.[16] The remaining 102

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[13] While the survey instruments are confidential, the general approach taken, through a series of focused questions, was to obtain expressed preference information (as opposed to revealed preference or market information) about the economic state of the company in the absence of the research project. Benefit data were derived by comparing these responses to the current economic state of the company.

[14] Through these interviews, the quality of the benefit data was improved in two ways. First, evaluative consistency was achieved by applying uniformity of interpretation across companies. For example, it was possible to discover if member companies were interpreting questions incorrectly or inconsistently; as a result, the needed information could be extracted through an iterative process of correcting inconsistencies and inaccuracies. Where companies deviated in their responses from individual to individual, the interview process facilitated an understanding of the reason for this and offered a mechanism for accounting for it. Second, the interview process also provided a forum to allow for an explanation of member company responses. On occasion, a question had to be restated to make it more applicable to the individual company. In doing this, the original basis of the question was left intact while making it more applicable to each member company. Through these follow-up interviews, the interviewee was able to narrow the bands on range responses and to quantify their qualitative responses.

[15] In fact, in some cases a company would report that a project had significantly high nonquantifiable benefits, but low quantifiable ones.

[16] In SEMATECH's project management process, Master Deliverables List (MDL) files are created once a project has been approved by SEMATECH's Investment Council and the supporting contracts have been signed with the project suppliers. Of the 56 projects with no or incomplete MDL files, 26 were new projects that had not progressed to the point where contracts were signed or the MDL records created. Of the remaining 30 projects, sixteen were small (under $100,000), internal SEMATECH projects for while no MDL files were not created. The remaining

projects (totalling $381.8 million) are therefore referred to herein as the population of projects available to study.

There are five distinguishing characteristics of the population of projects that are relevant for defining a representative sample. First, there is an overarching characteristic to much of what SEMATECH funds. Their research is oriented toward supporting the technological infrastructure of the industry as opposed to supporting company-specific technological needs.[17]

Second, the population contained three types of projects: Joint Development Projects (JDPs), Equipment Improvement Projects (EIPs), and SEMATECH Improvement Projects (SIPs). A JDP is a program in which a SEMATECH team partners with an external supplier (usually a SEMI/SEMATECH supplier), university, or national laboratory to develop a new tool, material, or process that supports phase requirements of future generations of technology.[18] An EIP, as the name suggests, is a program in which either existing manufacturing equipment or systems are improved from a competitive manufacturing perspective. An SIP is a program that generally resides at SEMATECH, requires a least six months to complete, and has a budget that exceeds $100,000. As shown in Table I, the majority of SEMATECH projects in the population fall into the JDP category.

Table I. Distribution of population projects, by type (n = 102)

Project type	% of total
Equipment improvement projects	23.5%
Joint development projects	52.0%
SEMATECH improvement projects	24.5%

Third, JDPs dominate SEMATECH's research agenda not only in terms of number of projects, but also in terms of budget. JDPs are the larger scale projects. As shown in Table II, the mean budget of a JDP is $5.0 million, contrasted with $3.5 million for an EIP and $1.3 million for an SIP.[19] Just over 69 percent of the total cost of all 102 projects is budgeted to JDPs. EIPs, as suggested from Table II, are the next most costly — 21.9 percent. SIPs account for only 8.8 percent of SEMATECH's total budget. Further, seven of the eight most costly projects previously conducted or currently being conducted by SEMATECH are JDPs. The most costly JDP in the population is $45.5 million, the most costly EIP is $26.5 million, and the most costly SIP is $8.3 million.

Table II. Mean budget for population projects, by type (n = 102)

Project type	Mean budget
Equipment improvement projects	$3.5 million
Joint development projects	$5.0 million
SEMATECH improvement projects	$1.3 million

fourteen were projects: (i) aborted, (ii) started in the early years before SEMATECH began creating MDL files, or (iii) merged with other projects that had begun before MDL files were created.

[17] By this we mean that SEMATECH supports generic research.

[18] A SEMATECH team is comprised of assignees from member companies and direct SEMATECH hires.

[19] These means were calculated using nominal values of the total annual budget of each project, summed through 1993.

Fourth, the majority of projects in the population are budgeted within the $1.0 million to $10.0 million range. Just over one-third of all SEMATECH projects cost less than $1.0 million. Nearly 60 percent are within the $1.0 million to $10.0 million range, and only eight percent are budgeted at over $10.0 million.

Fifth, just over one-half – 56 percent – of the projects in the population are active.

Based on these characteristics of the population of projects, four criteria for the selection of a representative sample of projects were imposed on the study: (i) the sample should contain EIP, JDP, and SIP projects; (ii) the budget distribution associated with the sample of projects should be weighted toward JDPs; (iii) the range of sample projects, defined by budgets, should be large and should be dominated by projects in the $1.0 million to $10.0 million range; and (iv) the sample should contain both closed and open projects.

2. SAMPLE OF SEMATECH PROJECTS

After reviewing these criteria with SEMATECH officers, a list of candidate projects was formulated. During this process, a fifth criterion became explicit: only projects for which there is a SEMATECH individual who is both familiar with the project and available to provide background information will be considered.

Eleven projects were selected.[20] The sample conforms well to the five criteria listed above. First, it contains at least one project from each project-type – six EIPs, four JDPs, and one SIP. Although this numerical distribution of sample projects, by type, does not directly parallel the distribution of population projects in Table I, the distribution of sample projects by budget does, as discussed below.

It should also be noted that there is now a decreasing emphasis on SIPs at SEMATECH. For example, of the 25 SIPs in the population, only eight are active at the time of this study. Of those eight, none was begun in 1992 and only two were begun in 1993 (at a total estimated budget of less than $1 million). For this reason, only one SIP was included in the sample.

Second, the distribution of sample project budgets, by type of project, is similar to that of the population, as discussed above: 69.3 percent to JDPs, 21.9 percent to EIPs, and 8.8 percent to SIPs. Specifically, 58.9 percent of the total sample budget is allocated to JDPs, 41.0 percent to EIPs, and less than 1.0 percent to SIPs. While JDPs account for the largest share of budgets in the sample, EIP and SIP cost shares are not as equal as in the population. This distributional difference is by design, owing partly to the decreased emphasis on SIPs within SEMATECH.

Third, the range of project budgets parallels that of the population. Three of the eleven sample projects (27 percent) have budgets of less than $1.0 million; five (46 percent) are within the $1.0 million to $10.0 million range; and three are budgeted at more than $10.0 million. In addition, the sample contains one project that ranks among the smallest four projects in the population, and two projects that would rank among the largest four in the population.

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[20] For reasons of confidentiality, neither the names of these projects nor a description of their technological focus are reported herein.

Fourth, six of the eleven projects, or 55 percent, are open compared with 56 percent for the population. All of these open projects were near completion, allowing SEMATECH member firms to provide a reasonable expected benefit stream.

And fifth, SEMATECH individuals familiar with the sample projects were available to assist with the collection of background information.

V. Estimated Returns to Member Companies

1. RETURN ON INVESTMENT (ROI) CALCULATIONS

One method for evaluating the returns to collective investments in research is to calculate an internal rate of return. The internal rate of return is defined as that rate of discount, *r,* that reduces the flow of net economic benefits over *t* years from a research project or collection of research projects to zero. Stated alternatively, *r* is that rate which equates the present value of net benefits to zero.

Time series values on net benefits were calculated for the SEMATECH projects as follows.[21] First, the costs for each project were obtained directly from the business analyst at SEMATECH. The cost values were then summed across projects to establish a total cost for each year. Second, for each year, survey-measured benefits were summed first across companies, and then across projects. Thus, for each time period, there is a total cost value and an aggregated total benefit value for the entire sample of projects. Costs were then subtracted from the aggregated benefit values, by year, resulting in annual net benefit values to use in an internal rate of return formulation. As described below, sensitivity tests were performed for several different internal rate of return calculations under alternative cost and aggregation methods.

Regarding aggregation, the internal rate of return was calculated on a weighted and an unweighted basis. The weighted calculations are based on aggregating reported company benefits across companies and then across projects. Similarly, costs were then aggregated across projects and subtracted from benefits, resulting in annual net benefits to use to calculate an internal rate of return. This is a stream of weighted net benefits because the size of each project is explicitly taken into account in terms of the value of net benefits. Alternatively, unweighted calculations are done by calculating the internal rate of return for each project separately, and then calculating the average (median) of the individual return estimate. This is an unweighted analysis because all sized projects are treated equally.

Regarding costs, they were quantified in two ways. First, because the original intent of the study was to analyze the return to member companies resulting from their investment in SEMATECH, reported project costs were divided by two because the government funded one-half of the expenditures. For comparison, separate calculations were done using total costs; member plus government costs. Finally, SEMATECH's project cost accounting, especially in the early years, did not allow for the allocation of some internal expenses, such as facility costs, labor, equipment

[21] Project costs were incurred as early as 1989. Costs for 1994 were negligible and excluded from the analysis. Benefits were realized as early as 1990 for the selected projects, and they extend to 1998 for some of the projects.

and consumables, and other non-project indirect costs. Thus, project costs, as reported by SEMATECH, are exclusive of these charges. Internal rate of return estimates based on project costs alone and project costs burdened with overhead are also calculated for comparison purposes.

The results from the internal rate of return calculations are presented in Table III.[22] The weighted returns to SEMATECH member companies when only member company, unburdened costs are considered are 59 percent. When burdened, which is a more realistic cost consideration, the returns are 25 percent.

Table III. Internal rate of return analysis

	Member company $		Member company plus federal $	
Benefit definitions	**Project cost only**	**Project cost with burden**	**Project cost only**	**Project cost with burden**
Weighted	59%	25%	24%	2%
Unweighted	209%	124%	122%	63%

Because the investment base at SEMATECH includes more than just member contributions, although the return estimates above are of most interest to the members, internal rate of return estimates that include federal funds, especially those corresponding to burdened costs, provide a more accurate picture of the returns that members are receiving from private plus social cost outlays. When burdened federal dollars are included in the cost calculations, the direct, tangible weighted returns to members are 2 percent.[23]

While the sample of projects is representative of SEMATECH's past projects, SEMATECH is restructuring a number of its programs and, as a result, the sample considered in this study may not represent the mix of future projects. However, the estimated returns for unweighted benefits in the lower portion of Table III may be more indicative of the magnitude of returns possible in the future because SEMATECH expects most of its projects to be of comparable size. Looking at burdened member plus federal costs, the return estimate is 63 percent. This is perhaps the best estimate of the private returns to private and public investments in SEMATECH.

2. BENEFIT-TO-COST CALCULATIONS

The benefit-to-cost ratios that correspond to the data described above are reported in Table 4. As before, the reported benefits from each company were aggregated across companies, and then across projects, and finally across years in real terms.[24] Costs were aggregated in the same fashion.

Based on the weighted methodology, the ratio of benefits received by member companies to their cost contributions to SEMATECH research that generated those benefits is 2.8 based only on project costs, and 1.4 based on burdened project costs. In other words, on the basis of project costs alone, SEMATECH members receive $280.00 in project-specific returns for each $100.00

[22] No multiple solutions were found for these calculations.
[23] Recall that the purpose of this paper is to present estimates of the returns to member companies as opposed to total social returns.
[24] The Consumer Price Index was used for these adjustments.

they allocate to SEMATECH. Or, on the basis of burdened project costs, they receive $140.00 for each $100.00 they allocated.

Table IV. Benefit-to-cost analysis

	Member company $	
Benefit definitions	**Project cost only**	**Project cost with burden**
Weighted	2.8	1.4
Unweighted	6.4	3.3

As noted in terms of the internal rate of return analysis, the weighted analyses produce legitimate estimates, but they are not necessarily the best indicator of SEMATECH's performance for the mix of projects that may exist in the future. The unweighted ratio for fully-burdened cost is 3.3.

Of course, when federal dollars are added to the cost basis, all of the ratios in Table 4 are reduced in half.

VI. Summary Observations

In recent years, R&D consortia have become common in the United States. SEMATECH is perhaps the most ambitious of these and certainly the one that has received the lion's share of attention and government support. It is not surprising, then, that there has been much debate about whether or not SEMATECH has been successful. This intense and continuing scrutiny of SEMATECH indicates the importance of carefully evaluating its effectiveness.

The intent of this paper is to add to the body of information available to all interested parties as they seek to gauge the usefulness not only of SEMATECH, but also of collaborative research arrangements in general. Further, most studies to date of SEMATECH have been qualitative in nature or, when quantitative, they have lacked methodological rigor.[25] The emphasis of the research conducted here was on measuring net benefits in a methodologically rigorous manner. Only an empirically-based study can provide the necessary insights into SEMATECH's effectiveness and would thus assist in informing the overall debate about the usefulness of collaborative research.

The decision to go forward with a study stressing quantitative measurement of tangible benefits dictated several outcomes with regard to the final design of the study. First, to some degree it limited the scope of potential SEMATECH benefits that were examined to only those that could be quantified. Thus, even though interviewees referenced intangible benefits that they felt were extremely important, no attempt was made to explore these systematically. Second, only benefits flowing from research results were considered – clearly the category of tangible benefits that members and SEMATECH officers believed generated the fewest member benefits.

It is important to emphasize that spillover benefits to other constituents were not considered. Examining these categories of benefits and benefit recipients was defined to be outside the scope of the study. As a result, caution should be exercised when comparing the return measure presented here to social rates of return presented by other researchers.

[25] A notable exception is Irwin and Kienow (1994).

The fact that each SEMATECH member company appeared to be able to internalize a significant return on their own contribution to SEMATECH raises an important issue about the appropriability of the research funded by SEMATECH. It is not unreasonable to speculate, based on these findings, that absent the government funding the projects studied would not have been undertaken. As we noted earlier, the eleven projects studied create technology infrastructure for the industry. Firms have a difficult time appropriating returns from this type of research if it is not funded collectively or publicly.[26]

In light of the findings presented here, it is interesting that three of the original fourteen members exited the consortium. Clearly, the fact that some firms have exited after the end of their initial five-year commitment indicated that there is a variance in the returns perceived by member companies. While it was beyond the scope of this study to determine the reasons for their exit, the study does nevertheless offer several potential insights about cooperative research arrangements in general. Because SEMATECH is a complex research organism – with activities spanning research integration, research results, and research communities – there is a fairly high threshold of commitment required by a member company to obtain a high return on its investment. In other words, companies need to establish a "pull mechanism" in order to extract full value from SEMATECH's menu of research endeavors. Companies that are not prepared or equipped to effectively extract and integrate SEMATECH research results are likely not to perceive sufficient returns on their investments.

In this regard, there are several lessons from SEMATECH. As conjecture, the more complex a research consortium agenda (i.e., the broader its menu of research activities), the higher the threshold of pull-related investments that are required in the member companies to obtain adequate perceived returns. Second, the more the research results relate to pre-commercial, generic know-how, the greater the threshold of commitment to make complementary investments for pulling relevant know-how from the consortium.

Several lessons learned from this study can perhaps be generalized to other research consortia. First, while economic theory would predict that the benefits to sponsoring companies are the "glue" that binds a collaborative research organization, more often than not, participating companies in SEMATECH had a difficult time quantifying the benefits that they received. In only a few cases did the company endeavor to quantify benefits on their own (i.e., independent of this study). Companies seem to rely mostly on "resonance" benefits to justify their continued participation.[27] This suggests, perhaps, that the intangible benefits may weigh more importantly in the sponsoring companies' decision to continue to participate.

Second, collaborative research does not seem to inhibit competition. While performing this research, it became apparent that SEMATECH collectively would investigate some technology A, while a member company on its own would investigate competing technology B in the event that the results of SEMATECH's research were not directly applicable. This is not surprising because, while SEMATECH's research is at the generic end of the research spectrum, the

[26] See Leyden and Link (1992) and Tassey (1992) for support of this proposition.
[27] "Resonance" benefits can be thought of as those that result from an industry-wide focusing effect that would not have occurred in the absence of SEMATECH.

member companies are still competing with each other in terms of new and improved market projects. Further, such behavior indicates that even though SEMATECH assists in developing a strategic approach to the technology development – pursing the development of a common technology roadmap – companies are still vigorously exploring various alternatives in order to enhance their competitive position.[28] Indeed, the U.S. semiconductor industry has advanced its overall competitive position vis-a-vis Japanese based rivals, and some consider SEMATECH to have been a factor.

Third, in evaluating the benefit-to-cost ratios, defining appropriate costs is easier than defining appropriate benefits. That said, traditional cost accounting procedures may not capture all relevant costs associated with a particular research project. Collaborative research organizations should seek to put in place a cost allocation system that provides accurate historical cost tracking. As to measuring member company costs, there are several steps that member organizations can take to develop a more complete awareness on their costs of participating, such as establishing a specific cost center for all direct costs of participation. As to measuring benefits, consortia can seek to obtain a consensus on their benefit categories and seek to devise simple tracking approaches to monitor benefits generated. Even if the approach is too fraught with practical problems, at the very least member companies should achieve an agreed upon taxonomy of perceived benefits that they can qualitatively refer to over time in assessing the benefits of continued participation.

In conclusion, SEMATECH has provided an organizational structure in which important processes and technologies have been advanced, which could not have been justified on economic grounds, based on the estimates presented herein, outside of a collaborative research arrangement. Government funding has been helpful. The results presented here suggest the members can justify their membership, given government funding, based on tangible research benefits alone. Certainly there are many other categories of perceived benefits not captured in the focused analysis of this study, and if analyzed would present a more optimistic picture for SEMATECH. Once government support terminates in 1997, SEMATECH management will be challenged to adapt to the loss of government support by selecting a mix of projects that continues to benefit the industry as a whole and at the same time provides companies a sufficient return to justify their continued membership.

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[28] See Teece (1994).

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