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Sematech: Purpose and Performance

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ABSTRACT In previous research, we have found a steep learning curve in the production of semiconductors. We estimated that most production knowledge remains internal to the firm, but that a significant fraction "spills over" to other firms. The existence of such spillovers may justify government actions to stimulate research on semiconductor manufacturing technology. The fact that not all production knowledge spills over, meanwhile, creates opportunities for firms to form joint ventures and slide down their learning curves more efficiently. With these considerations in mind, in 1987 14 leading U.S. semiconductor producers, with the assistance of the U.S. government in the form of $100 million in annual subsidies, formed a research and development (R&D) consortium called Sematech. In previous research, we estimated that Sematech has induced its member firms to lower their R&D spending. This may reflect more sharing and less duplication of research, i.e., more research being done with each R&D dollar. If this is the case, then Sematech members may wish to replace any funding withdrawn by the U.S. government. This in turn would imply that the U.S. government's contributions to Sematech do not induce more semiconductor research than would otherwise occur.

In 1987, 14 U.S. semiconductor firms and the U.S. government formed the research and development (R&D) consortium Sematech (for Semiconductor Ma/nufacturing Technology). The purpose of the consortium, which continues to operate today, is to improve U.S. semiconductor manufacturing technology. The consortium aims to achieve this goal by some combination of (*i*) boosting the amount of semiconductor research done and (*ii*) enabling member firms to pool their R&D resources, share results, and reduce duplication.

Until very recently, the U.S. government has financed almost half of Sematech's roughly $200 million annual budget. The economic rationale for such funding is that the social return to semiconductor research may exceed the private return, and by enough to offset the social cost of raising the necessary government revenue. That is, the benefits to society—semiconductor firms and their employees, users of semiconductors, and upstream suppliers of equipment and materials—may exceed the benefits to the firms financing the research. In previous work, we have found evidence suggesting that some semiconductor production knowledge "spills over" to other firms (1). Depending on their precise nature, these spillovers may justify government funding to stimulate research.

It is not clear, however, that the government's contributions to Sematech result in more research on semiconductor manufacturing technology. We estimated that Sematech induces member firms to lower their total R&D spending (inclusive of their contributions to the consortium; ref. 2). Moreover, we estimated that the drop exceeded the level of the government's contributions to Sematech. Such a drop in total semiconductor R&D spending might reflect greater sharing and less duplication of research. This increase in the efficiency of R&D spending makes it conceivable that more research is being done despite fewer R&D dollars. But it could instead be that the same amount of research is being conducted with less spending. If so, then Sematech members should wish to fully fund the consortium in the absence of government financing. As a result, the government's Sematech contributions might be less effective in stimulating research than, for example, R&D tax credits.

The Purpose of Sematech

The semiconductor industry is one of the largest high-technology industries in the United States and provides inputs to other high-technology industries such as electronic computing equipment and telecommunications equipment. It also ranks among the most R&D-intensive of all industries. In 1989 for example, U.S. merchant semiconductor firms devoted 12.3% of their sales to R&D (3), compared with 3.1% for U.S. industry overall (4). ["Merchant" firms are those that produce chips solely for external sale (e.g., Intel) as opposed to internal use (e.g., IBM).]

In our previous work (1), we tested a number of hypotheses regarding production knowledge in the semiconductor industry. We employed quarterly data from 1974 to 1992 on shipments by each merchant firm for seven generations (from 4-kilobyte up to 16-megabyte) of dynamic random access memory chips. We found a steep learning curve; per unit production costs fell by 20% with each doubling of experience. We also found that most production knowledge, on the order of two-thirds, remains proprietary, or internal to the firm. Many of the steps in memory chip production are identical to those in the production of other computer chips such as microprocessors. As a result, joint research and production ventures abound in the industry and often involve producers of different types of computer chips. These ventures are designed to allow partners to slide down the steep learning curve together rather than individually.

The one-third component of production knowledge that spills over across firms, meanwhile, appeared to flow just as much between firms based in the same country as between firms based in different countries. Depending on their source, these spillovers could push the social return to research on semiconductor production technology above the private return to such research. If so, then the policy prescription is a research subsidy to bring the private return up to the social return. Given that the spillovers were no stronger domestically than internationally, however, an international agreement to subsidize world research on semiconductors would be the optimal policy. Our results provide no justification for favoring the industry of one country over another.

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Abbreviation: R&D, research and development.

The spillovers we found may, however, reflect market or nonmarket exchanges between firms. We have in mind joint ventures, movement of technical personnel between firms, quid pro quo communication among technical personnel, and academic conferences. In these cases, the policy prescription is far from obvious. For example, suppose the spillovers occur solely through joint ventures. On the one hand, venture partners do not take into account any negative impact of their collaboration on other firms' profits. On the other hand, if knowledge acquired within ventures spills over to nonmembers, then the government should encourage such ventures (5).

The U.S. government has taken several steps to encourage research on semiconductor technology (6). The Semiconductor Chip Protection Act of 1984 enhanced protection of intellectual property, and the National Cooperative Research Act of 1984 loosened antitrust restrictions on R&D joint ventures. Partly as a result of this legislation, Sematech was incorporated in August of 1987 with 14 founding members (AT&T Microelectronics, Advanced Micro Devices, International Business Machines, Digital Equipment, Harris Semiconductor, Hewlett-Packard, Intel, LSI Logic, Micron Technology, Motorola, NCR, National Semiconductor, Rockwell International, and Texas Instruments). With an annual budget of about $200 million, Sematech was designed to help improve U.S. semiconductor production technology. Until very recently, the Advanced Research Projects Agency contributed up to $100 million in government funds to Sematech.

How does Sematech function? Under its by-laws, Sematech is prohibited from engaging in the sale of semiconductor products (7, 8). Sematech also does not design semiconductors, nor does it restrict member firms' R&D spending outside the consortium. Sematech members contribute financial resources and personnel to the consortium. They are required to contribute 1% of their semiconductor sales revenue, with a minimum contribution of $1 million and a maximum of $15 million. Of the 400 technical staff of Sematech, about 220 are assignees from member firms who stay at Sematech's facility in Austin, Texas, from 6 to 30 months. Because the objective has been to bolster the domestic semiconductor industry, membership has been limited to U.S.-owned semiconductor firms. U.S. affiliates of foreign firms are not allowed to enter (a bid by the U.S. subsidiary of Hitachi was turned down in 1988). However, no restrictions are placed on joint ventures between Sematech members and foreign partners.

The Sematech consortium focuses on generic process R&D (as opposed to product R&D). According to Spencer and Grindley (7), "this agenda potentially benefits all members without threatening their core proprietary capabilities." At its inception, Sematech purchased and experimented with semiconductor manufacturing equipment and transferred the technological knowledge to its member companies. Spencer and Grindley (7) state that "central funding and testing can lower the costs of equipment development and introduction by reducing the duplication of firms' efforts to develop and qualify new tools."

Since 1990, Sematech's direction has shifted toward "subcontracted R&D" in the form of grants to semiconductor equipment manufacturers to develop better equipment. This new approach aims to support the domestic supplier base and strengthen the links between equipment and semiconductor manufacturers. By improving the technology of semiconductor equipment manufacturers, Sematech has arguably increased the spillovers it generates for nonmembers. Indeed, Spencer and Grindley (7) argue that "[s]pillovers from Sematech efforts constitute a justification for government support. The equipment developed from Sematech programs is shared with all U.S. corporations, whether they are members or not." These spillovers may be international in scope; Sematech members may enter joint ventures with foreign partners, and equipment manufacturers may sell to foreign firms.

According to a General Accounting Office (9) survey of executives from Sematech members, most firms have been generally satisfied with their participation in the consortium. The General Accounting Office Survey indicated that the Sematech research most useful to members includes methods of improving and evaluating equipment performance, fabrication factory design and construction activities, and defect control. Several executives maintained that Sematech technology had been disseminated most easily through "people-to-people interaction," and that the assignee program of sending personnel to Austin has been useful. These executives also noted that, as a result of Sematech, they had purchased more semiconductor equipment from U.S. manufacturers. Burrows (10) reports that Intel believes it has saved $200-300 million from improved yields and greater production efficiencies in return for annual Sematech investments of about $17 million. The General Accounting Office (11) has stated that "Sematech has demonstrated that a government-industry R&D consortium on manufacturing technology can help improve a U.S. industry's technological position while protecting the government's interest that the consortium be managed well and public funds spent appropriately."

Sematech has also drawn extensive criticism from some nonmember semiconductor firms. According to Jerry Rogers, president of Cyrix Semiconductor, "Sematech has spent five years and $1 billion, but there are still no measurable benefits to the industry." T. J. Rodgers, the president and chief executive officer of Cypress Semiconductor, has argued that the group just allows large corporations to sop up government subsidies for themselves while excluding smaller, more entrepreneurial firms (10). A controversial aspect of Sematech was its initial policy, since relaxed, of preventing nonmembers from gaining quick access to the equipment it helped develop. These restrictions raised questions about whether research undertaken with public funds was benefiting one segment of the domestic semiconductor industry at the expense of another.

Another heavily criticized feature of Sematech has been its membership fee schedule, which discriminates against small firms. Sematech members, as noted earlier, are required to contribute 1% of their semiconductor sales revenue to the consortium, with a minimum contribution of $1 million and a maximum of $15 million. This fee schedule places proportionately heavier financial burdens on firms with sales of less than $100 million and lighter burdens on firms with sales of more than $1.5 billion. Many smaller firms such as Cypress Semiconductor say they cannot afford to pay the steep membership dues or to send their best engineers to Sematech's Austin facility for a year or more. Even if these companies joined, moreover, they might have a limited impact on Sematech's research agenda.

Sematech's membership has also declined. Three firms have left the consortium, dropping its membership to 11, and another has reserved its option of leave. (Any firm can leave Sematech after giving 2 years notice.) In January 1992, LSI Logic and Micron Technology announced their withdrawal from Sematech, followed by Harris Corporation in January 1993. Press reports in February 1994 indicated that AT&T Microelectronics notified Sematech of its option to leave the consortium in 2 years, although a spokesman denied the company had definite plans to leave. All of the former members questioned the new direction of Sematech's research effort, complaining that Sematech strayed from its original objective of developing processes for making more advanced chips toward just giving cash grants to equipment companies. Departing firms have also stated that their own internal R&D spending has been more productive than investments in Sematech.

The Performance of Sematech

Sematech's purpose is to improve U.S. semiconductor firms' manufacturing technology. As discussed, the rationale for the

U.S. government's subsidy to the consortium rests on two premises: first, that the social return to semiconductor research exceeds the private return (meaning the private sector does too little on its own); and second, that government contributions to Sematech result in more semiconductor research being done.

We call the hypothesis that Sematech induces more high-spillover research the "commitment" hypothesis. Under this hypothesis, we would expect Sematech to induce greater spending on R&D by member firms (inclusive of their Sematech contributions). Firms need not join Sematech, however, and those that do can leave after giving 2 years notice. Firms should be tempted to let others fund high-spillover R&D. Under this hypothesis, then, the 50% government subsidy is crucial for Sematech's existence. The commitment hypothesis both justifies a government subsidy and requires one to explain Sematech's membership. Relatedly, a government subsidy could be justified on the grounds that not all U.S. semiconductor firms have joined Sematech, and that some of the knowledge acquired within the consortium spills over to nonmembers. Based on the commitment hypothesis, Romer (12) cites Sematech as a model mechanism for promoting high-spillover research.

Not mutually exclusive with the commitment hypothesis is the hypothesis that Sematech promotes sharing of R&D within the consortium and reduces duplicative R&D. We call this the "sharing" hypothesis. Under this hypothesis, Sematech's floor on member contributions is crucial because without it, firms would contribute next to nothing and free ride off the contributions of others. The sharing hypothesis implies greater efficiency of consortium R&D spending than of independent R&D spending. From a private firm standpoint, Sematech contributions were all the more efficient when matched by the U.S. government. Under this sharing hypothesis, we would expect Sematech firms to lower their R&D spending (inclusive of their contributions to Sematech). This is because members should get more research done with each dollar they contribute than they did independently. Since their contributions to Sematech are capped at 1% of their sales (far below their independent R&D spending), the consortium should not affect the efficiency of their marginal research dollar. As a result, it should not affect the total amount of research they carry out.

Unlike the commitment hypothesis, the sharing hypothesis does not provide a rationale for government funding. Firms should have the appropriate private incentive to form joint ventures that raise the efficiency of their R&D spending. Perhaps fears of antitrust prosecution, even in the wake of the National Cooperative Research Act of 1984, deter some semiconductor firms from forming such ventures. The stamp of government approval may provide crucial assurance for Sematech participants such as IBM and AT&T. Still, a waiver from antitrust prosecution for the research consortium should serve this function rather than government financing.

What does the evidence say about these hypotheses? Previously (2), we estimated whether Sematech caused R&D spending by members to rise or fall. To illustrate our methodology, consider for a moment broad measures of the performance of the U.S. semiconductor industry. Sematech was formed in the fall of 1987. After falling through 1988, the share of U.S. semiconductor producers in the world market has steadily risen, and the profitability of U.S. semiconductor firms has soared. Some view this rebound as confirmation of Sematech's positive role in the industry. But this before-and-after comparison does not constitute a controlled experiment. What would have happened in the absence of Sematech? We do not know the answer to this, but we can compare the performance of Sematech member firms to that of the rest of the U.S. semiconductor industry. Any factors affecting the two groups equally, such as perhaps exchange rate movements and the U.S.–Japan Semiconductor Trade Agreement, will be a function of the year rather than Sematech membership per se. And factors specific to each firm rather than to Sematech membership can be purged by examining Sematech member firms before Sematech's formation. This is the approach we used to try to isolate the impact of the Sematech consortium on member R&D spending (2).

We found that R&D intensity (the ratio of R&D spending to sales) rose after 1987 for both members and nonmembers of Sematech, but that the increase was larger for nonmembers than for members (2). When we controlled for firm effects, year effects, and age of firm effects, we found a 1.4 percentage point, a statistically significant effect of Sematech on member firms' R&D intensity. This result was not sensitive to the exact sample of firms or time period covered, or to the use of R&D relative to sales versus assets.

Is our estimated impact of Sematech on member firm R&D spending economically significant? In 1991, our sample of semiconductor firms had sales of $31.1 billion with $3.2 billion in R&D expenditures (a ratio of 10.3%). In that year, Sematech members accounted for two-thirds of sales ($20.7 billion) and R&D ($2.2 billion) in our sample, for a ratio of 10.6%. If Sematech reduced this ratio by 1.4 percentage points, then in the absence of the consortium, firms would have spent 12.0% of sales on R&D, or $2.5 billion, or $300 million more. In the absence of Sematech, according to this exercise, the overall R&D/sales ratio of the industry would have been 11.2% rather than 10.3% in 1991. Under this interpretation, Sematech reduced the industry's R&D spending by 9%. (This whole exercise presumes that Sematech had no overall impact on semiconductor sales or on other firms.)

To summarize, we estimated a negative, economically significant impact of Sematech membership on R&D spending (2). This accords well with the sharing hypothesis, under which the consortium increases the efficiency of inframarginal member R&D spending. Under this hypothesis, Sematech members should replace any Sematech funding that the government withdraws. The evidence is less easy to reconcile with the commitment hypothesis, wherein Sematech commits members to boost their research on high-spillover R&D. One cannot reject the commitment hypothesis, however, because the two hypotheses are not mutually exclusive. The validity of the sharing hypothesis could be masking the fact that more high-spillover R&D is being carried out as a result of the consortium.

Conclusions

In a previous study (1), we found that most semiconductor production knowledge remains within the firm. Since semiconductor firms slide down related learning curves whether they produce memory chips or microprocessors, efficiency gains can be leaped from joint ventures. With this in mind, Sematech was formed in 1987. In our study (1), we also found that some semiconductor production knowledge spills over across semiconductor firms. These spillovers could justify government actions to stimulate semiconductor research. With this in mind, the U.S. government has funded almost half of Sematech's budget. In another study (2), we estimated that Sematech induces member firms to lower their R&D spending. This suggests that Sematech allows more sharing and less duplication of research. Under this interpretation, it is not surprising that Sematech members have stated that they wish to fully fund the consortium in the absence of government financing. Moreover, this evidence is harder (but not impossible) to reconcile with the hypothesis that, through government funding, Sematech induces firms to do more semiconductor research.

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