OFFSETS: A STRATEGIC TOOL

Statement of

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[*] Please note: The views expressed here are the views of Dr. Wessner and do not necessarily represent the views of the National Research Council.

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Good morning, Chairman Hunter and members of the Committee. My name is Charles Wessner, and I serve the National Research Council's Board on Science, Technology, and Economic Policy. The National Research Council is the operating arm of The National Academies, which consist of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine. As you know, Congress chartered the National Academy of Sciences in 1863 to advise the government on matters of science and technology. My comments are based on work I directed for the Board on Science, Technology, and Economic Policy (STEP) at the National Research Council. I must emphasize, however, that the views I will express are my own.

My comments today do draw on two National Research Council reports. The first, *Trends and Challenges in Aerospace Offsets*[1] was requested by the White House National Economic Council. This comprehensive study examined the impact of offsets on aerospace employment, the health of the sector and that of their suppliers, and their role in the global competition for aircraft sales. This study was exceptional in that every effort was made to provide a balanced view by including industry representatives, offsets practitioners, labor representatives, and expert economists.

Because the challenge is essentially the same in origin and nature, I also wish to draw to your attention the National Research Council's recent report *Securing the Future: Regional*

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[1] National Research Council, *Trends and Challenges in Aerospace Offsets*, C. Wessner, ed. Washington DC: National Academy Press, 1999

and National Programs to Support the Semiconductor Industry, carried out under the leader of Intel's Chairman Emeritus, Gordon Moore. This report describes the technical hurdles and policy challenges facing the U.S. industry today. It describes the success of past cooperation between the government and industry, cooperation that fended off a major trade and technology challenge in the late 1980s and early 1990s to the U.S. semiconductor industry, and outlines the massive programs under way in Asian and European nations to support their national semiconductor industries. U.S. leadership in this critical technology cannot be taken for granted.[2] As with aerospace, constructive cooperation with U.S. industry is essential to retain the benefits of this industry for the U.S. economy.

But first let me briefly address the offsets issue.

What are offsets?

But first, what are offsets? One of Berkeley's outstanding economists, David Mowery, defines an offset as "a provision in an international export transaction that commits the seller firm to provide technology, to procure locally produced components, or to provide other forms of technical and other assistance to firms in the purchaser nation that go beyond those deemed economically necessary to support the sale."[3]

Offsets come in two forms. Through "direct" offsets, the purchaser receives work or technology directly related to the weapons sale, typically by producing the weapon system or its components under license. "Indirect" offsets involve barter and counter-trade deals, investment in the buying country, or the transfer of technology unrelated to the weapons being sold. Both types of offsets interfere in what might be called the "normal" operation of

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[2] National Research Council, *Securing the Future, Regional and National Programs to Support the Semiconductor Industry*, C. Wessner, ed., Washington DC: The National Academies Press, 2003.

[3] David Mowery, "Offsets in Commercial and Military Aerospace: An Overview," in National Research Council*, Trends and Challenges in Offsets*, op cit., 1999.

the market, but direct offsets send aerospace work overseas and sometimes help other nations move up the value chain in aerospace production.

Offsets are a Reality but not the Main One

It is important to keep in mind that offsets may not be desirable, but they are a fact of life. Shrinking military budgets around the world have reduced the demand for military equipment, creating a buyer's market. This increased international competition allows customers to extract very favorable deals from suppliers. In part, offsets are simply a means for foreign governments to justify large purchases of foreign equipment with taxpayer money. But offsets are also a symptom of a broader challenge mounted by foreign governments determined to support their aerospace industries – both their commercial and defense components – by whatever means possible. In a strategic sense, they are one tool from a tool kit of foreign industrial policies focused on the aerospace industry and its high-tech manufacturing.

Recognizing that private American companies are competing in an environment shaped by national governments' industrial policies is the point of departure for clear analysis and for effective American policy making. If you believe, as I do, that the aerospace industry is a major asset for the American economy, a major exporter, a generator of well-paid, high value-added jobs, then you are in good company. Policy makers in many countries share your view. They see the aerospace industry as a potential source of high-paying jobs, export markets, and national technological competency.[4] Offsets are one means of obtaining these benefits.

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[4] National Research Council, *Conflict and Cooperation in National Competition for High-Technology Industry*. National Academy Press, Washington, D.C., 1996, p. 88. See Box H.

Citing this competitive environment, offset practitioners see themselves as responsible for making the sales that keep aerospace jobs in the U.S., and keep U.S. production lines hot. They argue that we have production capabilities that we would not have without the sales generated through offsets. This view is supported, in part, by the findings of the Presidential Offsets Commission which observe that offsets can contribute to U.S. national security by facilitating the export of U.S. defense products, maintaining production lines, and increasing interoperability.[5]

Some jobs are retained and maintained through sales facilitated by offsets. Basically, the industry argues that more jobs are retained than are lost through offsets-facilitated exports. On the other hand, the workers who make planes and the parts for planes are understandably concerned about the impact of offsets on their current and future work. There are also concerns about transfer of U.S. technology, the erosion of the U.S. supplier base, particularly at the second- and third-tier levels, and the increased dependence on foreign suppliers for U.S. defense products.

Impact on Employment

With respect to employment, there are two things to keep in mind. First, offsets are not responsible in themselves for the really large employment losses in this industry. The post-Cold War downsizing, the downturn in the commercial aircraft industry, and the applications of new technologies, such as CAD/CAM, and new IT-based procedures account for much of the employment loss.[6] The second point is that offsets can and do cost jobs in some companies, and would appear to be reducing the capacity of the manufacturing

[5] National Commission on the Use of Offsets in Defense Trade, *Status Report of the Presidential Commission on Offsets in International Trade*, Washington, D.C.: Executive Office of the President, 2001, p. 83.
[6] See the paper by David Mowery, "Offsets in Commercial and Military Aerospace: An Overview" in C. Wessner, ed., *Trends and Challenges in Aerospace Offsets*. National Academy Press, Washington, D.C., 1999, p. 85-114.

base of the aerospace industry.[7] Those analysts who, during the course of the Academy discussions and analysis, predicted declines in aerospace employment have been proven correct.

In addition to structural changes, it is important to emphasize that there are dynamic changes in the supplier base. There are always winners and losers as companies drop and acquire suppliers as part of the normal churning of the economy. However, offsets are seen as an artificial and therefore politically sensitive intervention. Indeed union representatives have argued cogently that the increasing use of offsets directly undercuts the precepts of free trade and comparative advantage.

Impact on the Supplier Base

Offsets can also impact the employment and sales in the supplier base of the aerospace industry—with long-term effects. As Todd Watkins of Lehigh University describes in his paper in *Trends and Challenges in Aerospace Offsets*, the supply base is increasingly squeezed between two forces. One is competitive demands to be ever leaner as suppliers respond to their customers in the aerospace manufacturing industry.[8] The other force is foreign competition—companies that may have benefited from offset agreements and from home government subsidies—that now compete with U.S. firms. This places even greater demands on U.S. suppliers. These pressures may negatively impact the industries that supply critical components to the U.S. aerospace industry.

[7] See the paper by Todd Watkins, "Dual-Use Supplier Management and Strategic International Sourcing in Aircraft Manufacturing" in C. Wessner, ed., *op. cit.*, p. 167-196. See also the presentation by Kirk Bozdogan in C. Wessner, ed., *op. cit.*, p. 65-69.

[8] Todd Watkins, "Dual Use Supplier Management and Strategic International Sourcing in Aircraft Manufacturing, in National Research Council*, Trends and Challenges in Offsets*, op cit., 1999.

This conclusion reinforces that reached by the Presidential Commission on Offsets in International Trade.[9] The Commission found that while *quantitative* levels of offsets have remained relatively steady, there has been a *qualitative* increase in the negotiated transactions. These qualitative increases refer to the transfer of often sensitive technologies to foreign defense industries, which improve the competitiveness of foreign firms and rarely result in the transfer of technology back to the U.S.

Good and Bad Offsets

This illustrates a key point about offsets. Offsets themselves are neither good nor bad, but there are good and bad offsets. If done well, they can keep U.S. production lines hot and help retain U.S. jobs and U.S. technological leadership. If done badly, they can cost jobs, disrupt other sectors of the economy, and transfer technologies that have been developed in part with taxpayer dollars. Better data would help us to make better judgments about the impact of offsets on the U.S. economy.

Initiatives to Curb Offsets

International agreements to limit offsets and other current practices in the trade area are necessarily long-term undertakings. Negotiations are likely to be most effective when accompanied by coherent national measures to support the U.S. industry. Unilateral measures are unlikely to succeed, and may have perverse effects. Measures curbing the use of offsets by U.S. firms could harm the prospects for U.S. sales and employment. Unilateral disarmament is not a policy many would advocate in military affairs. The ability of the U.S. to "lead by example" does not seem any more compelling in national commercial

[9] The Status Report of the Presidential Commission on Offsets in International Trade can be accessed at http://www.clw.org/atop/offsets_commission.html

competition. This is particularly true of industries viewed as strategic by many governments around the world.

Whatever international effort is undertaken, we should heed the concerns of industry that has proposed that cures not be worse than the current situation, either in terms of employment or export sales or counterproductive technology restrictions. There is no simple fix to the offsets issue, not least because it is part of a broader challenge.

Policy Choices

The fundamental question for U.S. policy makers is how does the United States organize itself to focus on what everyone agrees are industrial sectors that are key to national security and major contributors to a robust economy?

With respect to offsets, the reality is that there are increasing demands on U.S. firms for offsets. We basically have three choices:

- The first is that we stay with the status quo, leaving private U.S. competitors to deal with the demands of foreign governments and subsidized competitors.
- The second is to seek bilateral arrangements at the government level and/or seek multilateral solutions. These are unlikely to succeed, particularly in the absence of other policy initiatives.
- The third, and most promising, is to concentrate on domestic measures to strengthen the industry, thus enhancing its competitiveness and providing leverage to work on bilateral understandings.

The real challenge in aerospace offsets is the need to recognize the challenge other countries' aerospace policies pose for U.S. industry and to develop cost-effective public-private partnerships to retain and refurbish the design and manufacturing expertise necessary for the U.S. to remain a major supplier.

Immediate measures could focus on R&D tax credits, lower regulatory burdens, renewed support for aerospace R&D—where NASA seems to have diminished its expenditure and infrastructure. These would represent concrete measures to help the industry to compete. On a longer-term perspective, several commissions have researched industry needs. A common element, in my view, is the need to provide incentives that motivate government agencies to cooperate in achieving a common vision of the U.S. aerospace industry and a roadmap to get there. A forum bringing together the industry, the aerospace workforce, and the aerospace university research community to determine what needs to be done to keep the U.S. competitive might well be a positive step towards a constructive national strategy.

Challenges to the U.S. Semiconductor Industry

It is also important to recognize that the challenge to the U.S. aerospace industry is not an isolated phenomenon. In the time remaining I would like to raise the challenges facing the U.S. semiconductor industry. They are not facing offsets requirements. Instead they face requirements for direct investment for manufacturing and increasingly for the location of R&D facilities in their overseas markets.

As you know, the semiconductor industry is one of the most vibrant and productive U.S. industries. It is, of course, a supplier of critical components to the U.S. defense industrial base. This leading U.S. industry also faces challenges which will affect its U.S. manufacturing, its workforce, and its supplier base.

Semiconductors are pervasive and an important source of productivity in the modern economy. As the NRC's report *Securing the Future* notes, their rapid technological evolution—characterized by continuously increasing productivity and contemporaneously decreasing cost—are a source of growth throughout the economy, both in emerging industries and in more traditional industrial sectors.[10] A significant element of the strong performance of the U.S. economy in the last decades rooted in the investment and subsequent application of information technologies, which are ultimately driven by advances in semiconductor technology.[11] Semiconductors also play a crucial role in ensuring our national security by allowing for advances in the capabilities of new devices and new applications for national defense. The pervasive impact of the microelectronics sector on the nation's well-being—through improved communications, advances in health care, and better national security technologies—underscores the importance of the United States' role as the world's preeminent semiconductor producer.

The U.S. semiconductor industry is today, the largest value-added industry in manufacturing—larger than the Iron and Steel and the Motor Vehicles industries combined. And the electronics industry, based on semiconductors, is the largest US manufacturing industry.[12] As of August 2001, the semiconductor industry employed some 284 thousand high skilled workers in the United States.

The NRC report, *Securing the Future* also highlighted the promotional policies of governments in every country in which the semiconductor industry has emerged. As

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[10] Op cit. For an analysis of the role of new information technologies in the recent trends in high productivity growth, often described as the "New Economy," see Council of Economic Advisors, *Economic Report of the President,* H.Doc. 107-2, Washington D.C.: USGPO, January 2001. See, National Research Council, *Measuring and Sustaining the New Economy, Report of a Workshop,* D. Jorgenson and C. Wessner, eds., Washington D.C.: National Academy Press, 2002.

[11]See National Research Council, *U.S. Industry in 2000: Studies in Competitive Performance,* Washington D.C.: National Academy Press, 2000.

[12] Bureau of Economic Analysis, Statistical Abstract of the United States: 2001, Department of Commerce, Table 641, Washington DC: US Government Printing Office, 1999, page 418.

Thomas Howell notes in his paper, *Competing Programs; Government Support for Microelectronics*' "In a growing number of newly industrializing countries promoting an indigenous capability in microelectronics—Taiwan, Korea, Singapore, China, and Malaysia—government policies emphasize the acquisition and diffusion of advanced semiconductor technology from the industrialized countries rather than [by] pursuit of leading-edge R&D." Countries such as Germany, France, and Belgium—yes, Belgium—also have major programs to support semiconductor industry R&D and investment. There is only one outlier, and that is the United States, where at the Federal level, we have no major cooperative R&D program, despite the success of SEMATECH.

With respect to semiconductors, a series of steps can be taken. The goal is not to restrict the industry with regard to its use of technologies or its investments overseas. That is likely to be counterproductive. What we can do is partner with industry to develop the technologies, encourage cutting-edge research, produce the students for the next generation, and provide incentives for investment in the United States. These incentives should seek to counterbalance the substantial subsidies of other countries while improving the business climate here in the U.S. Positive-sum environmental regulations and depreciation allowances attuned to industry investment cycles (i.e., depreciation over three, not five, years), major grants for new research facilities, and incentives for students and foreign talent, where required, can all help to retain and grow a vibrant U.S. industry.

As a concrete example, the recent Academy report on challenges facing the U.S. semiconductor industry recommended more support for the cooperative, university-based Focus Center Research Program. The financing for this program is relatively limited; the potential benefits are large, and the program already has a positive track record. Reinforcing this type of successful government-industry partnership is key.

Enhanced investments in nanotechnologies are another key step. It is important for the U.S. economy to build capacity in nanotechnologies, but commercialization is also essential. Programs such as SBIR and ATP, to encourage their commercialization, are key ingredients for a successful U.S. policy to anchor this tremendously promising technology in the U.S. economy. Support for research is not enough. Support for early-stage commercialization is also required.

A Broader View of the Challenge

In closing, let me just underscore the need for a broader view of the challenges facing the U.S. semiconductor and aerospace industries. In my view, government policies that support the sectors as a whole and provide sustained attention are the best means to maintain employment, encourage innovation, and ensure the future of these leading U.S. industries and a robust U.S. defense base. We have acted together to create and retain industries in the recent past, and with your help we can do so again.

APPENDIX:

National Research Council
Securing the Future:
Regional and National Programs to Support the Semiconductor Industry

Chapter 2: Findings and Recommendations[*]

FINDINGS

The federal government has played a significant role in supporting the growth of the semiconductor industry since its inception.[1] The industry has benefited from close cooperation with government, both through generous procurement contracts such as those related to defense and space exploration, and through research consortia. This support for industry research and development is fully justified. The semiconductor industry's technological progress has enabled major advances in technologies directly relevant to core government missions including those in national security, communications, health, weather, the environment, and education. In addition, there is growing recognition of the importance of the industry's contributions to the productivity growth of the U.S. economy.[2]

The contribution of new technologies to growth, especially information technologies, is now recognized at the highest levels of U.S. policymaking. Notably, Federal Reserve Chairman Alan Greenspan has affirmed the contribution of new technologies to the low inflation, low unemployment, and the continued high growth rates that have characterized the U.S. economy in the latter half of the1990s.[3] Much of the technological advance that has made these productivity gains possible is dependent on the unprecedented decrease in cost of increasingly more powerful semiconductors.[4]

[*] National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry*, Charles W. Wessner, ed., Washington, D.C.: National Academies Press, 2003, pp. 65-89.

[1] As Laura Tyson observed in 1992: "The semiconductor industry has never been free of the visible hand of government intervention. Competitive advantage in production and trade has been heavily influenced by policy choices, particularly in the United States and Japan. Some of these choices, such as the provision of public support for basic science, R&D, and education in the United States, have had general, not industry-specific objectives. But other choices, such as the provision of secured demand for industry output through military procurement in the United States and through preferential procurement of computers and telecommunications equipment in Japan, have been industry specific in intent and implementation." Laura D'Andrea Tyson, *Who's Bashing Whom?: Trade Conflict in High Technology Industries*. Institute for International Economics, Washington, D.C., 1992, p. 85.

[2] Dale Jorgenson and Kevin Stiroh, "Raising the Speed Limit: U.S. Economic Growth in the Information Age," in *Brookings Papers on Economic Activity*, (2), 2000, p. 125-212.

[3] Alan Greenspan, *Technological Innovation and the Economy*, Remarks Before the White House Conference on the New Economy, Washington, D.C. April 5, 2000, Federal Reserve Board.

[4] *Ibid.* See also *National Research Council, Measuring and Sustaining the New Economy,* Dale W. Jorgenson and Charles W. Wessner, eds., Washington, D.C.: National Academy Press, 2002.

I. THE SEMICONDUCTOR INDUSTRY: A HISTORY OF COMPETITION AND COOPERATION

Firms in the U.S. semiconductor industry have a deserved reputation as fierce competitors in both American and foreign markets. Yet, at key points in the history of the American semiconductor industry, particularly in the decade of the eighties, the industry launched cooperative efforts through organizations such as the SRC (1982) and SEMATECH (1987).[5] This cooperative research has pooled expertise, lowered costs, and encouraged the dissemination of knowledge across the industry.[6] After two decades of relative declines, the decade of the 1990s witnessed a major resurgence in the competitive position of American industry in many sectors.[7] As previous analysis by the National Research Council suggests, an important part of the improvement in the competitive position of American industry can be attributed to the growth in the application of information technologies, particularly after 1995.[8] A key challenge of the new century is to sustain the high rate of technological advance that has characterized the semiconductor industry, which underpins the information technologies which have in turn contributed to the growth of the American economy as a whole, is a key challenge of the new century.[9]

A. A Steady Increase in U.S. R&D Investments

In aggregate terms, the outlook for R&D investments in the United States appears favorable. On December 20, 2001, Congress approved a record federal R&D budget for 2002 of $103.7 billion—a 13.5 percent increase over FY 2001. Total R&D funding reached a preliminary $264.6 billion in 2000 or 2.68 percent of total GDP. This amount reflects an increased R&D share of GDP from the 2.63 percent in 1999.[10] Total U.S.

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[5] The Semiconductor Research Corporation, founded in 1982, is based in Research Triangle Park, North Carolina, and has an office in San Jose, California. Its stated goal is to operate globally in order to provide competitive advantage to its member companies as the world's premier university research management consortium delivering relevantly educated technical talent and early research results. In the SRC's words; "The goal in 1982, as it is today, was to define common industry needs, invest in and manage the research that would expand the industry knowledge base and attract premier students to study semiconductor technology." In addition, the SRC also trains and produces graduates who are highly and relevantly skilled to perform at the frontier of semiconductor research.
The SEMATECH (SEmiconductor MAnufacturing TECHnology) consortium was a public-private industry partnership formed in 1987 in order to reinvigorate the semiconductor industry in the United States, which had lost significant market share to Japanese firms. The consortium eventually focused on encouraging cooperation among firms to establish standards and helped to develop roadmaps for the evolution of the industry. The consortium stopped receiving federal support in 1996 and has further evolved to include foreign firms. It is now known as International SEMATECH. Currently, partnerships are underway with members, equipment and materials suppliers, national laboratories, and other consortia.

[6] Kenneth Flamm, and Qifei Wang, *SEMATECH Revisited: Assessing Consortium Impacts on Semiconductor Industry R&D*, in this volume.

[7] See National Research Council, *U.S. Industry in 2000: Studies in Competitive Performance*, Washington, D.C.: National Academy Press, 2000.

[8] *Ibid*. See also: Jorgenson and Stiroh, *op. cit.*, 2000; and National Research Council, *Measuring and Sustaining the New Economy*, *op.cit*.

[9] *Ibid*.

[10] These figures use a preliminary estimate for 2000 form the National Science Foundation. The data are derived from the National Science Foundation's, *National Patterns of R&D Resources: 2000 Data Update*, "National expenditures for R&D, from funding sectors to performing sectors: 1993-2000."

R&D expenditures show a steady increase. For example, between 1995 and 2000, R&D expenditures increased at an average rate of 7.74 percent.[11]

B. Increases Mask Substantial Shifts

Overall, increases in R&D investments are widely recognized as a good thing in that the social returns on such investments (that is the gains for society as a whole) are very high, on the order of 40 to 50 percent.[12] However, the composition of R&D investments also matters and in this regard, current trends are a cause for concern. Federal support for R&D has not kept pace with private sector investments, which have risen dramatically (see Figure 1). In 1980, the federal share of R&D was roughly 48 percent. In 1999, it had fallen to 28 percent of the total. In part, this reflects U.S. industry's commitment to developing new products and processes and in part, the declines reflect the budgetary constraints and uncertainties of the mid-nineties. Whatever the cause, the current differential trends are a source of concern because, as noted below, the government and industry focus on different phases of the innovation system.

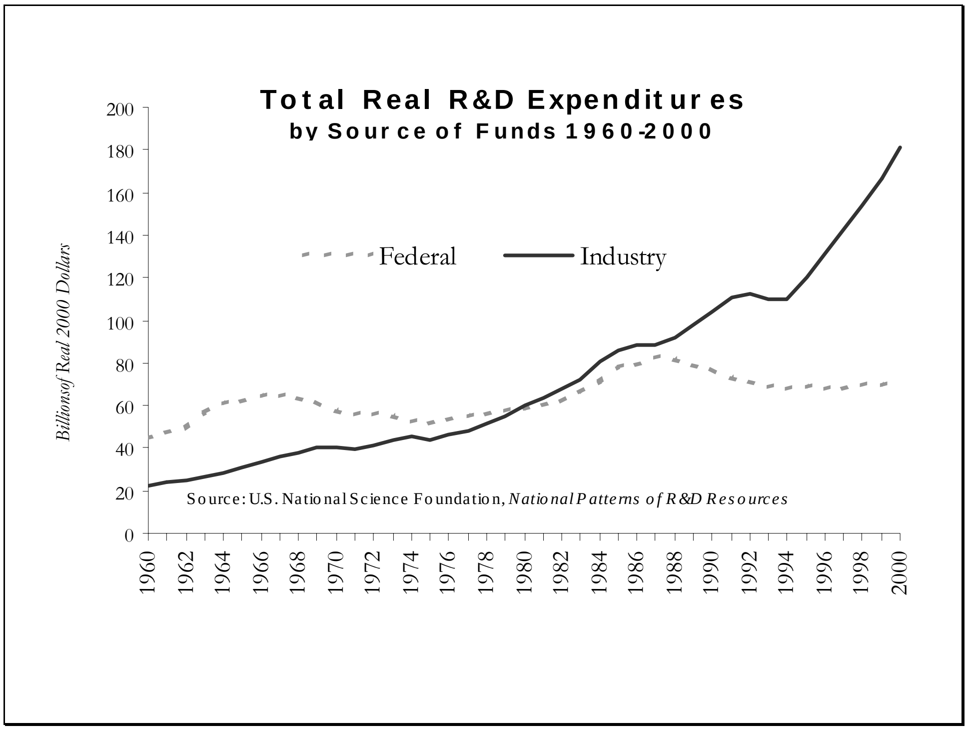

FIGURE 1 Total Real R&D Expenditures By Source of Funds 1960-2000. SOURCE: National Science Foundation, National Patterns of R&D Resources.

[11] *Ibid.*

[12] There is a substantial literature on the social benefits or "spillovers" attributed to R&D investments from Edwin Mansfield's early work in 1977 to more recent analysis by Zvi Griliches. See for example, Martin N. Baily and A. Chakrabarti, *Innovation and the Productivity Crisis*, Washington, D.C.: The Brookings Institution, 1998; and Zvi Griliches, *The Search for R&D Spillovers*, Cambridge, MA: Harvard University Press, 1990.

The Nature of Industry R&D

The contribution of industry to the R&D budget has focused more on product development than on basic research. Of the $43.5 billion of federal R&D devoted solely to research in FY2001, $22 billion, or 50.7 percent was channeled into basic research.[13] The semiconductor industry devotes $14 billion to R&D or 14 percent of sales per year (as of 2000).[14] The industry also devotes a significant portion of its R&D effort to university-based research through the Semiconductor Research Corporation (SRC), the jointly funded Focus Center Research Programs, and industry R&D collaboration through SEMATECH.[15]

In general, however, industry has been less inclined to fund the basic research on which the future growth of the economy ultimately depends.[16] Yet, much of the current technological progress the United States, and indeed the rest of world enjoys today rests on inventions, and investments made thirty and forty years ago.[17] In addition, many of the large industry laboratories that once supported major technological advances such as the transistor, no longer exist or have seen their research strategies substantially modified.[18]

BOX A. THE MICROELECTRONICS ADVANCED RESEARCH CORPORATION (MARCO)[19]

MARCO, a cooperative program organized under the auspices of SRC, funds and operates a number of university-based research centers in microelectronics as part of its Focus Center Research Program (FCRP).

- The Focus Centers concentrate on those areas of microelectronics research that must be addressed to maintain the historic productivity growth curve of the industry
- Focus Programs involve multiple universities and place strong emphasis on cross-fertilization of ideas during the basic research stage.

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[13] See American Association for the Advancement of Science; *Congressional Action on Research and Development in the FY 2001 Budget.*

[14] See <http://semichips.org/ind_facts.cfm>.

[15] The *Focus Center Research Program* is a national research network formed in 1998. It is jointly funded by the U.S. semiconductor industry and the federal government. Its purpose is to address core issues in technology development for the semiconductor industry. The program supports long-range, broad-based research that seeks to establish new perspectives and approaches to technological challenges facing the industry. In March of 2001, the Semiconductor Industry Association announced that it would double the size of the FCRP. Subsequent economic conditions have made the timing of this decision uncertain.

[16] National Research Council, *Allocating Federal Funds for R&D*, Washington, D.C.: National Academy Press, 1995. See also National Research Council, *Government-Industry Partnerships in Biotechnology and Information Technologies: New Needs and New Opportunities*, Charles W. Wessner, ed., Washington, D.C.: National Academy Press, 2002.

[17] David Tennenhouse, vice-president and Director of Research and Development at Intel, emphasized this point in his presentation at; *The Global Computer Industry Beyond Moore's Law: A Technical, Economic, and National Security Perspective*. A Joint Strategic Assessments Group (SAG) and Defense Advanced Research Projects Agency (DARPA) Conference, January 14-15, 2002.

[18] Richard Rosenbloom and Bill Spencer, *Engines of Innovation: U.S. Industrial Research at the End of an Era*. Boston: Harvard Business School Press, 1996. For a condensed version, see Rosenbloom and Spencer, "The Transformation of Industrial Research" in *Issues in Science and Technology*, 8(3):68-74.

[19] MARCO was established in 1998. For additional information on MARCO, see the SRC website. <http://src.org/member/about/fcrp.asp>.

- Focus Program research is typically longer-term—normally eight years away from commercialization.
- Advances made under the Focus Program can become proposals to the SRC to address long-term needs identified in the Industry Roadmap (ITRS).[20]

C. The Expansion in Foreign National R&D Programs

As noted above, governments around the world have played an active role in the development of the semiconductor industry. In its early years, the U.S. industry received substantial support for research and development from the federal government, particularly to achieve national missions in defense, (e.g. the Minuteman program,) and in space exploration, (e.g. the Apollo program.) Governments around the world have also taken an active approach in supporting the entry of their national firms into the global semiconductor market.[21]

Japan's early VSLI program, for example, helped bring its producers to the forefront of the industry in only a few years.[22] In 1987, SEMATECH was founded to aid a beleaguered U.S. industry. Korea followed in the late 1980s and 1990s with generous state-supported financing for DRAM production by its *chaebols*. Taiwan's innovative policy mix of equity finance, technical support, favorable tax treatment, and the development of the Hsinchu Science and Technology Park Complex helped propel its industry forward in the 1990s. Enhanced R&D support and other programs are not confined to new entrants. Several European countries, operating in conjunction with European Union, have put in place programs that have contributed to a strengthened competitive position for European producers.

A wide variety of policy instruments—ranging from substantial government funding for national R&D programs, to favorable tax treatment (e.g., short depreciation allowances) and, in the past, trade measures such as tariffs and private restraints of trade, (i.e., restrictive internal market arrangements)—have been used to promote domestic semiconductor firms. Given the perceived contributions of SEMATECH, countries and regions interested in supporting the semiconductor industry have adopted the consortium model as a means of encouraging cooperation among firms within a national industry and as a vehicle for providing government support.

The combination of technical challenges facing the semiconductor industry and the perceived success of cooperative programs in the United States have lead policy makers

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[20] See *International Technology Roadmap for Semiconductors*, <http://public.itrs.net/Files/2001ITRS/Home.htm>.

[21] See the proceedings below for a discussion of the wide range of programs underway in Japan, Taiwan, and Europe (the latter both at the EU, regional, and national levels). The paper by Thomas Howell in this report, *Competing Programs: Government Support for Microelectronics*, provides original documentation concerning the focus and funding of many of these programs. The steady growth of these programs and the levels of public support reflect both the perceived importance of the industry and the perceived success of the American model. See for example the chart summarizing program goals and funding in Thomas Howell, *op cit*., in this report. Howell identifies about 17 programs currently underway in the microelectronics industry, outside of the United States.

[22] For a description of these programs and a prescient prediction of the recovery of European firms, see Thomas, Howell, Brent Bartlett, and Warren Davis, *Creating Advantage: Semiconductors and Government Industrial Policy in the 1990s.* Santa Clara CA: SIA, 1992.

in several countries to increase government funding in support of their national semiconductor industries.[23] Box B describes current trends in national programs to support national semiconductor industries.

BOX B. SIGNIFICANT GLOBAL TRENDS IN THE SEMICONDUCTOR INDUSTRY AS A RESULT OF NATIONAL PROGRAMS

- **Substantial Support for Microelectronics in Japan**. The Japanese government has initiated a series of R&D initiatives and has provided substantial support in cooperation with the Japanese industry. These initiatives are intended to contribute to a "national revival" in the competitive position of the Japanese semiconductor industry.

- **Strong Support for Microelectronics in the European Union**. European Union and national government supported R&D projects—such as JESSI (the Joint European Submicron Silicon Initiative), MEDEA+ (the Micro-Electronics Development for European Applications), and IMEC (Inter-university Micro-Electronics Centre)—have helped to reverse declines in the European microelectronics industry, considerably improving its global competitive standing.

- **The comparative advantage of other nations in leading-edge mobile communications and digital technologies will be leveraged**. Japan and the EU have designed comprehensive strategies to challenge the U.S. leadership in microelectronics by leveraging their present and expected future advantages in mobile communications and digital home appliances.

- **The Challenge of the foundry model**. Taiwan's pioneering of a new business model—the dedicated foundry—has the potential to revolutionize the industry. Taiwan has emerged as a major production base, in part through government capital to launch the industry and through a supportive environment such as the Hsinchu Park Complex.

- **China: A future competitor**. China is making a concerted effort to become a significant competitor in microelectronics. Its government has made substantial efforts to attract foreign investment and promote the diffusion of more advanced foreign technology to the Chinese mainland, while promoting indigenous producers. The evolution of the Chinese microelectronic industry will continue to be augmented by the ongoing movement of Taiwanese manufacturing information technology to mainland China.

[23] *Ibid.*

II. THE SEMICONDUCTOR INDUSTRY FACES SIGNIFICANT CHALLENGES

The substantial increases in semiconductor power—predicted by Moore's Law—are becoming more challenging to continue. To do so, the industry must overcome a series of technical hurdles, including the need for both new materials and designs. It must also address the need for skilled labor required to overcome these hurdles amidst emerging changes in the structure of the industry.

Given the economic importance of the industry, there is very limited research on the impact of SEMATECH on R&D in the semiconductor industry, its role in the resurgence of the U.S. industry, and its potential lessons for other U.S. consortia.[24] With regard to the industry as a whole, there is limited economic research as to the sources of the industry's pronounced cyclical swings, its contributions to productivity, and its subsequent impact on the economy at large. Scant public policy attention has been focused, as well, on the research requirements needed to keep this industry on its positive course, and on the skilled labor and advanced training needed to sustain this trajectory.

A. Need for Highly Skilled Human Capital

1. *Continued Progress depends on the supply of talented and skilled labor.*

In order for the semiconductor industry to maintain high growth rates and respond to the growing challenges within the industry, the U.S. faces a long-term need to bolster support for highly skilled workers. While, at this writing, the industry is showing the effects of a historically sharp downturn, this cyclical feature should not mask the growing long run demand for the skilled workers needed to keep the industry on its current growth path. Sustaining the industry's remarkable rate of technological advance requires persistent creativity and ingenuity. Such an innovative environment is sustained by a trained workforce well grounded in the disciplines—such as physics, mathematics, and engineering—that underpin the semiconductor industry. This long-term growth in the demand for skilled labor has emerged against the decline in U.S. federal funding for these disciplines (see Figure 1). The U.S. is also competing globally to generate and attract the human capital necessary to the long-term health and development of the semiconductor industry. [25]

2. Generating a Skilled and Qualified Workforce in the Microelectronics Industries.

Despite ongoing initiatives to address the skilled manpower needs of the industry by organizations such as the Semiconductor Research Cooperation (SRC), there is concern within the industry as to whether there will be *enough* skilled graduate students to meet future demand—a problem some believe is worsening. The SRC has documented a significant drop in the graduation rate of electrical engineering students in the United States from 1988 to the present and projects no recovery from these low levels in coming years.[26]

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[24] See the paper by Kenneth Flamm and Qifei Wang, "Sematech Revisited: Assessing Consortium impacts on Semiconductor industry R&D," in this report.

[25] See Thomas Howell, "Competing Programs: Government Support for Microelectronics," *op. cit.*

[26] For a discussion of the decrease in engineering students and its implications for the microelectronics industry, see Michael Polcari's statements in the Proceedings of this report, under *Current Challenges: A U.S. and Global Perspective,* pp. 115-116. For a recent review of these challenges, see National Research Council, *Building a Workforce for the Information Economy,* Washington, D.C.: National Academy Press, 2001.

To compound this challenge, competition for the limited pool of talented workers in engineering fields is global, and U.S. industry will face increased difficulty in attracting the young skilled workers it needs to continue growing. The U.S. exhibits one of the lowest yields, 5.3 percent, in producing engineers when comparing the number of bachelor's degrees in engineering to all bachelor's degrees. In the sheer production of engineers on a yearly basis, the U.S. is surpassed by Asian nations as a group by almost six times[27]. Other nations in Europe and Asia have recognized this growing demand for skilled labor in microelectronics and appear to be making a concerted effort to address this global challenge (See Figure 2).[28]

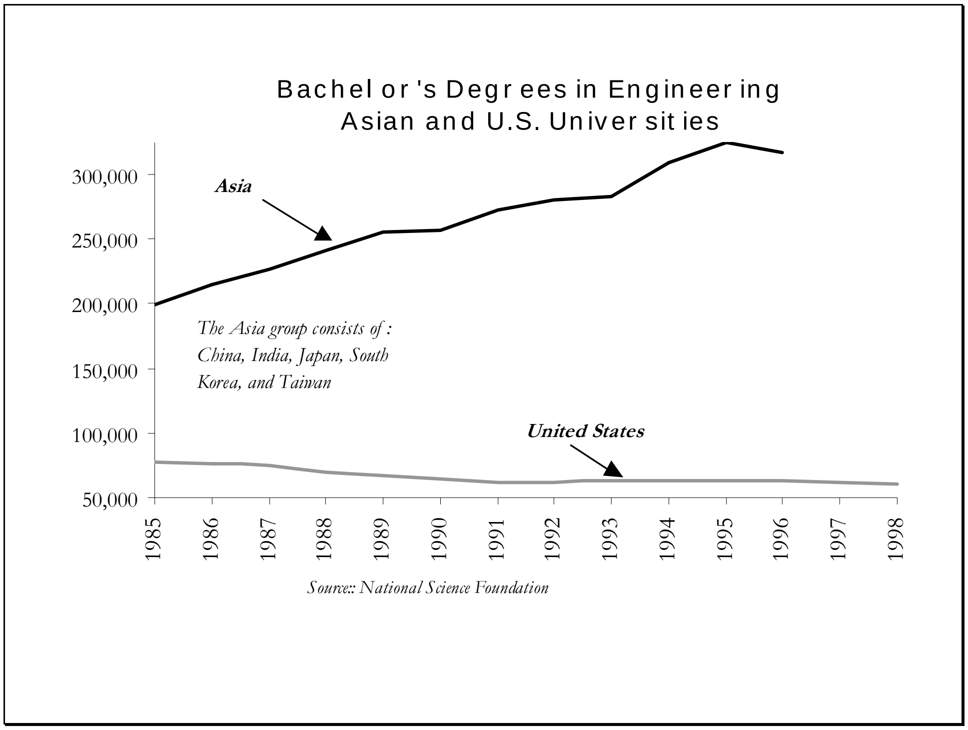

FIGURE 2 Bachelor's Degrees in Engineering: Asian and U.S. Universities. SOURCE: National Science Foundation.

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[27] This group of Asian nations consists of China, India, Japan, South Korea, and Taiwan.

[28] Germany, for example, has witnessed a major decrease in the supply of engineering graduates since the early 1990s, which has subsequently spurred a worldwide search to attract qualified labor to the German semiconductor industry. See Wilhelm Beinvogl's comments on the German industry's global search for skilled workers to satisfy skilled labor demand in the semiconductor industry. Proceedings, *Panel III: European Partnerships, Government-Industry Partnerships in Europe II,* this report, p. 148. Japan has not noticed the same falloff in the number of technical graduates on a per annum basis. However, industry experts believe that there is an impending increase in demand for qualified and skilled workers, which, to the detriment of industry growth rates, may not be satisfied given current trends. Toshiaki Masuhara notes that, in the field of designing VLSI chips in Japan, a study completed several years ago found that there is a company demand four times larger than the number of students. See the Proceedings of this report, p. 136. This shortage exists as well in Taiwan, where it may become difficult to sustain the growth rates of Taiwanese firms without an increase in the supply of engineers and electronics personnel. Genda J. Hu from Taiwan's TSMC (Taiwan Semiconductor Manufacturing Cooperation) noted that the company would have a difficult time maintaining its projected growth rate without an increase in the supply of skilled workers. When asked if this skilled-worker shortage was a problem in Taiwan, Mr. Hu responded; "on a large scale, there is a problem." See the Proceedings of this report, *Panel IV: The Taiwanese Approach,* p. 150-156 and 163

Recommendations for a resolution to this general trend are beyond the purview of this report. The declines in the supply of engineers and the reductions in the federal spending on these disciplines are likely to augment the challenge faced by the industry as it seeks new solutions to pressing technical problems.

B. Structural Changes in the Industry Present New Challenges and Opportunities

1. Vertical Specialization and the Emergence of the Foundry Model.

The semiconductor industry is becoming more vertically specialized. For example, the foundry model—low-cost, state-of-the-art fabrication facilities ("fabs") found in Taiwan and other Asian nations, where firms produce semiconductors under contract with other companies—is revolutionizing the industry. The foundry model of production can offer substantial cost savings in manufacturing new generations of chips. In some cases, these cost savings may be the result of lower costs of capital reflecting preferential tax treatment or more direct government subsidies for industries that are viewed as strategic by government policy makers

The emergence of design houses—firms which specialize in the design of semiconductors only and do not produce them—is yet another sign of vertical specialization in the industry and functions congruently with the foundry model of production. Some analysts are concerned that, over time, the development of new technologies, especially manufacturing technologies may become more closely associated with the foundries themselves. To the extent that offshore design houses are involved in this process significant technical capability and know-how may be transferred. The consequences of this phenomenon are not clear nor are they unidirectional. For example, in the near-term, the availability of these fabrication facilities can work to the benefit of some U.S. firms—especially those that focus on design.[29] This specialization stands in contrast to the U.S. industry, which has typically housed both of these functions under one roof. In part, these trends reflect the global scale of the industry; they reflect, as well, as the active industrial policies of leading East Asian economies. For example, Singapore and Malaysia have contributed significant public funds and have extended tax incentives to companies constructing "fabs," while Taiwan has approximately 100 "design houses," also supported through various government incentives.[30]

While far from certain, one foreseeable outcome of the growth in this model could entail a steady increase in U.S. manufacturers commissioning "design houses" in Taiwan or Europe, and then contracting a foundry-firm to manufacture that particular design.[31] In any case, U.S. merchant device producers may face increasing challenges from the substantial capacity generated by government-supported fabrication facilities abroad.[32] At the same time, as noted above and in the Introduction, fabless producers in the U.S. benefit from greater opportunities to obtain lower-cost access to state-of-the-art fabrication facilities. If the rate of growth and ultimate impact of this vertical disintegration within the industry is unclear, there is growing concern about the impact of these trends on the R&D funding that drives the industry. To date, the foundries have tended to be fast followers—rapidly

[30]See the paper by Thomas Howell in this report; "Competing Programs: Government Support for Microelectronics."
[31] *Ibid*.
[32] See "The Great Chip Glut," *The Economist*, August 11, 2001.

adopting the new manufacturing technologies that drive the industry. As foundries gain market share, it is not clear that the necessary levels of R&D investment required to sustain the industry's growth will be made.

2. The Risk of Knowledge and Technology Transfers.

A further possible challenge to consider from a U.S. perspective concerns the relationship between the foundries and the design manufacturers. In order to take advantage of the foundry model as an outsourcing alternative to in-house production, designs must be shared with the foundries. As particular aspects of semiconductor design are necessarily shared with foreign-owned and controlled fabrication facilities, over time some elements of the U.S. industry may see their comparative advantage in design erode. At the same time, reverse engineering is immensely complex, time consuming, and, in principle, limited by intellectual property protection. Nonetheless, a great deal of production knowledge occurs on a "learning by doing" basis. Again, the long-term consequences of this process are not clear, but the potential consequences of these developments for U.S. industry, economic growth, and national security suggest that better data collection and further analysis would be appropriate.[33]

C. Significant Technical Challenges

Discovering a method that allows for the continued improvement in semiconductor productivity presents another significant challenge to the semiconductor industry. Much of the progress to date has been the result of scaling—progressively shrinking component size. This process has been the basis of the growth in the semiconductor industry for the past 30 years. Once scaling reaches its limits, the productivity growth of the industry may also diminish. The long-term challenge will be to find new methods to continue the progress in semiconductor productivity, which entails development of new materials and design structures. (Some of these major material challenges are listed and described in Box C.)

Another prominent challenge involves the evolution of lithography toward the use of smaller wavelengths. In the past, the industry has produced several generations of chips by using a specific lithography system with a particular wavelength.[34] This system of lithography has now evolved to one where new wavelengths are introduced and the system is changed in fewer generations. This development has placed a large burden on the equipment industry to keep pace with these rapid changes. For instance, in some cases where the limits of prevailing systems have been approached, companies have resorted to using other, less efficient methods to circumvent the true material barriers. These methods of circumvention however, do not present real long-term solutions and in many cases represent a "huge tax on the industry in terms of time and resources.[35]"

The future of shorter wavelengths needed for the increase in semiconductor productivity appears to be approaching, and thus there is a need to prepare the shift to new lithographic systems such as EUV (Extreme Ultra-Violet).[36] However, these changes require

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[33] Reflecting the growing interest in this topic, *The Advisory Group on Electron Devices Forum* operating under the aegis of the Department of Defense organized a conference to review global economic and technological trends affecting U.S. leadership in microelectronics on September 24, 2002.

[34] For a more detailed discussion of the impending challenges in lithography, see Michael Polcari's discussion in the Proceedings, *Current Challenges: A U.S. and Global Perspective*, *op.cit*. pp. 111-117.

[35]Michael Polcari*, op. cit.*, p.112.

[36] *Ibid*.

significant research and development. Some experts have suggested that with current levels of investment, it is not reasonable to expect to find solutions relatively soon.[37]

BOX C. LONG-TERM CHALLENGES IN THE SEMICONDUCTOR INDUSTRY[38]

Over the long-term[39], some of the major *Performance Enhancement* challenges in the semiconductor industry entail:

- **Moving beyond current methods and materials**. This includes implementation of non-traditional (non-CMOS)[40] device structures and architectures, including new methods of chip interconnections and memory.
- **The need for Next-Generation Lithography (NGL) technologies**. Since optical lithography will not be viable due to the limits of scaling, the development of NGL technologies such as Extreme Ultraviolet (EUV)are needed.
- **Interconnect Issues.[41]** Scaling or miniaturization of established interconnect structures will no longer allow for the achievement of performance targets. There is a need for material innovation and design in this area.

Some of the major challenges in the long run for *Cost-Effective Manufacturing* in semiconductors are:

- **New Designs to Address Noise Management.[42]** Noise sensitivity is becoming a major issue in semiconductor devices in an age where advances in technology require semiconductors to run at a high speeds with low noise, i.e., few disturbances or unwanted signals. In order for semiconductors to continue along the path of their yearly power increases, more attention needs to be devoted to modeling, analysis, and estimation at all design levels.
- **Error Tolerant Designs.** The cost of manufacturing, verification, and testing may be reduced by relaxing some of the 100 per cent correctness standards for devices, as the scaling of the design complexity and the increasing transistor count will greatly reduce the potential for failures.

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[37] *Ibid*.
[38] For a more thorough and in depth technical description of the long term challenges facing the semiconductor industry, see *International Technology Roadmap for Semiconductors: Executive Summary*, 2001 Edition, <http://public.itrs.net/Files/2001ITRS/Home.htm>.
[39] *Ibid*. The Roadmap defines long-term as 2008-2016.
[40] Complimentary Metal Oxide Semiconductor, or CMOS, is the silicon-based material used in most current semiconductors.
[41] The interconnect can be thought of as a line which allows devices to communicate with each other. More specifically, an *interconnect* is a metal conductor line (copper in advanced semiconductors) connecting elements of an integrated circuit.
[42] Noise is a term used to describe any unwanted signal or disturbance that detracts from the performance of the semiconductor device. A more complete treatment of noise in semiconductor devices is given by; *Microwave Noise in Semiconductor Devices*, Hans Ludwig Hartnagel, Ramunas Katilius, Arvydas Matulionis, January 2001.

- **Need for New, Larger Area Starting Materials.** In order to maintain the productivity gains of semiconductors, there is a pressing need for research and engineering to find new large area starting substrate material.[43]

III. INTERNATIONAL TRENDS

A. International Convergence in Semiconductor Technology

The gap between the United States and countries such as Taiwan and South Korea in semiconductor industry technology is narrowing. Korea and Taiwan exhibit global strength and significant progress in memory technologies and foundry-based fabrication facilities. Over time, these trends point towards a shared global leadership. Complacency about the strength of the U.S. industry vis-à-vis its global competitors would be misplaced. As one recent Academy analysis observed:

> "The revival of the U.S. semiconductor industry is an impressive feat, for which government policymakers and industry managers, engineers, and researchers should share in the credit. But the unexpected nature of this revival, its rather complex causes, the contributions to it of cyclical factors, and the fragility of its foundation all suggest that competitive strength in this industry cannot be taken for granted….In other words, U.S. semiconductor firms must maintain their strategic agility and strength in product innovation while avoiding significant erosion in their manufacturing capabilities in order to maintain their strength. The task will require imagination and collaboration among government, industry, and academia."[44]

B. An Increase in Global Partnerships

Global partnerships have become very common in the semiconductor industry. Both Europe and Asian countries have established consortia in order to create industry standards, map-out future issues and challenges, and conduct collaborative research. In both Asia and Europe, policymakers recognize the potential contributions of consortia to overcoming the myriad technical challenges facing the semiconductor industry. Many of the leading figures in the industry, though not all, believe the effort to overcome the multiple technological challenges faced by the industry should be international in scope if these challenges are to be met in the required timeframes.[45] National and international consortia are likely to be a key element in encouraging the research that will aid in meeting these challenges.

1. Private partnerships and government-industry partnerships represent an integrated national approach to develop semiconductor technology.

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[43] *International Technology Roadmap for Semiconductors: Executive Summary,* 2001 Edition, *op. cit.*, pp. 14-15.
[44] Jeffrey T. Macher, David C. Mowery, and David A. Hodges, "Semiconductors," *U.S. Industry in 2000, Studies in Competitive Performance*, David C. Mowery, ed., Washington, D.C.: National Academy Press, 1999, pp. 283-284.
[45] See the presentations of Genda Hu of the Taiwan Semiconductor Manufacturing Company and Masataka Hirose of Hiroshima University in this volume.

a. Japan's Pre-competitive R&D Programs. In Japan, SELETE (SEmiconductor Leading Edge Technology Corporation), a joint-venture company established in 1996, conducts R&D on behalf of the Japanese semiconductor industry. SELETE, which is not directly funded by government, has been successful in the promotion and evaluation of technologies, developing advanced technologies, and carrying out special projects. By comparison, ASET (Association of Super-Advanced Electronics Technologies) is completely funded by the government and focuses on equipment and chip R&D for 70-100nm technology.

b. Europe's Multinational, Multi-firm Partnerships. MEDEA (Microelectronics Development for European Applications) is a multinational, multi-firm partnership. It is similar to SEMATECH in that it was jointly financed by government and industry. MEDEA has helped develop a better understanding between semiconductor suppliers and system houses, helped develop a better idea of where to focus R&D resources, and has fostered closer cooperation among companies in different European countries—both vertically and horizontally. MEDEA officials report that these efforts demonstrate that collaboration in the semiconductor industry can have positive effects for society (employment in the industry increased) and that it can be a productive use of public funds. As result of MEDEA's success, MEDEA-Plus was initiated in 2001 to address the challenges facing the semiconductor industry noted above.

c. Government-industry Partnering in Taiwan. The semiconductor industry in Taiwan was born out of government support and partnerships in the mid-1970s. Today, the major semiconductor companies in Taiwan are world leaders in their specialties. One of the most successful joint ventures between industry and government is Taiwan Semiconductor Corporation (TSMC). TSMC is a positive example of a government-industry equity partnership in terms of return to society on public investments.[46] The dynamic effects for the Taiwanese economy associated with the establishment of a rapidly growing, highly competitive industry are substantial.[47]

IV. THE IMPACT OF SEMATECH: A GOVERNMENT-INDUSTRY PARTNERSHIP

SEMATECH is widely perceived as effective in accomplishing its goals. The consortium's members believe that participation in the consortium has been worthwhile, as evidenced by their continued participation and contributions. This positive assessment is

[46] The most evident return is in the investment itself. Originally, the government had invested about $100 million in TSMC—the stock was later sold for $400 million.

[47] The highest return is the long-run economic impact of having a leading semiconductor producer in Taiwan. Taiwan's science park approach (notably Hsinchu Park) to creating partnerships between government and industry has shown substantial success. Though in the beginning there were many foreign companies in the park, by the late 1990s, roughly 80 percent of the companies were either local or domestic. Direct equity investment by the government has proved effective. Most of the financial capital provided to the Park originated from the government. Currently only about 4 percent of financial capital comes from the government.

further reflected in the industry's willingness to discontinue public funding while continuing to support the consortium.

The foreign competitors of the U.S. industry share the perception that SEMATECH contributed to the resurgence of the American semiconductor industry and have established a variety of similar programs. These programs are often on a significantly larger scale and have greater underlying political support. Furthermore, a significant number of foreign producers have affirmed their belief in the program's effectiveness by joining SEMATECH, since it became an International consortium in 1999.[48]

These trends underscore the importance of public-private cooperation to support research and technology development in the semiconductor industry. In light of the growing significance of R&D collaboration in both the equipment and device industries, providing policy and financial incentives to encourage such cooperation is an increasingly important way to sustain the investments needed to transition to successive generations of new technologies. [49]

A. Sources of SEMATECH Contributions

1. Flexible Objectives and Industry Leadership

By definition, an R&D consortium's contributions are due in part to its ability to adapt its goals to the conditions of a rapidly evolving industry.[50] The cost sharing

[48] This "market-based" judgment of the consortium's utility is, in the end, the most compelling. Economic analysis of SEMATECH's impact is extremely challenging. As Ken Flamm and Qifei Wang observe; "Finally, the underlying models of R&D cooperation which ultimately must be the basis of a scientific effort to untangle the chains of causality are simply too simplified at this point to capture the complexity of the real world of SEMATECH: a real world in which companies committed to R&D carried out within a joint venture while at the same time competing through internal R&D efforts which also may have spilled over to competitors, a real world in which the menu of consortium activities changes over time with experimentation and learning. At the end of the day, the only absolutely certain thing about SEMATECH is that a substantial portion of its member companies must have found it to be of net value-- having actually run the experiment of ending public subsidy, and finding that its consumers continued to buy its output." See Kenneth Flamm and Qifei Wang, "Sematech Revisited: Assessing Consortium impacts on Semiconductor industry R&D," *op.cit*.

[49] The operation of an effective consortium entails an agreement on achievable goals in accordance with a sense of shared interests. In addition, a consortium needs an effective management structure tightly linked to member interests, as well as a long-term commitment from its participants to contribute highly trained and qualified personnel and to provide financial support. For a further discussion of characteristics of successful national and international consortia, see *Conflict and Cooperation in National Competition for High-Technology Industry*. Washington, D.C.: National Academy Press, 1996. pp. 48-51.

[50] While many believe that SEMATECH contributed to the resurgence of the U.S. semiconductor industry in the early 1990s, it was by no means the only element in this unprecedented recovery. For example, time for the industry to reposition itself was provided by the 1986 Semiconductor Trade Agreement. The U.S. industry also repositioned itself, profiting from shifts in demand, i.e., away from DRAMS (where Japanese skill in precision clean manufacturing gave significant advantage) towards microprocessor design and production (where U.S. strengths in software systems and logic design aided in their recovery. Arguments about which of these elements were most decisive probably miss the point. The recovery of the U.S. industry is thus like a three-legged stool. It is unlikely that any one factor would have proved sufficient independently. Trade policy, no matter how innovative, could not have met the requirement to improve U.S. product quality. On the other hand, by their long-term nature, even effective industry-government partnerships can be rendered useless in a market unprotected against dumping by foreign rivals. Most importantly, neither trade nor technology policy can succeed in the absence of adaptable, adequately capitalized, effectively managed, technologically innovative companies. In the end, it was the American companies who restored U.S. market share.

arrangement with the government and industry management of the research agenda has contributed to this flexibility. Indeed, while it benefited from strong leadership, no single entity dominated the consortium or determined its direction. Members, including Department of Defense officials, reached a broad consensus on technical goals and then left the consortium management to implement the program.

BOX D. CONTRIBUTIONS OF THE CONSORTIUM

SEMATECH HAS made a variety of important contributions to the health of the semiconductor industry in the United States. For example, the consortium has:

- Played an integral role in promoting the development of effective manufacturing technology in the semiconductor industry.
- Developed industry wide standards for manufacturing tools, notably through collaboration with the equipment industry and through industry-wide technology road maps.
- Fostered a shared perspective on the technological development required to maintain the industry's high growth rate through the semiconductor roadmap process.
- Aided companies in:
  - -developing reliable manufacturing tools
  - -creating an effective quality control process
  - -understanding the needs of the industry and advancing the sophistication of the manufacturing process

The industry interaction within the consortium, and between the consortium members and the suppliers, improved the dynamics between the device makers and the equipment industry, with collaboration generating new technical perspectives for the participants and encouraging the give-and-take between manufacturer and supplier necessary to expedite the technology development process.

2. Analyzing SEMATECH

Measuring the contributions of research consortia is a difficult task. As noted in this report, there have been relatively few empirical analyses of the impacts of R&D cooperation on industrial R&D.[51] For the semiconductor industry, some empirical analysis suggests that the

[51] Few researchers have empirically assessed the effects of joining SEMATECH on its member firms' expenditure on private R&D. As noted by Kenneth Flamm and Qifei Wang in "Sematech Revisited: Assessing Consortium impacts on Semiconductor industry R&D" in this report, even though SEMATECH is the highest profile R&D consortium in the United States, it has been the focus of study for only three statistically rigorous papers. One study (Irwin and Klenow, 1996) found that SEMATECH firms reduced their individual expenditures on R&D by about $300 million dollars. They further concluded that the reduction in firm level R&D of member firms does not justify public support for the consortia, since firms are essentially free-riding on federal funds and would have expended the equivalent federal funds out of their own budgets had there not been a consortium. Irwin and Klenow argue further that firms joined SEMATECH to "share" information but not to necessarily "commit" funding for high spillover R&D, which if true, would have resulted in an increase in R&D. There are both conceptual and econometric flaws with this argument, as pointed out by Flamm and Wang in this report. The researchers interpret the data as member firms reducing R&D expenditure that would have been conducted in the absence of the

BOX E: ORGANIZING SUCCESSFUL CONSORTIA

Because of its contributions, SEMATECH is sometimes considered a model for future public-private partnerships.[52] Some of its lessons for organizing a successful consortium are [53]:

- *Understand the Need for Cooperation*—the great range of R&D needs, from basic science to manufacturing infrastructure to whole new industries, are, arguably, best understood in terms of a process where industry works in close cooperation with universities and government research laboratories. To achieve the full benefits of cooperation, it is important to:
- *Ensure Quality Leadership*, including key leaders of the major participating industries
- *Convey your Message* publicly to leaders in the government and private sectors
- *Focus the Program* on key sectors and build on this developed strength, rather than approach the entire industry
- *Set Measurable Objectives* for advancing generic or pre-competitive knowledge
- *Set Uniform Requirements* of participation so that support is not fragmented
- *Plan first—Spend later*: Roadmaps are needed before consortia can be properly launched
- *Develop an Industry-driven process*—recent collaborative work, such as on extreme ultra-violet lithography, show that successful consortia are industry-driven.

consortium has boosted the "effective" R&D level of its members.[54] The work of Flamm and Wang suggest that SEMATECH reduced the R&D expenditures of its membership somewhat, in part by eliminating duplication.[55] In essence, if the number of dollars spent on similar R&D projects across firms is reduced, and the yield of overall industry R&D is unchanged, then this is a better outcome from both a social standpoint, for society, and for industry since resources are freed which can be put to productive use elsewhere. This is a positive result both for the firms and for society as a whole. Moreover, this outcome lends

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consortium, rather than reducing poorly appropriable R&D, which would not have occurred at all had it not been for the consortium's formation. Further, even a "commitment" approach to R&D among consortium members, with relatively low spillovers, would actually lower R&D, a conclusion the authors do not draw. See Irwin, Douglas A. ; Klenow, Peter J. "High-Tech R&D Subsidies: Estimating the Effects of Sematech," *Journal of International Economics* v40, n3-4 (May 1996): 323-44. For a critical analysis of the paper and other studies, see Flamm and Wang in this report.

[52] National Research Council, "Government support for technology development: The SEMATECH experiment," *Conflict and Cooperation in National Competition for High-Technology Industry,"op.cit*., pp. 141-51.

[53] See remarks by William Spencer in the Proceedings section of National Research Council, *Partnerships for Solid-State Lighting, Report on a Workshop,* Washington, D.C.: National Academy Press, 2002. Toshiaki Masuhara of Hitachi also suggests a number of criteria for organizing a successful consortium. See his presentation in Panel VI of the Proceedings of this volume.

[54] See Kenneth Flamm, and Qifei Wang, "Sematech Revisited: Assessing Consortium impacts on Semiconductor industry R&D" in this volume.

[55] *Ibid*.

credence to the idea that a consortium can add to the dynamic efficiency of both its member firms and the industry as a whole.

While the precise measurement of contributions is difficult, SEMATECH is widely believed, within the industry, both in the U.S. and abroad, to have made a positive contribution to the resurgence of the U.S. semiconductor industry. More indirectly, the consortium's activities have contributed to greater cooperation among producers, suppliers, and the government. For example, the current promising cooperation on next-generation lithography tools, i.e., the EUV Consortium, illustrates this enhanced willingness to collaborate in innovative ways. This positive perception of SEMATECH has contributed to its emulation, notably in foreign programs to support national or regional semiconductor industries and among other U.S. industries, e.g., in optoelectronics and nanotechnologies.[56] More broadly, SEMATECH helped sustain the rapid technological progress of the industry as projected by Moore's Law. This technical progress was facilitated by the collaborative research encouraged by the consortium, including the development of the Semiconductor Industry Roadmap.

For its part, the government partner achieved many of its objectives. The Department of Defense achieved its goal of maintaining a robust, technologically advanced manufacturing capability within the U.S. SEMATECH thus helped the government achieve a key objective, namely, sustaining a U.S.-based industry able to provide cutting-edge, low-cost devices to support defense requirements[57] and thereby avoiding the risk of dependency on foreign suppliers for U.S. defense systems.[58] Throughout the decade of the nineties, the Defense Department was able to acquire higher performance, lower cost components from commercial suppliers than would have been available from a dedicated defense production facility. This trend contributed to dual-use defense acquisition designed to benefit from the rapid evolution of commercially available semiconductors characterized by rapidly increasing performance and falling costs.[59]

The combination of rapid gains in semiconductor capabilities and sharply falling costs have contributed to the government's capacity to carry out many other non-defense

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[56] See Box B in the Introduction in this volume. See also National Research Council, *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative*, Washington, D.C.: National Academy Press, 2002.

[57] A healthy U.S. industry also ensured a surge capacity for the defense industrial base, should it be required.

[58] The erosion of the U.S. semiconductor industry's position was a source of growing concern to federal defense officials and was reflected in the creation of the National Advisory Commission on Semiconductors (NACS). One of the NACS' missions concerned the dependency of modern weapons systems on state-of-the-art semiconductor devices. Specifically, under the legislation creating the Commission, Congress notes in its findings that: "Modern weapons systems are highly dependent on leading edge semiconductor devices, and it is counter to the national security interest to be heavily dependent upon foreign sources for this technology." The charter further states that this Committee shall "identify new or emerging semiconductor technologies that will impact the national defense or United States competitiveness or both." For the objectives set forth for NACS, see <http://www4.law.cornell.edu/uscode/15/4632.html>.

[59] See Jacques Gansler, *Defense Conversion: Transforming the Arsenal of Democracy*, Cambridge, MA: MIT Press, 1995. See also the presentation by Paul Kaminski, then Undersecretary for Technology and Acquisition, in National Research Council, *International Friction and Cooperation in High Technology Development*, Washington, D.C.: National Academy Press, 1997, pp. 132-133. Dr. Kaminski points out that tighter linkages with commercial markets shorten cycle time for weapons systems development and reduce the cost of inserting technological improvements into DoD weapons systems. By placing greater reliance on commercial sources, DoD can field technologically superior weapons at a more affordable cost.

missions more efficiently. These contributions are reflected in the economy as a whole. Also, as noted above, the U.S. economy recorded substantial gains in productivity growth between 1995-1999 with productivity growth more than double that of the 1973-1995 period. The Council of Economic advisors attributed "these extraordinary economic gains" to three factors, namely technological innovation, organizational changes in businesses, and public policy.[60] Two of these factors concern information technology, in particular the simultaneous advances in information technologies – computers, hardware, software, and telecommunications – which combine these new technologies in ways that sharply increase their economic potential. Progress in semiconductor capabilities enabled advances in information technologies, driving innovation in each of these product areas. In short, the government and the economy as a whole have benefited from the contributions of a robust U.S. industry.[61]

As described in greater detail in the Introduction, the SEMATECH consortium's contributions to the resurgence to the U.S. industry were significant but are best understood as one element of a series of public policy initiatives that collectively provided a positive policy framework for U.S. semiconductor producers. Overall, SEMATECH's record of accomplishment was achieved in no small part through the flexibility granted its management and the sustained support provided by DARPA, the public partner, complemented by the close engagement of its members' senior management and leading researchers.

[60] Council of Economic Advisors. *Economic Report of the President*. Washington, D.C.: Government Printing Office, 2001.

[61] These broader contributions may be relevant with respect to proposals for recoupment of federal contributions to government-industry partnerships. Some analysts suggest that the best means of recoupment is, in fact, the tax system. For example, many of the companies that have thrived following SEMATECH's inception have returned the government's original investment to the consortium many times over in the form of tax revenue. See testimony by Christopher T. Hill, Vice Provost for Research and Professor of Public Policy and Technology, George Mason University, before the Subcommittee on Environment, Technology and Standards, Committee on Science, U.S. House of Representatives, 14 March 2002.

RECOMMENDATIONS

The Committee's recommendations outline a series of modest steps that nonetheless, may prove important to the long-term welfare, economic growth, and security of the United States.

Resources for University-based Semiconductor Research

To better address the technical challenges faced by the semiconductor industry and to better ensure the foundation for continued progress, more resources for university-based research are required.

The Committee believes that universities have an important role in maintaining a balance between applied science and fundamental research. This balance is key in generating ideas for future research.

The Committee suggests consideration of the development of three-way partnerships among industry, academia, and government to catalyze progress in the high-cost area of future process and design. These partnerships would:

a. **Sponsor more initiatives that encourage collaboration between universities and industry**, especially through student training programs, in order to generate research interest in solutions to impending and current industry problems.
b. **Increase funding for current programs.**[62] Research programs that are already operational, such as the Focus Center Research Program developed by the SRC could usefully be augmented through substantially increased direct government funding. These centers also represent opportunities for collaborative research with other federal research programs, such as those supported by the National Science Foundation.
c. **Create Incentives for students.** A key role for universities is to ensure the flow of technical innovation and skills that originate with students. In order to address the undersupply of talented workers and graduate students in the industry, more incentive programs should be established. Since professors typically respond to appropriate research incentives, augmented federal

[62] The president's FY 2003 budget makes important steps in this direction. It calls for a 3 percent increase, to $1.9 billion, in the *Networking and Information Technology Research and Development Program* (NITRD). This particular program could play a key role in funding the basic research that confronts the technical challenges in the semiconductor industry. The NITRD coordinates key advanced information technology research across multiple agencies to make broad advances in computing and networking. These advances manifest themselves in the development of new technologies such as computing platforms and software, which can support advances research in physics, materials science and engineering as well as biomedical and earth and spaces sciences. The 2003 budget envisions emphasizing critical areas of research such as networks security issues, high-assurance software and systems; micro- and embedded sensor technologies; revolutionary architectures to reduce cost, size, and power requirements of high end computing. The budget emphasizes research on the social and economic impacts of developments in the fields of information technology. For the text on the president's proposed initiatives, see *Fiscal Year 2003, Analytical Perspectives,* Budget of the United States Government, Washington, D.C.: U.S. Government Printing Office. 2002. p. 164.

support for programs that encourage research in semiconductors would attract professors and graduate students.[63] In addition, specific incentive programs could be established to attract and retain talented graduate students.

[63]See Paula Stephan and Grant Black, "Bioinformatics: Emerging Opportunities and Emerging Gaps," in National Research Council, *Capitalizing on New Needs and New Opportunities: Government-Industry Partnerships in Biotechnology and Information Technologies, op. cit.*, p. 244.