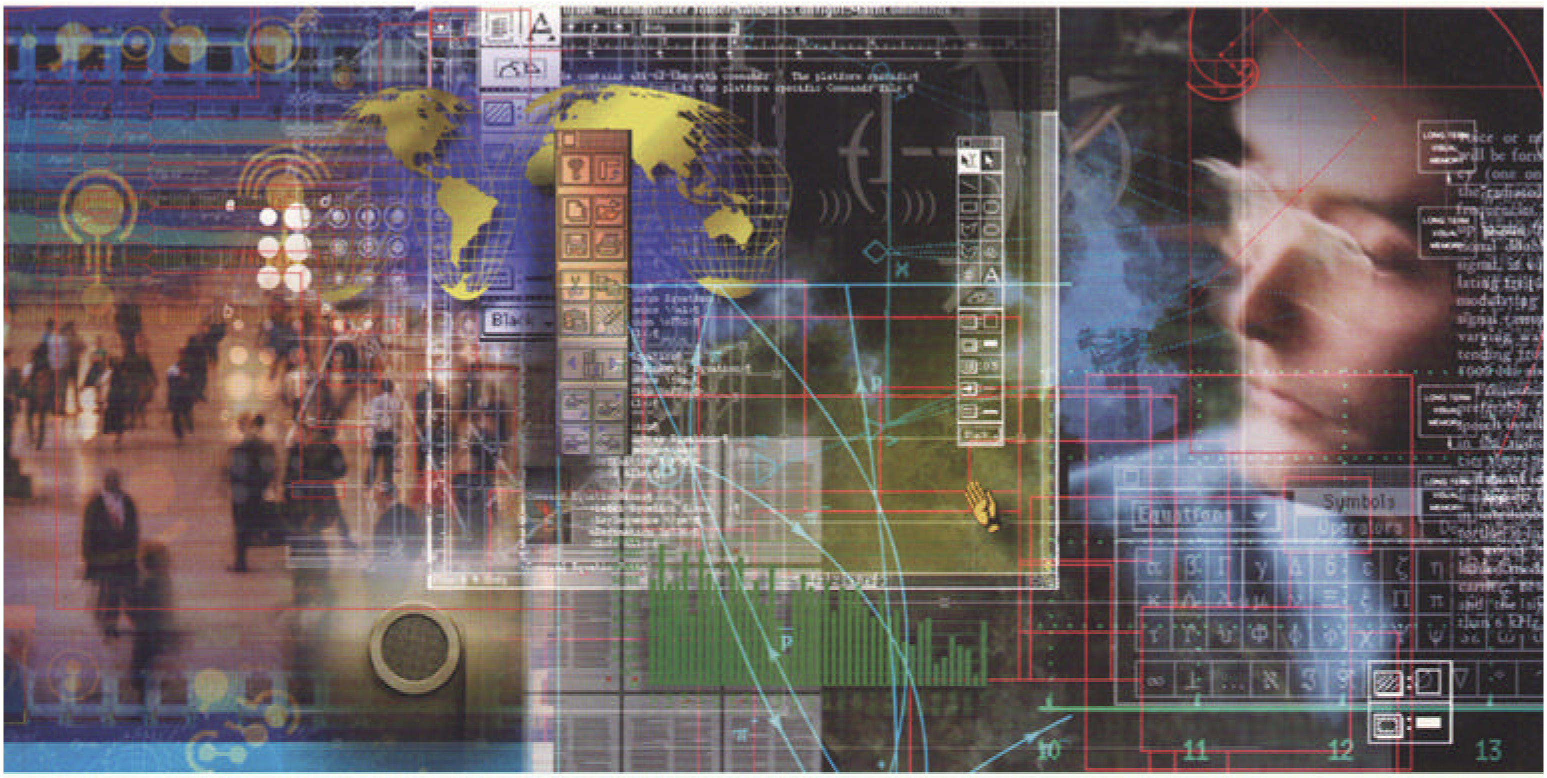
AMERICA’S SEMICONDUCTOR INDUSTRY:

TURBOCHARGING THE U.S. ECONOMY



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Preface

Try to imagine what your life would be like without semiconductors. If you are a member of the baby boom generation, the “transistor” radio you put under your pillow at night to fall asleep listening to a baseball game or the latest pop song was probably the first time you benefited from semiconductor technology. Little did you know that the semiconductor in that little radio would transform our world within your lifetime.

Take a minute to consider your surroundings. Are you holding a “hard” copy of this report? If so, it was either printed in an electronic printing process or copied by a machine using sophisticated electronics to identify and mix shades of gray or tones of different colors. Maybe you are reading this as it appears on the monitor of a computer. What other things do you see? A touch-tone telephone? A cellular phone? Is there a pocket calculator on the table or on your desk? Do you have a digital diary in your pocket? What about the environment of the room you are in? Is its temperature controlled by an electronic thermostat? If you are in a public place, look to the ceiling. Do you see a sprinkler system? Is it triggered by a smoke-sensing electronic device? What other electronics do you see? A television, a stereo, a radio? This morning were you awakened by a digital stereo clock radio? Was your coffee made by an automatic coffee maker? What’s just outside? Your car? Does it have electronic fuel injection? How fuel efficient is it compared to the autos of a generation ago? Does your car offer you and your family the protection of air bags that inflate instantaneously when they “sense” a collision?

Now consider what your life would be like without any of these things and you would still not have a full appreciation of the impact of the semiconductor on your life, our economy, and the future. All these things and more were made possible by the semiconductor, a miniscule item made of material like sand that carries one millionth of the electrical current carried by a copper wire, but can switch the current on and off, and by doing so, communicate. Copper built the past and cities like Butte, Montana. Semiconductors are building the future and worlds of knowledge.

1. Introduction

> *"The microchip has become ¾ like the steam engine, electricity and the assembly line ¾ an advance that propels a new economy."*
>
> *TIME*, Man of the Year: Intel's Andrew Grove: His Microchips Have Changed the World—and Its Economy. December 29, 1997/January 5, 1998, p. *50*

This report presents a study of the semiconductor industry—the industry that manufactures the microchip. It focuses on three aspects of the industry: its contribution to the U.S. economy, its impact on the economy, and the benefits of its unsurpassed technological progress.

The conventional contribution of any industry to the U.S. economy is measured by the value it adds to the raw materials, partly finished products, and services it purchases from other industries. This "value added" is estimated by subtracting the industry's purchases of these intermediate products and services from its sales receipts.

Economic impacts are measured by the employment, wages, and tax revenues generated throughout the U.S. economy as a result of the demand for an industry's products or services. In this study, we estimated the economic impacts of the demand for semiconductors. A direct effect is found in the semiconductor industry itself. But an indirect effect is found initially in the industries that sell products, services, and plant and equipment to the semiconductor industry, and eventually in all other industries as they sell to and buy from each other. As a result, the demand for semiconductors generates employment, wage, and tax revenue impacts that far exceed the semiconductor industry's employment, wages, and taxes.

But these measures are an incomplete accounting of the key role played in the U.S. and world economies by the semiconductor industry. The unsurpassed technological progress in semiconductor manufacturing has brought us more powerful semiconductors at lower prices. As a result, the semiconductor has become the catalyst of more efficient production processes; a burgeoning high-tech industry; new, better, and less costly consumer products and services; and a growing economy with low inflation.

This study was commissioned by the Semiconductor Industry Association (SIA) to reveal the important contributions of the semiconductor to the U.S. economy. The SIA represents U.S.-based semiconductor manufacturers and seeks to maintain American leadership in market share and technology. Today the SIA focuses on solving problems of unfair trade practices in world markets and fostering a U.S. economic climate conducive to the highly competitive and capital intensive semiconductor industry. The SIA presents a comprehensive review of global and U.S. semiconductor trends since 1978 in its *Annual Databook*.[1]

The study was conducted by the Family, Industry, and Community Economics (FICE) group of Nathan Associates Inc. Nathan Associates provides analysis of the impacts of industries and economic development projects worldwide. Its FICE group focuses on U.S. industries and public policy. The FICE group recently completed a study of the economic impact of the U.S. software industry[2] and is currently studying the impacts and benefits of dispersed channels of software distribution.

The transistor—the basic building block of the semiconductor—is 51 years old. Invented at Bell Labs in 1947, it was a *wunderkind*. Made of germanium, a weak or "semi" conductor of electricity, it was able to amplify electric current and communicate by turning the current on and off.[3] Although its alphabet was limited to a zero when the current is on and a one when the current is off, "words" are spelled by a sequence of transistors. Four transistors form a 4-character "word." In a binary number system, the various combinations of zeroes and ones in a sequence of four transistors can communicate the decimal integers 0 through 15, or 16 different values.[4] An 8-bit sequence can communicate the decimal integers 0 through 255. Binary words can be transformed into decimal values and, by following a few simple conventions, each value can be associated with a different symbol of any language to form a complete system of communication.

Ten years later, the integrated circuit was born and electrical engineers arranged transistors, resistors, and other electrical components on a single polished thumbnail-sized slice of sand creating the microchip. Every 18 months the number of transistors squeezed onto a microchip doubled until today the most powerful microprocessor contains four million transistors.[5]

Today the transistor and the microchip on which it resides are ubiquitous. More than four quadrillion transistors are manufactured each month.[6] In a year, manufactured transistors outnumber the raindrops falling on California.[7] They are found on microchips that control the appliances we use daily in our homes. They are on chips in our automobiles. They are in our televisions and telephones. They are found in the medical technology that lengthens and improves the quality of our lives. And they power our computers.

The effects of the semiconductor industry have been profound. Recent studies document the significant economic contribution and impacts of the software[8] and high-technology[9] industries, but the transistor and technological progress in semiconductor manufacturing fueled the digital revolution, gave birth to the software industry, and put the "high" in high technology.

This report demonstrates the numerous ways in which the semiconductor industry has propelled and will continue to propel the U.S. economy into the digital era.

- The demand for semiconductors has created a manufacturing industry that, among all manufacturers, is the leading contributor to the gross domestic product of the U.S. economy.

- Since 1991, the semiconductor industry has accounted for nearly eight percent of U.S. economic growth in the manufacturing division of the economy.

- The semiconductor industry's demand for intermediate product; new plant, machinery, and equipment; and skilled labor generated employment throughout the economy for 1.5 million people in 1996 who earned wages totaling $49.6 billion. Tax revenues collected on the business and personal incomes generated directly and indirectly by the demand for semiconductors totaled more than $17.8 billion in 1996.

- Industry investments in research and development have produced astounding advances in technology. Every six to seven years since 1970, microprocessor advances result in a 90 percent reduction in the price of one million instructions per second of performance. The value of the benefit of such progress can be estimated in terms of dollars that consumers were willing to pay for semiconductors but did not have to pay because of falling prices. Economist Kenneth Flamm estimates that in 1995, the value of a year's price decline was worth $12 billion to consumers. Twenty years of price declines generated a cumulative benefit worth $340 billion in 1995 or five percent of the entire value of goods and services produced in the U.S. economy in 1995.

These and other more detailed findings are presented and discussed in this report. Following the introduction, Chapter 2 presents a history of the semiconductor industry's performance and contribution to the U.S. economy, as well as a discussion of the outlook for the industry through 2002. Chapter 3 presents and discusses estimates of the employment, wage, and tax revenue impacts generated in the U.S. economy as a result of the demand for semiconductors. In Chapter 4, we present estimates of the economic benefit of technological progress in semiconductor manufacturing and put the conventional measures of industry contribution and impact into a context that reveals the increasingly important role played by the semiconductor in our lives.

2. Contribution and Performance

This chapter analyzes the conventional measures of contribution and performance of the semiconductor industry between 1987 and 1996, the most recent year for which data are available, and presents a forecast of the industry's contribution to the U.S. economy through 2002.[10] The contribution of the industry is measured by the value it adds to the raw materials, partly finished products, and services it purchases from other industries. Performance measures analyzed include the industry's value of product shipments, employment and wages, spending on new plant and equipment, and research and development (R&D) spending.

Industry trends are identified and compared initially with other manufacturing industries, and later with selected service industries and manufacturing industry groups.[11] Historical data for the semiconductor industry and other industries are presented in Appendix A.

Now more than 50 years old, the semiconductor industry has had a phenomenal run and does not appear to be slowing down.

- In 1995, the semiconductor manufacturing industry became the leading contributor among all manufacturing industries to the gross domestic product (GDP) of the U.S. economy.

- The industry's contribution to the economy is growing nearly three times faster than the economy itself. By 2002, the industry's share of the U.S. economy will likely double.

- Technological progress in semiconductor manufacturing has provided unprecedented improvements in product performance and price, and resulted in rapidly growing demand for semiconductors. The value of industry shipments grew 15.4 percent per year between 1987 and 1996, 3.4 times faster than the growth rate of shipments of all other manufacturing industries.

2.1 CURRENT TRENDS

> *"The U.S. now enjoys what in many respects is the healthiest economy in its history, and probably that of any nation ever. ¼ Driving all this is the microchip."*
>
> *TIME,* Man of the Year: Intel's Andrew Grove: His Microchips Have Changed the World—and Its Economy. December 29, 1997/January 5, 1998, pp. 50-51

2.1.1 Industry Value Added¾ the Contribution to GDP

The production of semiconductors requires raw materials, partly finished products, and services of other industries. Examples include silicon, gold and other precious metals, doped chemicals and other doped materials for electronic use, fabricated metal products, electric service from utilities, and wholesale trade service, among others. Because these materials and services are produced or provided by other industries, they are not part of the semiconductor industry's contribution to the economy.

The semiconductor industry's contribution to the U.S. economy is measured by the value it adds to the intermediate products and services it purchases from other industries. This value added is nothing more than the semiconductor industry's receipts from sales of its products (value of industry shipments) less the industry's expenditure on intermediate products and services.

2.1.1.1 Semiconductor Industry Is Leading Manufacturer

The transformation of the U.S. economy into the digital era can be seen in value added statistics.[12] In 1987, the top five manufacturing contributors to the U.S. economy were motor vehicles and passenger car bodies manufacturers, motor vehicle parts and accessories manufacturers, search and navigation equipment manufacturers, newspaper publishing and printing, and pharmaceutical preparations manufacturers. Semiconductor manufacturers ranked 17th (see Table 1).

By 1995, semiconductor manufacturers had risen to be number one among all manufacturing industries (see Figure 1) and number six among all industries in the manufacturing and service divisions of the U.S. economy (see Appendix A, Table A-1). Value added of the semiconductor manu-

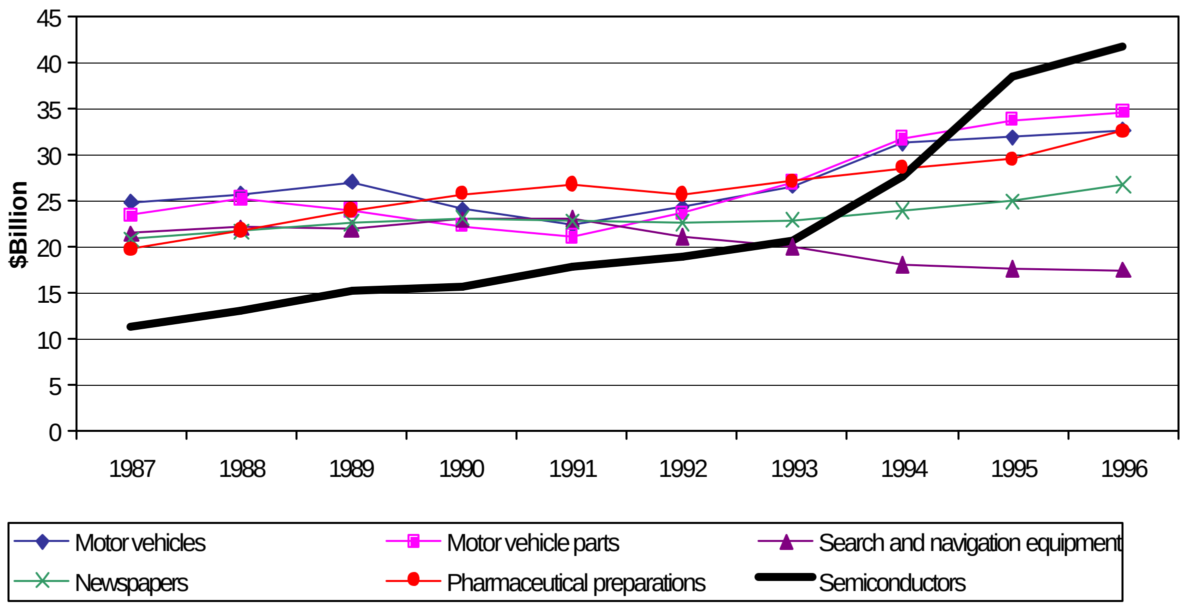
Table 1. Top 50 Manufacturing Industries Ranked by Value Added to the U.S. Economy, 1987 and 1996 ($million)

1987			1996		
Rank	Industry	Value added	Rank	Industry	Value added
1	Motor vehicles and car bodies	24,806	**1**	**Semiconductors and related devices**	**41,647**
2	Motor vehicles parts and accessories	23,438	2	Motor vehicles parts and accessories	34,677
3	Search and navigation equipment	21,485	3	Motor vehicles and car bodies	32,779
4	Newspapers	20,796	4	Pharmaceutical preparations	32,569
5	Pharmaceutical preparations	19,759	5	Newspapers	26,765
6	Petroleum refining	18,892	6	Commercial printing, lithographic	24,864
7	Industrial organic chemicals, nec	18,760	7	Plastics products, nec	24,595
8	Aircraft	15,577	8	Industrial organic chemicals, nec	22,239
9	Commercial printing, lithographic	15,463	9	Cigarettes	19,884
10	Electronic computers	14,985	10	Industrial machinery, nec	18,985
11	Plastics products, nec	14,452	11	Petroleum refining	18,888
12	Guided missiles and space vehicles	13,369	12	Radio and TV communications equipment	18,884
13	Cigarettes	12,086	13	Search and navigation equipment	17,526
14	Blast furnaces and steel mills	12,037	14	Electronic computers	16,916
15	Aircraft parts and equipment, nec	11,621	15	Blast furnaces and steel mills	16,125
16	Paper mills	11,395	16	Aircraft	15,714
17	**Semiconductors and related devices**	**11,227**	17	Telephone and telegraph apparatus	14,908
18	Bread, cake, and other related products	11,057	18	Paper mills	14,797
19	Photographic equipment and supplies	10,916	19	Electronic components, nec	13,965
20	Aircraft engines and engine parts	9,827	20	Photographic equipment and supplies	13,146
21	Toilet preparations	9,004	21	Periodicals	12,890
22	Telephone and telegraph apparatus	8,719	22	Bread, cake, and other related products	11,974
23	Industrial machinery, nec	8,484	23	Plastics materials and resins	11,766
24	Electronic components, nec	8,430	24	Aircraft parts and equipment, nec	11,272
25	Plastics materials and resins	8,310	25	Refrigeration and heating equipment	10,933
26	Radio and TV communications equipment	8,257	26	Book publishing	10,846
27	Periodicals	7,924	27	Toilet preparations	10,786
28	Refrigeration and heating equipment	7,511	28	Malt beverages	10,154
29	Bottled and canned soft drinks	7,374	29	Surgical and medical instruments	10,050
30	Book publishing	6,882	30	Special industry machinery, nec	9,513
31	Malt beverages	6,528	31	Surgical appliances and supplies	9,307
32	Sawmills and planing mills, general	6,230	32	Automotive stampings	8,801
33	Sanitary paper products	6,025	33	Aircraft engines and engine parts	8,766
34	Automotive stampings	5,974	34	Sanitary paper products	8,649
35	Industrial inorganic chemicals, nec	5,875	35	Construction machinery	8,593
36	Paints and allied products	5,857	36	Corrugated and solid fiber boxes	8,437
37	Construction machinery	5,629	37	Guided missiles and space vehicles	8,397
38	Corrugated and solid fiber boxes	5,559	38	Special dies, tools, jigs and fixtures	8,360
39	Computer peripheral equipment, nec	5,550	39	Miscellaneous publishing	8,171
40	Paperboard mills	5,410	40	Sawmills and planing mills, general	8,112
41	Soap and other detergents	5,299	41	Paperboard mills	8,044
42	Ready-mix concrete	5,177	42	Bottled and canned soft drinks	7,961
43	Ship building and repairing	5,134	43	Paints and allied products	7,765
44	Miscellaneous publishing	5,009	44	Poultry slaughtering and processing	7,746
45	Special dies, tools, jigs and fixtures	4,985	45	Soap and other detergents	7,240
46	Canned fruits and vegetables	4,851	46	Farm machinery and equipment	6,970
47	Tires and inner tubes	4,771	47	Instruments to measure electricity	6,928
48	Sausages and other prepared meats	4,712	48	Metal cans	6,710
49	Internal combustion engines, nec	4,672	49	Sheet metalwork	6,486
50	Fluid milk	4,625	50	Tires and inner tubes	6,400

Source: Nathan Associates Inc. from 1987 and 1992 BEA benchmark input-output accounts of the U.S. economy, 1987 and 1992 Census of Manufactures, and 1987 and 1995 Annual Survey of Manufactures.

facturing industry grew 15.7 percent per year between 1987 and 1996—nearly three times faster than the U.S. economy grew during the period and more than four times faster than growth in value added by all manufacturers excluding semiconductors. In 1996, value added to the economy by the semiconductor industry was 41.6 billion, 20 percent more than the next largest manufacturing industry (motor vehicle parts and accessories manufacturers).

Figure 1. Semiconductor Contribution to Economy Leads All Manufacturers

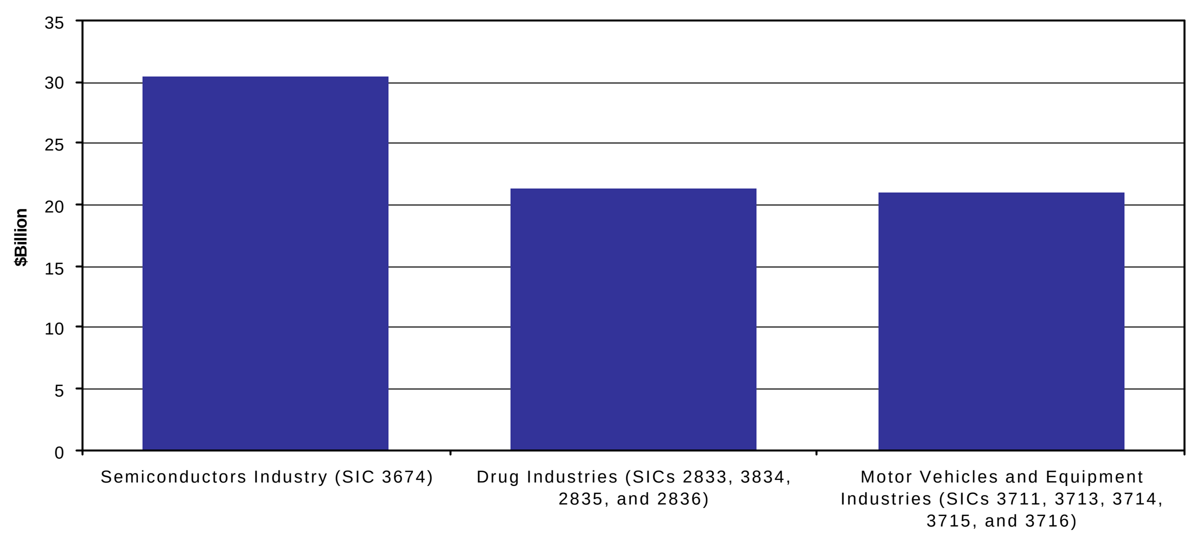


Note: In 1987 there were 11 other manufacturing industries not shown on this figure whose contribution to the U.S. economy exceeded the contribution of the semiconductor industry.
Source: Table 1.

2.1.1.2 Contribution to Economic Growth Exceeded Drug Industry Group and Motor Vehicles and Parts Industry Group

Between 1987 and 1996, the semiconductor industry's combined characteristics of size and growth resulted in a cumulative value added by the industry that was 50 percent greater than the cumulative value added by the industry *groups* to which the next largest manufacturing industries belong (see Figure 2).[13] Cumulative value added by the semiconductor industry was $30.4 billion. Cumulative value added by the group of industries that manufacture all motor vehicles and equipment (including car, truck, and bus bodies, parts and accessories, truck trailers, and motor homes) totaled only $20.9 billion. Cumulative value added by the group of industries that manufacture all types of drugs (including pharmaceutical preparations, medicinals and botanicals, diagnostic substances, and other biological products) totaled only $21.3 billion.

Figure 2. Semiconductor Industry Contributed More to Economic Growth than Groups of Other Leading Manufactures, 1987-1996



Source: Nathan Associates Inc.

2.1.1.3 Semiconductor Industry Accounted for 7.6 Percent of Total Manufacturers' Contribution to U.S. Economic Growth Since 1991

Between 1991 and 1996, semiconductor industry growth contributed an additional $19.5 billion to the U.S. economy—7.6 percent of the manufacturing division's total contribution to U.S. economic growth. More important, semiconductors are the building blocks of high-technology products. Growth in the semiconductor industry and other high-tech manufacturing industries accounted for nearly 20 percent of all growth in the contribution of the manufacturing division to the economy. These gains were a direct result of technological progress achieved by the semiconductor industry.

2.1.2 Other Performance Measures

2.1.2.1 Semiconductor Shipments Are Growing Three Times Faster Than All Other Shipments

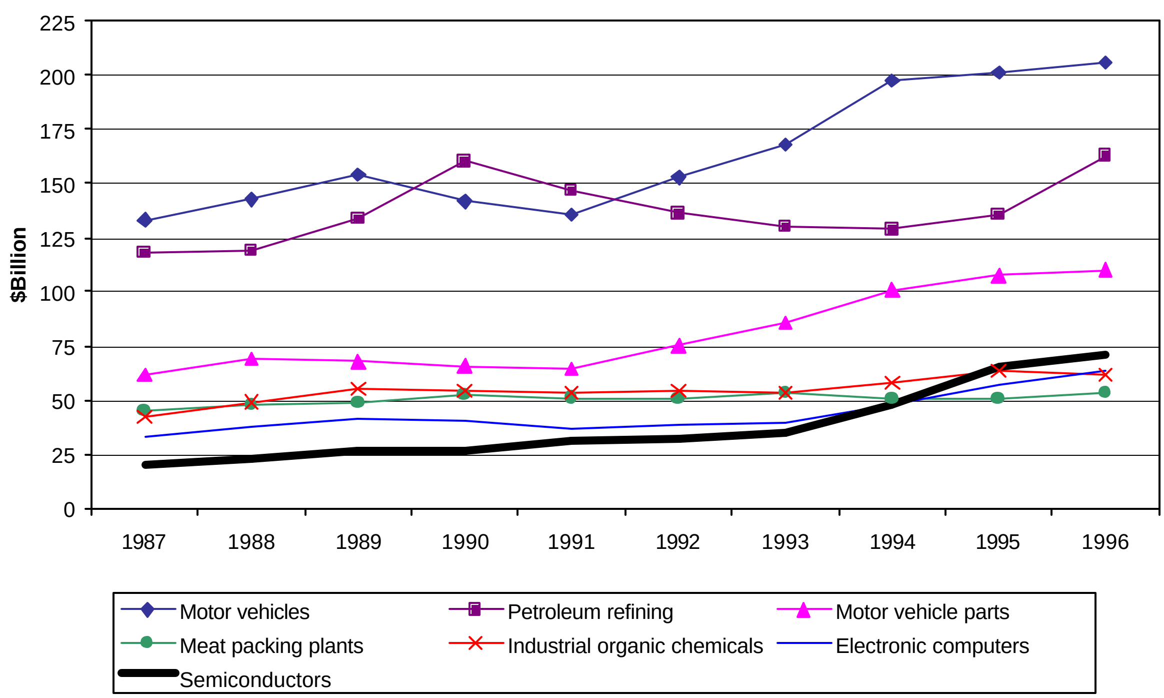
Underlying all economic activity is demand. Demand stimulates production. To help to understand the benefit of any industry, we usually consider what consumers are willing to pay and, indeed, paid for the industry's products. Hence, an important industry performance measure is industry receipts from the sale of its products, or the industry's value of product shipments.

Since 1987, the demand for semiconductors has generated growth in the value of semiconductor industry shipments of 15.2 percent per year. Only two other manufacturing industries had higher growth rates over the same time, but each was only approximately one-tenth the size of the semiconductor industry in 1987.[14] In contrast to the high growth rate of semiconductor industry shipments, the value of shipments of all manufacturers in the U.S. economy, excluding semiconductors, grew only 4.5 percent per year.

Between 1987 and 1996, the semiconductor industry's value of shipments climbed from 20th to fourth among all manufacturing industries (see Figure 3). In 1996, semiconductor industry shipments totaled $70.9 billion. The top three manufacturers were motor vehicle and passenger car body manufacturers ($206.2 billion), petroleum refineries ($162.9 billion), and motor vehicle parts and accessories manufacturers ($110.1 billion). Manufacturers of electronic computers ranked fifth in 1996 with shipment value of $64.0 billion.

The value of industry shipments should not be confused with the economic contribution of an industry. Shipment value exaggerates the contribution to the economy of any particular industry, but especially for those industries whose production processes use large amounts of intermediate products and services of other industries. Consider auto manufacturers. In 1996, their shipment value was more than double the value of semiconductor industry shipments. But the value added to the U.S. economy by the semiconductor industry was 27 percent greater than the value added by auto

Figure 3. Semiconductor Shipments Rose from 20th to 4th



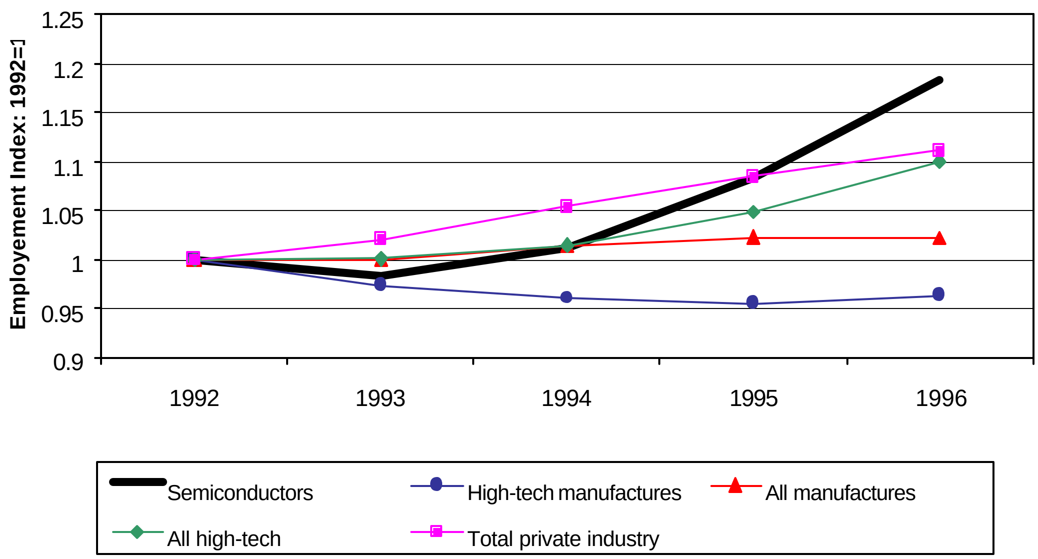
Note: in 1987, there were 13 other manufacturing industries not shown on this figure whose shipments exceeded the value of the semiconductor industry's shipments.
Source: Nathan Associates Inc. from Annual Survey of Manufacturers.

manufacturers. How can this be so? Because shipment value includes the cost of intermediate products purchased from other industries—it double counts the value added of other industries.

2.1.2.2 Employment and Wages Lead High-Tech Industry

Since the 1991 recession, industry employment has grown 4.3 percent per year, 8.6 times faster than all manufacturing employment excluding the semiconductor industry (see Figure 4).[15] The net gain between 1992 and 1996 totaled 39,800 jobs. Texas, Oregon, Arizona, and California lead the way in industry employment gains during the period (see Table 2).

Figure 4. Semiconductor Employment Growth Leads High-Tech



Source: Nathan Associates Inc. from data in Appendix A, Table A-3.

Table 2. Semiconductor Industry Employment by State, 1992 and 1996

State	1992	1996	Increase or (decrease)	Average annual growth (%)
Alabama	55	-	(55)	na
Arizona	27,328	34,458	7,130	6.0
California	56,281	62,878	6,597	2.8
Colorado	2,882	5,081	2,199	15.2
Connecticut	447	480	33	1.8
Florida	11,946	9,610	(2,336)	(5.3)
Georgia	143	92	(51)	(10.4)
Illinois	664	357	(307)	(14.4)
Indiana	561	571	10	0.4
Iowa	12	22	10	16.4
Kansas	66	45	(21)	(9.1)
Maine	2,126	2,250	124	1.4
Massachusetts	11,332	11,500	168	0.4
Michigan	277	216	(61)	(6.0)
Minnesota	1,421	2,496	1,075	15.1
Mississippi	151	254	103	13.9
Montana	43	25	(18)	(12.7)
New Hampshire	978	1,869	891	17.6
New Jersey	1,893	2,532	639	7.5
New Mexico	3,218	6,779	3,561	20.5
New York	14,447	9,469	(4,978)	(10.0)
North Carolina	788	1,607	819	19.5
Ohio	1,751	1,993	242	3.3
Oregon	10,231	19,947	9,716	18.2
Pennsylvania	7,694	7,556	(138)	(0.5)
Rhode Island	798	1,221	423	11.2
South Dakota	-	426	426	na
Texas	36,176	46,514	10,338	6.5
Virginia	3,619	3,483	(136)	(1.0)
Washington	1,958	2,590	632	7.2
Wisconsin	212	237	25	2.8
Other States (a)	17,773	20,509	2,736	3.6
Total reported by state	217,271	257,067	39,796	4.3

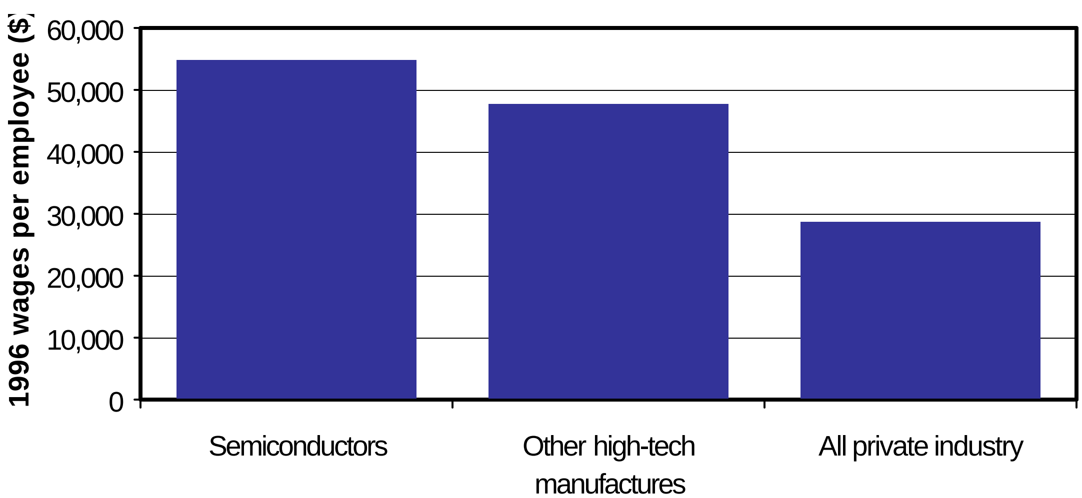
(a) Total of all states whose individual state employment is not disclosed by BLS for confidentiality reasons.

Source: Bureau of Labor Statistics, *Employment and Wages Annual Averages,* U.S. Department of Labor.

Output per worker in the semiconductor industry is high. In 1996 the industry employed 257,100 people. Industry shipments per employee were $275,900. The software industry, on the other hand, generated $166,000 in receipts per employee.[16]

The wafer fabrication process, which occurs primarily in the United States,[17] requires a highly skilled workforce, and, as a result, industry salaries and wages are high (see Figures 5 and 6) and growing. In 1996, the industry paid total wages of $14.1 billion, or $54,900 per industry employee. The industry's average annual wage was nearly twice the average of all private industry ($28,600) and 15 percent more than the average among all other high-tech manufacturing industries ($47,800).[18] Semiconductor production workers earned $36,600 per year, compared with an average of $28,100 earned by all other production workers. And since 1991, total semiconductor industry wages have grown 10 percent per year, while total private industry wages have grown only 5.6 percent per year.

Figure 5. Semiconductor Industry Pays Higher Wages



Source: Nathan Associates Inc. from data in Appendix A, Tables A-3 and A-4.

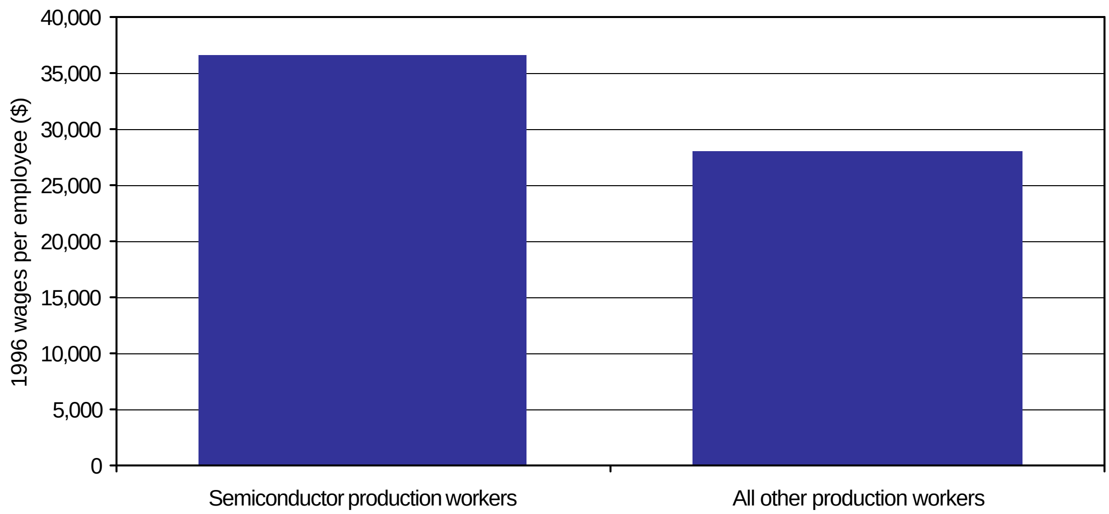


Figure 6. Semiconductor Production Workers Earn Higher Wages

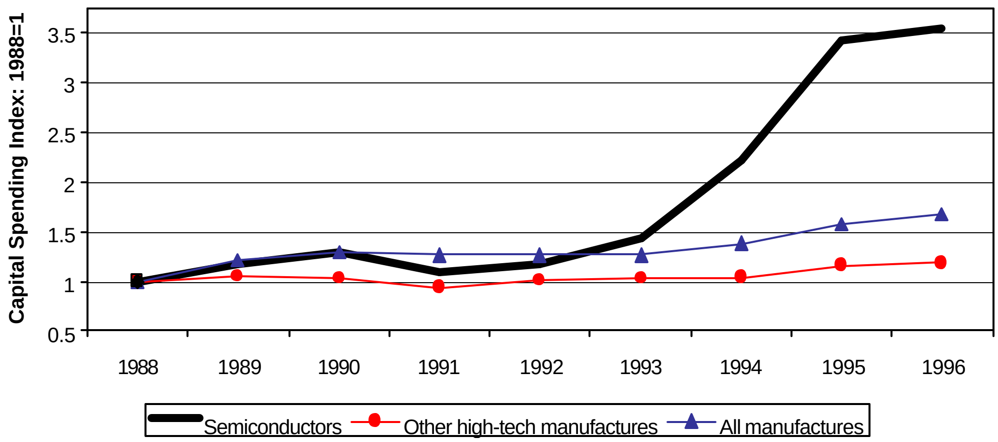
Source: Nathan Associates Inc. from data presented in the Annual Survey of Manufacturers.

2.1.2.3 New Capital Spending by the Semiconductor Industry in the United States in 1996 Nearly Equaled New Capital Spending by All Other High-Tech Manufacturers Combined

The semiconductor industry spends significant sums on new facilities and durable equipment in the United States. The cost of a fabrication plant doubles every three years.[19] In 1995, the cost was $1 billion. In 1997, a typical wafer fabrication plant, like the one jointly owned by IBM Corp and Toshiba Corp in Manassas, Virginia, came on-line at a cost of $1.7 billion.[20] An Intel facility in Hillsboro, Oregon totaled $2.2 billion, and LSI Logic’s Gresham Campus will require a $4 billion investment.

Between 1988 and 1996, the semiconductor industry’s annual expenditures on new capital at establishments in the United States grew 17.2 percent per year, 2.6 times faster than the rate at all manufacturing establishments in the United States and 8.2 times faster than the rate at all high-tech manufacturing establishments in the United States (see Figure 7). In 1996, the semiconductor industry spent $9.5 billion on new plants and equipment in the United States, an amount that nearly equaled the total spending by all other high-tech manufacturers ($9.8 billion in 1995, the most recent year for which data are available).

Figure 7. Growth in Semiconductor Industry New Capital Spending



Source: Nathan Associates Inc. from data in Appendix A, Table A-6.

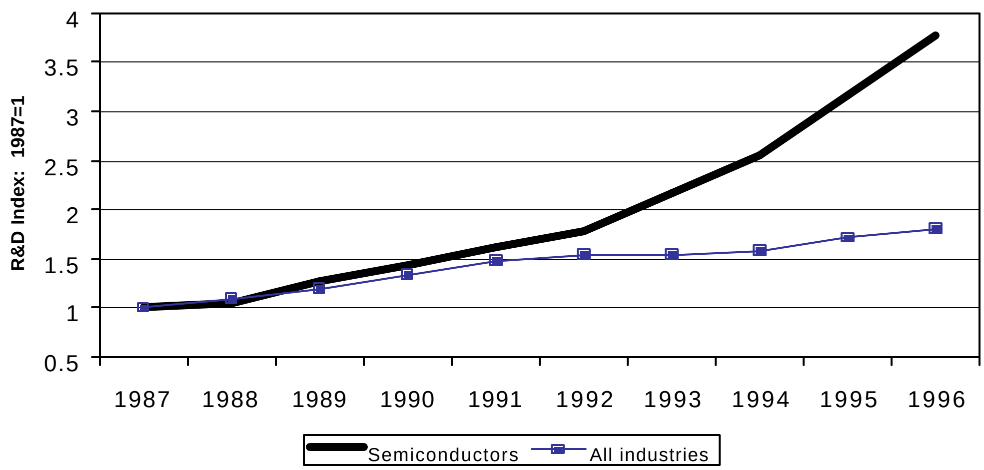
2.1.2.4 Semiconductor Industry Accounts for Five Percent of Growth in All Industry-Funded R&D Since 1987

The technological progress that has occurred in semiconductor manufacturing and all high-tech industries would not have occurred without R&D spending by the semiconductor industry. Since 1987, the industry has devoted 11.5 percent of its sales revenue to R&D. In 1996, semiconductor industry R&D spending totaled nearly $7 billion.[21]

Growth in R&D spending by the semiconductor industry has been 2.3 times faster than all industry-funded spending on R&D since 1987 (see Figure 8). Averaging 15.9 percent annual growth, the semiconductor industry accounted for five percent of growth in all industry-funded R&D spending between 1987 and 1996.[22]

When semiconductor industry R&D is combined with all high-tech industry-funded R&D, the total accounts for approximately 37 percent of all industry-funded R&D spending. In 1996, the total reached approximately $42 billion, or nearly $500 per employee in the nonagricultural private sector of the U.S. economy.

Figure 8. Semiconductor Industry R&D Growing More Than Twice as Fast as All Industry-Funded R&D



Source: Nathan Associates Inc. from U.S. National Science Foundation data as reported in the 1995 and 1997 Statistical Abstracts of the United States, Bureau of the Census, U.S. Department of Commerce.

Regardless of the measure we choose to consider, the contribution and performance of the semiconductor industry during the past decade have been phenomenal. The industry's contribution to the U.S. economy grew 15.7 percent per year, 2.9 times faster than the economy grew. Shipment value grew 15.2 percent per year, 3.4 times faster than growth in shipment value of all other manufacturing industries. Industry employment since the last recession has grown 4.3 percent per year, more than eight times faster than growth in all manufacturing employment. Industry wages grew 10 percent annually, 1.8 times faster than growth in total private sector wages. Annual spending on new plant and equipment by the semiconductor manufacturing industry grew 2.6 times faster than annual spending by all manufacturers and 8.2 times faster than high-tech manufacturers. And semiconductor R&D spending has grown 2.3 times faster than all industry-funded R&D.

2.2 INDUSTRY OUTLOOK

> *"At every stage in the semiconductor's explosive improvement, experts have said the party would soon end. Well, everything ends¾but this little revolution still has a long way to go."*
>
> *Forbes,* Faster, cheaper, better—forever. July 7, 1997, p. 172

In the wake of such progress, it seems only reasonable to ask whether the pace can be maintained. It is not a novel area of inquiry. In fact it has been a continuing question of interest to one of Intel's founders, Gordon Moore.

In 1965, Moore was asked to prepare a commentary for the 35th anniversary issue of *Electronics Magazine.* Asked to predict the future of the semiconductor industry over the following 10 years, he presented the initial version of what has come to be known as "Moore's Law."

Initially, Moore's Law predicted that there would be a thousand-fold increase in the number of transistors placed on a microchip between 1965 and 1975. In 1965, only 64 transistors could be squeezed onto a chip. Hence, Moore was predicting that by 1975, the cheapest chip component would be one of 64,000 in a complex integrated circuit. In other words, the number of transistors that could be put onto a microchip was predicted initially by Moore to double every year.

In 1975, Moore reviewed the progress of the industry and revised his initial prediction. Looking more closely at the sources of innovation in chip manufacturing, he predicted that the number of transistors squeezed onto a chip would double every two years. Today, chip performance and power doubles every 18 months at no additional cost to consumers.

Recognizing that Moore's Law is not a law of nature, an SIA collaborative effort involving more than 300 scientists from industry, academia, and the government, recently produced a roadmap for semiconductor technology growth through 2012.[23] The most powerful microprocessors today run at speeds of 750 megahertz and contain four million transistors. According to the roadmap, with continuing support for industry, university, and government research, the most powerful microprocessor chips in 2003 will run at a speed of 1,500 megahertz and contain 18 million transistors. The capacity of the most powerful memory chip (DRAM) will grow from 256 megabits to four gigabits.

Economics—not science—will challenge the industry's ability to achieve Moore's prediction. As noted by the SIA, increasingly large investments in new capital and R&D will be required. The cost of a state-of-the-art wafer fabrication factory is now doubling approximately every three years. By 2005, the cost of a new plant could exceed $10 billion. Whether the industry's revenues can continue rising at rates that will justify these investments remains to be seen.

Regardless of whether the industry keeps pace with Moore's Law indefinitely, it will likely continue growing at its trend rate at least over the next five years. The contribution of the industry to the U.S. economy will grow 15.7 percent per year. By 2002, industry value added will total $99.8 billion – or double the $41.6 billion in 1996.

Assuming GDP continues growing 5.5 percent per year (its average annual growth rate between 1987 and 1996), the semiconductor industry will account for two percent of all growth in the economy through 2002. The semiconductor industry's share of the U.S. economy will nearly double, from 0.5 percent in 1987 to nearly 1 percent in 2002.

To continue along its trend growth path, semiconductor manufacturers will require skilled workers. However, the industry anticipates that five years from now there will be a shortage of 40,000 skilled workers. To staff the manufacturing plants that are expected to come on-line in the United States during the next five years, the industry will need additional qualified technicians and skilled operators, jobs that require a minimum of two years of technical training and offer starting salaries today of $30,000. To ensure these workers are available, the semiconductor manufacturing industry and the materials and service suppliers to the industry have joined together in a national workforce development campaign. In partnership with community colleges across the country, the industry is investing in the human capital it will require to continue along its historical growth path.

3. Economic Impacts of the Demand for Semiconductors

> *"[E]ach industry employs the outputs of other industries as its raw materials. Its output, in turn, is often used by other producers as a productive factor, sometimes by those very industries from which it obtained its ingredients. Steel is used to make railroad cars and railroad cars are, in turn, used to transport steel and the coal and pig iron which are used in its manufacture."*
>
> Economic Theory and Operations Analysis, by William Baumol, 1977, p. 538

To appreciate fully the role of any industry in an economy, we must look beyond the industry itself to examine the ways in which it is linked to other industries. In this chapter we analyze the linkages or relationships between the semiconductor manufacturing industry and other U.S. industries, and we present estimates of the indirect effects on other industries generated by the demand for semiconductors. The most obvious indirect effect of the demand for semiconductors is found in the industries that produce or provide the materials, services, buildings, machinery, and equipment demanded and used by the semiconductor industry. But additional indirect effects are found throughout the U.S. economy as industries buy the products and services they require from other industries and sell the products and services they provide to other industries.

By looking beyond the semiconductor industry, we find that the total impact of the demand for semiconductors includes direct and indirect effects. The direct effect is found in the semiconductor industry itself—its employment and wages, and taxes paid by the industry and its employees. The indirect effect is found in all other industries, beginning with those that supply materials and services to semiconductor manufacturers, and ending with industries supplying other industries, none of which is directly supplying semiconductor manufacturers.

In 1996, the total impact of the demand for semiconductors and related devices included employment for 1.5 million people, $49.6 billion in household earnings from employment, and income tax revenues of $17.8 billion (see Table 3). The assumptions, data, and methods used to estimate these impacts are discussed in the remainder of this section. Appendix B contains data necessary to replicate the estimates of employment and wage impacts. Data and methods necessary to replicate estimates of tax revenues are either referenced in endnotes or presented in Appendix C.

Table 3. Summary of Economic Impacts of the Demand for Semiconductors, 1996 ($billion, except as noted)

Effect	Employment (thousands)	Wages	Federal Income Tax Revenue: Corporate	Federal Income Tax Revenue: Personal	State Personal Income Tax Revenue[(a)]
Direct	257.1	14.1	5.6	2.6	0.5
Indirect					
Spending on materials and services	682.5	19.3	0.7	3.5	0.7
Spending on labor	359.6	8.8	0.3	1.6	0.3
Spending on new plant & equip.	242.0	7.5	0.3	1.4	0.3
Subtotal	1,284.10	35.5	1.3	6.5	1.3
Total	1,541.20	49.6	6.9	9.1	1.8

(a) Exludes other taxes including state corporate income tax, property tax and sales tax.

3.1 DIRECT EFFECT

The demand for semiconductors and related devices stimulates semiconductor industry production, employment, and wages. In 1996, the industry employed 257,100 people and paid wages totaling $14.1 billion (see Chapter 2). Direct taxes were collected on the business incomes of industry companies and on the personal incomes of industry employees. Additional taxes were collected on industry-owned property and sales transactions. In this study, we estimated tax revenues from only three sources: the federal corporate, federal personal, and state personal income taxes. State corporate, as well as all property, sales, excise, and value-added taxes were not estimated.

In 1996, federal and state governments collected $8.7 billion in business and personal income taxes from the semiconductor manufacturing industry and its employees. The total consisted of $5.6 billion in federal corporate income tax revenue, $2.6 billion in federal personal income tax revenue, and $496.4 million in state personal income tax revenues. Underlying these estimates are the value of industry shipments, wages paid to industry employees, and estimated average tax rates.

From 10-K reports of leading semiconductor companies, the average federal corporate income tax rate was 7.9 percent of *sales* in 1996.[24] The average federal personal income tax rate in 1996 was 18.1 percent of total wages and salaries.[25] Average state personal income tax rates in 1996 varied from 2.8 percent of wages and salaries in Arizona to 6.7 percent in Oregon.[26] Florida, South Dakota, Texas, and Washington do not levy a state personal income tax. The weighted average state personal income tax rate in 1996 was 3.7 percent of wages and salaries.

3.2 INDIRECT EFFECT

Indirectly, the demand for semiconductors and related devices generated an additional 1.3 million jobs, $35.5 billion in household earnings from employment, and $9.1 billion in income tax revenues. These impacts were as a result of semiconductor industry spending on materials and services produced or provided by other industries, on labor services provided by households, and on the industry's investment spending on new plant and equipment.

3.2.1 Impact of Semiconductor Industry's Demand for Products and Services of Other Industries

In our discussion of industry value added, we introduced the notion that a manufacturing industry's value of product shipments includes the cost of materials and services produced by and purchased from other industries. Based on the 1992 benchmark input-output accounts of the U.S. economy (the most recent year for which the benchmark accounts are available), the semiconductor manufacturing industry's cost of its intermediate consumption of materials and services (excluding consumption of semiconductors) is approximately 34 percent of the industry's value of shipments. In other words, in 1996 the semiconductor manufacturing industry purchased approximately $23.8 billion worth of materials and services produced or provided by other industries. Not all of these materials, however, were produced at establishments in the United States. Some were produced offshore.

To determine the U.S. economic activity stimulated by the semiconductor industry's demand for materials and services of other industries, we need to estimate the semiconductor industry's purchases of materials produced at and services provided by establishments in the United States. Available data indicate that, overall, approximately 92 percent of total materials and services purchased by the semiconductor industry were produced at or provided by establishments in the United States. A detailed accounting of the U.S. produced share of each material or service purchased by the semiconductor industry is presented in Appendix B, Table B-3.

In 1996, the semiconductor manufacturing industry spent $22 billion on materials and services produced by establishments in the United States. Materials included such items as industrial inorganic and organic chemicals, primary nonferrous metals, plating and polishing products, and electronic components other than semiconductors and related devices. Services or non-material purchases included electric services provided by utilities and wholesale trade services, among others. Table 4 summarizes the products and services that accounted for 75 percent of the total consumed by the industry in 1996. Detailed items and spending amounts are in Appendix B, Table B-2.

Table 4. Leading Materials and Services Purchased by the Semiconductor Manufacturing Industry

Material or service		Share of total (%)
Wholesale trade services		14.6
Electroplating, plating, polishing, anodizing, and coloring services		6.4
Industrial inorganic and organic chemicals		6.3
Maintenance and repair of office, industrial, and commercial structures		6.3
Electric services from utilities		5.2
Electronic components other than semiconductors and related devices		4.9
Legal services		3.8
Advertising services		3.8
Real estate gents, managers, operators, and lessors services		3.6
Primary nonferrous metals		3.0
Computer and data processing services		2.8
Banking services		2.1
Other coating, engraving, and allied services		2.1
Miscellaneous repair shops		2.1
Industrial and commercial machinery and equipment parts		1.9
Engineering, architectural, and surveying services		1.6
Automotive repair shops and services		1.6
Telephone/telegraph communications services		1.5
Trucking and courier services, except air courier		1.3
	Subtotal	74.9
All others		25.1
	Total	100.0

Source: Appendix B, Table B-1.

The semiconductor manufacturing industry's 1996 demand for materials and services provided by other industries in the U.S. economy began a ripple effect throughout the economy that resulted in employment for 682,500 people, $19.3 billion in household earnings from employment, and $4.9 billion in income tax revenues. The industry-specific impacts of semiconductor manufacturers' spending are detailed in Appendix B, Table B-1.

The tax revenue impact consisted of $706 million in federal corporate income taxes, $3.5 billion in federal personal income taxes, and $714 million in state personal income taxes. The estimate of federal corporate income taxes was derived from a tax base estimate of $64.2 billion and an average federal corporate income tax rate of 1.1 percent of business receipts.[27] Personal income tax revenue impact estimates were derived from a tax base of $19.3 billion (the impact on household earnings from employment), an average federal rate of 18.1 percent of wages and salaries, and an average state rate of 3.7 percent of wages and salaries. Appendix C presents state income tax data.

3.2.2 Impact of Semiconductor Industry's Demand for Skilled Labor

Households can be considered as an "industry" that demands goods and services to produce its output—labor services. Hence, when the semiconductor industry demands labor, the wages and salaries it pays its employees can be thought of as a change in the final demand for services (labor) of the household industry. In the U.S. economy, every $100 change in final demand for labor provided by the "household industry" generates a total household earnings impact of $62.08. Every $1 million change generates an employment impact of approximately 27 jobs.

Household demand for goods and services generated by the $14.1 billion in wages paid to employees of the semiconductor industry resulted indirectly in additional employment for 359,600 people, wages of $8.8 billion, and income tax revenues of $2.3 billion. The income tax revenue impact consists of approximately $345 million in federal corporate income taxes collected from a base of $31.4 billion, and approximately $1.9 billion in federal and state personal income taxes collected from a wage base of $8.8 billion (see Appendix B, Table B-1 for precise tax bases).

3.2.3 Impact of Semiconductor Industry's Demand for New Plant, Machinery, and Equipment

A final component of economic impact is generated by the semiconductor industry's capital expenditures. In 1996, the industry spent $8.4 billion on new plant, machinery, and equipment produced in the United States.

The impact of the industry's capital spending can be found in communities like Ridgefield, California.[28] In 1996, Silicon Valley Group (SVG), a San Jose-based manufacturer of semiconductor equipment, opened a new facility in a building formerly occupied by Perkin-Elmer. Employing 600 people in the manufacturing of lithography tools, the SVG facility became one of the region's largest employers. The room-sized machines it manufactures are purchased and used by companies like Intel and IBM to transfer an image of a chip onto a silicon wafer.

In total, employment for more than 242,000 people, nearly $7.5 billion in wages, and $1.9 billion in income tax revenues were generated throughout the U.S. economy by the semiconductor industry's demand for new plant and new equipment like that manufactured by SVG and others. The tax revenue impact includes $278 million in federal corporate income taxes collected from a base of $25.2 billion, and approximately $1.6 billion in federal and state personal income taxes collected from a wage base of $7.5 billion. Again, state corporate income tax, property tax and sales tax revenues were not estimated.

In summary, the economic impact of the demand for semiconductors includes more than the direct effect on the semiconductor manufacturing industry itself. When the demand for semiconductors increases, the demand for materials, services, labor, plant, machinery, and equipment required to produce semiconductors increases, setting off a ripple effect throughout the U.S. economy. In 1996, once the ripple had played out, the demand for semiconductors had generated employment for 1.5 million people, wages of nearly $50 billion, and nearly $18 billion in tax revenue.

4. Industry and Consumer Benefits

> *"…. computer prices have recently declined at a faster-than-average rate; without this decline, overall inflation would have risen steadily since early 1994."*
>
> Council of Economic Advisors, 1998.
> Economic Report of the President, p. 58

The technological progress in semiconductor manufacturing benefits industries and consumers, often in ways not readily apparent. In this chapter, we examine the ways in which our lives are better because of semiconductors. We begin by reviewing a new study by economist Kenneth Flamm in which he estimates the benefit to all of us from declining semiconductor prices. We conclude with data and examples demonstrating how, as a result of the semiconductor industry's ability to provide more powerful semiconductors at lower prices, industries are finding new ways to use semiconductors to increase the efficiency of their production processes and to enhance their products and the quality of our lives.

4.1 DECLINING PRICES INCREASE PURCHASING POWER

> *"There were two major 30-year waves of railroad construction: the first 'antebellum' investment from 1830-1860, and a second post-Civil War surge from 1860-1890. Calculations of social benefit from the first wave suggest a value equal to roughly four percent of GDP in 1859. Analogous estimates for 1890 suggest that "gains probably exceeded 10 percent of national income." By comparison, our estimates suggest that 30 years of technological progress in semiconductors created a consumer benefit worth about 21 percent of U.S. GDP in 1995."*
>
> *"More for Less: The Economic Impact of Semiconductors,"* by Dr. Kenneth Flamm, December 1997, p. 32

The economic impacts examined and estimated in the previous chapter did not include the more important measure of the economic benefit of technological progress in semiconductor manufacturing during the past 51 years. It is this topic to which we now turn our attention.

Production processes, like semiconductor manufacturing, use resources such as land and labor, as well as materials, services, buildings, and equipment. The economic benefit of production is not measured by the value of these resources. Employment, purchases of intermediate products, and investment in new plant and equipment are economic costs that must be incurred to produce goods and services.

The benefit of economic activity lies in what it produces, not in what it uses up or consumes. To measure the benefit, we must consider what people are willing to pay for what the activity produces. In Chapter 2, we examined the semiconductor industry's value of product shipments, which is a measure of what purchasers were willing to pay *and paid* for the industry's products. However, the bigger story lies in what we cannot observe directly: the amount purchasers of semiconductors were willing to pay but did not have to pay to purchase semiconductors. This amount is a surplus value that people can spend on other goods and services, thereby increasing their purchasing power.[29] The surplus increases and the welfare of the consumer increases as the price of the product declines.

In a recent study, economist Kenneth Flamm analyzed the history of technological progress in semiconductor manufacturing and estimated that since 1970 the price of microprocessing capablilities, measured in one million instructions per second (MIPS), declined approximately 30 percent per year.[30] In other words, every six to seven years since 1970, the price per MIPS has declined 90 percent. To appreciate the magnitude of such change, consider past impacts of technological progress. During the Industrial Revolution, the cost of producing cotton cloth declined at a real rate of only 3.4 percent per year. And the first 30 years of the railroad had an impact on the U.S. economy that was only one-half to one-fifth of the impact of the semiconductor during its first 30 years.

We can begin to consider the cumulative impact of these price declines by posing the question: what would have happened if semiconductor prices had not fallen. The demand for semiconductors is not unlike the demand for other products. When the price of a semiconductor declines, additional quantities are purchased. For example, semiconductor price declines have allowed computers to migrate from a few hundred corporate computer centers to thousands of workstations to millions of desktops. Hence, if the price had not declined, semiconductor consumption would have been less than actually observed. Fewer industries and consumers of the products produced by those industries would have benefited from the technology of the semiconductor. And those who did purchase semiconductors at the higher price would have had less purchasing power to acquire other items.

Flamm estimates that if the price decline of the past 20 years had not occurred, the loss incurred by consumers of chips would have totaled $340 billion in 1995—nearly five percent of the total value of goods and services produced in the U.S. economy that same year. If in 1995 the average annual price decline had not occurred, semiconductor consumption would have been 23 percent to 25 percent lower and, as a result, buyers of electronic equipment using semiconductors would have incurred a loss worth $12 billion. One year’s worth of technological progress in semiconductor manufacturing provided consumers with an additional $12 billion available to spend on other goods and services in 1995.

In summary, technological progress in semiconductor manufacturing has enhanced our welfare by giving us more powerful products at rapidly declining prices. When, over time, we can purchase a product of constant or improving quality at a falling price, we can either purchase more of the product or use the money we save from paying a lower price to purchase other items. Either way, our welfare is enhanced.

4.2 SEMICONDUCTORS ARE UBIQUITOUS

> *"We really have failed to articulate fully how technology has changed manufacturing. ¼ I think the story is pretty incredible."*
>
> Jerry Jasinowski, President, National Association of Manufactures, as reported by Scott Thurm in the *San Jose Mercury News*, February 6, 1998

As prices declined and semiconductor functionality and power increased, the use of semiconductors became more widespread. Industries began to use semiconductors to improve the efficiency of their production processes and to provide new and better products and services. Workers began to use semiconductor-based technology to increase their productivity. And consumers began to find the semiconductor in more and more of the products they depend on in their daily lives.

4.2.1 Fueling High-Tech Industry Growth

A recent report sponsored by the American Electronics Association and The Nasdaq Stock Market documented the importance of the high-technology industry to the U.S. economy.[31] High-tech industry includes manufacturers, as well as communications services industries, and software and computer-related services industries. In 1996, high-tech employment totaled 4.3 million workers who earned an average annual wage of $49,586, 73 percent more than the average annual wage earned in the private sector of the U.S. economy.

The major segments of the high-tech industry are the major consumers of semiconductors. According to SIA data, the computer and office equipment manufacturers, communication equipment manufacturers, communications service providers, and software and computer-related service providers in the high-tech industry purchased nearly four-fifths of all semiconductors produced.

Technological progress in semiconductor manufacturing since 1989 fueled the gains achieved by the high-tech industry since the last recession. Consider just a few of the major innovations. In 1989, Intel released its 80486DX chip containing 1.2 million transistors. Four years later, Intel released the Pentium chip containing 3.1 million transistors. And in 1995, the Intel Pentium Pro chip contained 5.5 million transistors.

Between 1991 and 1996, the value added by all high-tech industries to the U.S. economy rose from $304 billion (five percent of GDP) to $454 billion (six percent of GDP). High-tech industry growth contributed $149 billion in value added to the U.S. economy during the period, accounting for nine percent of total economic growth. These gains would not have been achieved without the technological progress and price performance achieved by the semiconductor industry.

4.2.2 Raising Productivity and Slowing Inflation

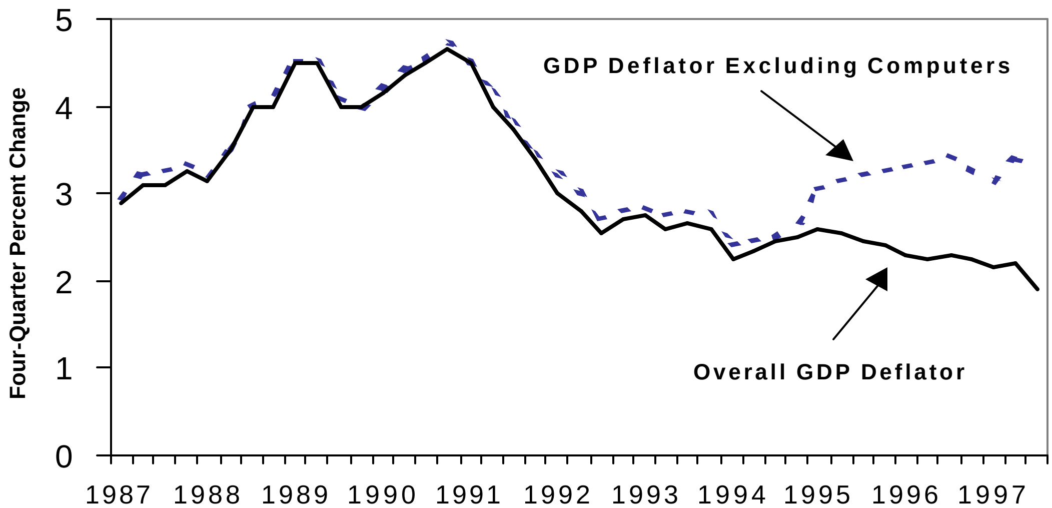
The computer industry is the most obvious industry beneficiary of technological progress in semiconductor manufacturing. According to data collected and maintained by the SIA, the computers and office equipment manufacturing industry group and the computer programming, data processing, and other computer related services industry group purchased approximately 60 percent of all semiconductors in the U.S. market.

Consider just a few of the innovations and accomplishments in the computer industry that can be attributed to the increasing power and decreasing memory costs of semiconductors since 1991. Microsoft introduced Windows 3.1 in 1992, Windows NT in 1993, and Windows 95 in 1995. Sun Microsystems introduced Java in 1995. In 1997, an IBM computer became the new chess champion. And throughout America, the share of households with a personal computer rose from 33 percent in 1994 to 41 percent in 1996; those with an Internet link rose from nine percent in 1994 to 35 percent in 1996.[32]

Along with this progress has come increasing productivity. Noted economist Alan Krueger found that workers who use a computer at the office are more productive than those who do not, and, as a result, they earn wages that are 10 percent to 15 percent higher than workers who do not use a computer.[33]

These gains in productivity combined with increasing computing power at decreasing prices have contributed to an era of low inflation. Since 1991, inflation has slowed to three percent per year or less. Not since the 1960s has such low inflation been sustained over as long a period. According to the *Economic Report of the President,* without the faster-than-average recent rate of decline in computer prices, overall inflation would have risen steadily since early 1994.[34]

Figure 9. Computer Chips Contribute to Lower Inflation



Sources: Department of Commerce (Bureau of Economic Analysis) and Council of Economic Advisors, 1998. Economic Report to the President.

4.2.3 Delivering Better Products and Services

As industries put the semiconductor to use, the consumer benefits from new and enhanced products. In the remainder of this report we describe three major areas in which the semiconductor is playing a large and important role: the automobile, bio- and medical technology, and communications technology.

4.2.3.1 Transforming the Automobile

> *"The Ford Taurus has more computing power than the original Apollo that went to the moon [in 1969]."*
>
> Alex Trotman, Ford Motor Co. Chairman and Chief Executive Officer, as reported by Matt Nauman in the *San Jose Mercury News,* Business Monday, September 8, 1997, p. 1E

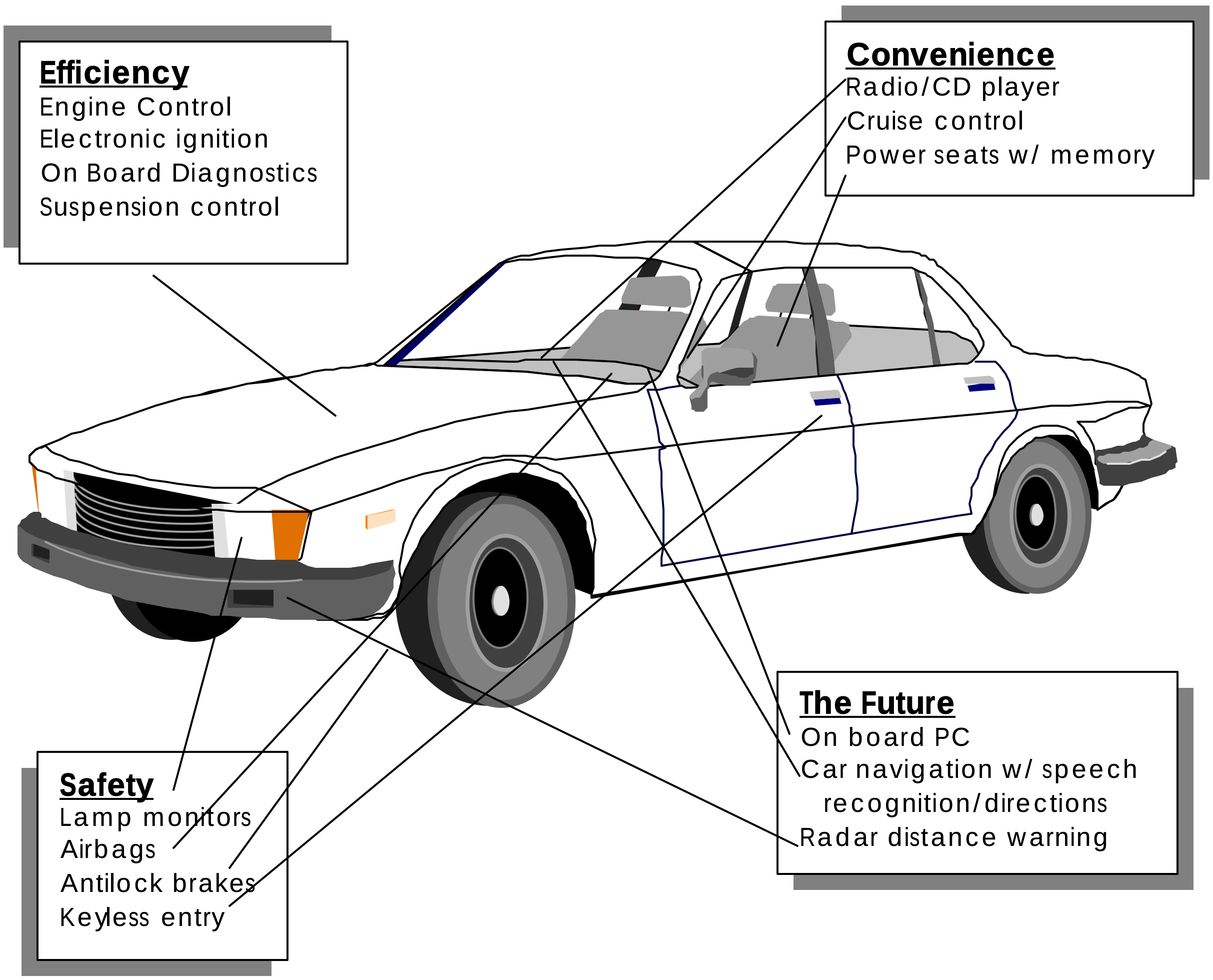
The benchmark input-output accounts of the U.S. economy reveal the emerging use of semiconductors by auto manufacturers as early as 1987. But between 1987 and 1992, the auto manufacturing industry's share of all semiconductor consumption nearly tripled.

The role played by the semiconductor in today's automobile would hardly have been imaginable a generation ago. In the early 1970s, automakers were still seeking mechanical solutions to controlling auto emissions.[35] By 1974, cams, valves, thermocouples, and dampers were not getting the job done to the satisfaction of the government and the consumer. By 1978, electronics had solved the problem. Today most automobiles rely on an electronic engine controller. As stated by Gary Dickinson, President and Chief Executive Officer of Delco Electronics Corporation, "Engine performance, emissions, fuel economy, entertainment, air bags, antilock brakes, instrumentation and even climate are all electronically controlled."[36] And semiconductors control the electronics.

Today, an automobile is a computer on wheels (see Exhibit 1). Recently announced electronics products include automobile personal computers that can take dictation, send electronic mail, and get you home when you are lost.[37] In 1993, the average worldwide semiconductor dollar content per vehicle was $87.[38] By 1995, the average had climbed 31 percent to $114. It's predicted to climb another 22 percent by 1999.

The role of the semiconductor in automobiles and transportation systems is still in its infancy, but smart cars using global positioning to transport us on smart highways are not far off.[39] Here in the United States, Delco Electronics introduced a concept vehicle in 1996 with 10 times the microprocessors or 50 times the computing power of the typical new car.[40] Consider just a few of the more

Exhibit 1. Today's Cars are Computers on Wheels



than two dozen features of the electronic car of the future: collision warning systems; keyless entry and ignition; turn-by-turn navigation systems; and a full-color, head-up display for navigation, emergency notices, and night vision. On the automated highway system, vehicles will be fully actuated. Steering, throttle, and braking will all be controlled electronically.

4.2.3.2 Powering Advances in Bio- and Medical Technology

John Steele Gordon reminds us of the biotechnology field's debt to the semiconductor.[41] Without the semiconductor and the computers it powers, DNA scientists would be unable to accomplish their task of mapping the human genome. Special silicon microchips are required to speed the mathematics used in sequencing the genome's three billion DNA base pairs.[42]

Today it takes imagination to appreciate the benefits of unlocking the secrets of DNA. Understanding our genetic profiles will help us predict, prevent, and cure disease. New pharmaceuticals will be developed at lower cost. Biologists will be able to engineer substitutes for blood vessels, heart valves, bone, skin, and cartilage. Biologists will be able to develop drought and pest resistant crops that grow faster and are richer in nutrients. Biologists are already developing bacteria that absorb or digest environmental toxins. These biotechnology advances were and will continue to be made possible by advances in semiconductor technology. They will extend and improve the quality of our lives, and enable us to be more productive.

In medical technology, semiconductors are the building blocks of high-tech diagnostic scanners like computed-tomography or CT scanners.[43] As reported by Peter Wayner, microprocessors are not the only types of computers capable of the mathematics required to construct three dimensional images, but the declining cost and increasing power of microprocessors are the reason why CT scanners have proliferated. Wayner describes the impact technological advances in semiconductors has had on CT scanners. Picker Nuclear Medicine in Highland Heights, Ohio, once powered its scanners with a minicomputer that required dual multiprocessors. Today Picker relies on workstations that have only one microprocessor, but it is capable of performing at a rate more than four times faster than the previous generation's microprocessors. The enhanced performance allows real-time manipulation of images, and, as a result, doctors are better able to evaluate the health of a patient's organs and diagnose disease.

4.2.3.3 Making the World Smaller

> *"By making things smaller, everything gets better simultaneously. ¼. As you leave this meeting I want to encourage each of you to think smaller."*
>
> Gordon E. Moore, Intel Corporation, in his presentation to the International Society for Optical Engineering at the International Symposium on Microlithography on February 10, 1995

By heeding these words, the semiconductor manufacturing industry has done more than merely shrink the transistor; it has shrunk our world and brought everyone closer together. The ways in which we communicate and obtain information have changed dramatically. Consider the most obvious development—the Internet, a virtual library. It is available 24 hours a day, delivering news, entertainment, and education. Over the Internet we can send mail electronically anywhere in the world in minutes. Today a busy executive can use e-mail to resolve an important issue with colleagues around the world in a single day.[44] A decade ago, weeks might have transpired before telephone calls or written memoranda were received and returned.

Communication equipment manufacturers are using semiconductors in their digital phones and communication satellites. Cellular phones are nothing more than microprocessors hooked up to radio antennas.[45] As reported by Peter Wayner, cellular communication systems will probably be the first communication systems in much of Africa. Vast and remote regions of the globe will be a phone call away but they will likely never be never be strung with traditional phone lines.

The transistor truly was a *wunderkind*. By shrinking it and cramming more and more of them onto a single slice of polished sand, the semiconductor industry endowed it with transforming power. And now more than 50 years old, it shows no signs of tiring. As the semiconductor shrinks in size to virtually nothing, its impact expands into nearly every dimension of our lives.

APPENDIX A
Contribution and Performance Measures of Semiconductor and Other Industries

APPENDIX B
Employment and Wage Impacts of the
Demand for Semiconductors

B1 **Economic Impact of Spending by the Semiconductor Industry, 1996**

B2 **Derivation of Estimated 1996 Spending by the Semiconductor Industry on U.S. Produced Materials, Services, and New Plant and Equipment**

B3 **Estimation of 1992 U.S. Produced Share of Materials, Services, and New Machinery and Equipment Purchased by the Semiconductor Industry**

APPENDIX C
State Personal Income Tax Revenue Impacts of the Demand for Semiconductors

C **Derivation of State Personal Income Tax Revenues Collected on Wages of Semiconductor Employees**

Endnotes

[1] Technecon Analytic Research, Inc. *SIA 1997 Annual Databook: Semiconductor Industry Association Review of Global and U.S. Semiconductor Competitive Trends 1978-1996*. San Jose, CA: Semiconductor Industry Association.

[2] Nathan Associates Inc. 1997. Building an Information Economy: Software Industry Positions U.S. for New, Digital Era. Washington, DC: Business Software Alliance.

[3] Transistors are made of materials that are not good conductors of electricity. The materials, such as germanium, selenium, and principally silicon, are called semiconductors. A semiconductor carries only one-millionth of the current that a copper wire carries.

[4] In our decimal number system there are 10 different characters: 0, 1, 2, …, 9. A binary number system uses only two characters, 0 and 1. In either system a number can consist of one or more of its characters. Consider just the numbers consisting of only two digits. In the decimal number system, a 2-digit number can be any of 100 different combinations of its 10 characters—00, 01, 02, …, 09, 10, 11, 12, …, 97, 98, and 99. In a binary number system, however, a 2-digit number can be one of only four possible combinations—00, 01, 10, and 11. To transform a binary number into a decimal number we need to perform simple arithmetic operations involving multiplication and addition. First, however, remember that there is a shorthand way of writing repeated multiplication of the same number. For example, 2 x 2 can be rewritten using the exponential expression 2^2. Likewise, 2 x 2 x 2 can be rewritten as 2^3. Any number "a" can be multiplied by itself any number of times "n" and written as an exponential expression a^n. In this expression, the number "a" is called the base and the number "n" is called the exponent. The exponential expression can be read as the number "a" raised to the power "n." To convert the value of a binary number into a decimal number, we multiply the character in each digit of the binary number by an exponential expression, 2^n, where, in the expression, the exponent "n" increases as you move from right to left across the digits of the binary number. The character in the far right-hand digit is multiplied by the expression 2^0. Multiply the character in the next digit to the left by 2^1, and so forth. Recall that any number raised to the 0 power equals 1 and any number raised to the first power equals the number itself, i.e., $2^0 = 1$ and $2^1 = 2$. Hence the 4-character binary number 1010 can be translated into a decimal number as follows: $(0 \times 2^0) + (1 \times 2^1) + (0 \times 2^2) + (1 \times 2^3) = 10$. The decimal equivalent of the binary number 1011 is 11.

[5] The ability to double the number of transistors placed on a chip every two years was predicted by Gordon E. Moore in 1975. In 1965, Moore predicted the number of transistors packed onto a chip would double every year until 1975.

[6] Isaacson, W. 1997. driven by the passion of Intel's. *Time*, 29 December, 50.

[7] *Ibid*.

[8] Nathan Associates Inc. *Op. Cit.*

[9] Platzer, M.D. 1997. Cybernation: The Importance of the High-Technology Industry to the American Economy. Washington, DC: American Electronics Association and The Nasdaq Stock Market.

[10] The semiconductor manufacturing industry is defined in the Standard Industrial Classification (SIC) to include all establishments primarily engaged in manufacturing semiconductors and related devices, including semiconductor parts such as chips, wafers, and heat sinks. Like all establishments, those in the semiconductor industry ship secondary products in addition to their primary product. However, the specialization ratio of the semiconductor industry is 96 percent. Of all semiconductor industry product shipments, 96 percent are shipments of semiconductors and related devices. Remaining shipments include other electronic components and computer peripheral equipment, among other products. Moreover, semiconductors are manufactured by establishments in other industries, such as the telephone and telegraph apparatus manufacturing industry. But 97 percent of all shipments of semiconductors are manufactured at establishments classified as members of the semiconductor

manufacturing industry. Therefore, government reported measures of the activities of semiconductor manufacturing establishments are reasonably accurate measures of semiconductor manufacturing activity. See U.S. Bureau of the Census. unknown. *Census of Manufactures, Industry Series, Electronic Components, Industries 3671, 3672, 3674, 3675, 3676, 3677, 3678, and 3679, 1992*. Prepared by the Economics and Statistics Administration, Bureau of the Census, U.S. Department of Commerce (MC92-I-36E). Washington, DC.

[11] We begin by comparing the semiconductor industry with other manufacturing industries identified in SIC by a 4-digit code. According to the S*tandard Industrial Classification Manual 1987* of the Office of Management and Budget, an establishment is classified according to its primary activity—by its principal product or group of products produced or service provided. An establishment is an economic unit at a single physical location where business is conducted or where services or industrial operations are performed. An establishment is not necessarily identical with a company, which might consist of one or more establishments. To be recognized as an industry, a group of establishments constituting the proposed classification must be statistically significant in the number of persons employed, the volume of business conducted, and other measures of economic activity. Four-digit codes identify establishments within an industry, such as SIC 3674—Semiconductors and related devices manufacturers. Three-digit codes identify an industry group, such as SIC 367—Electronic components and accessories manufacturers, which includes industries 3671—Electron tubes manufacturers, 3672—Printed circuit boards manufacturers, 3674, 3675—Electronic capacitors manufacturers, 3676—Electronic resistors manufacturers, 3677—Electronic coils, transformers, and other inductors manufacturers, 3678—Electronic connectors manufacturers, and 3679—Manufacturers of other electronic components not elsewhere classified. A 2-digit code identifies a major group, such as SIC 36—Electronic and other electrical equipment and components, except computer equipment. A letter identifies a division of the economy, such as division D—Manufacturing.

[12] Value added statistics reported here are estimates based on the 1987 and 1992 input-output benchmark accounts of the U.S. economy and manufacturing industry shipment value reported in the quinquennial Census of Manufacturing Industries and the Annual Survey of Manufactures. Input-output accounts are maintained by the Bureau of Economic Analysis of the U.S. Department of Commerce. Census and Survey data are collected and reported by the Census Bureau of the U.S. Department of Commerce. The Census of Manufactures reports a measure of value added in manufacture but it does not include a complete accounting of services purchased by manufacturing industries. BEA, however, adjusts Census data to develop more complete estimates of industry value added. It is of interest to note that data collected and maintained by the SIA indicate that semiconductor industry value added as a percentage of industry output might have increased since 1992. In 1996, the industry's value added to output ratio might have been 1.6 percentage points higher than it was in 1992. If so, 1996 semiconductor industry value added was $1.1 billion or 2.7 percent higher than the estimate presented in this report.

[13] For the distinction between an industry group and an industry, see note 11 above.

[14] The *in vitro* and *in vivo* diagnostic substances manufacturing industry grew 19.1 percent per year over the period and the industry that manufactures biological products except diagnostic substances grew 17.4 percent per year. Both are part of the drug manufacturing industry group.

[15] Employment and wage data presented here are from the Covered Employment and Wages Program (ES-202 program), a cooperative program involving BLS and Sate Employment Security Agencies. The program produces a comprehensive tabulation of employment and wage information for workers covered by state unemployment insurance laws. It is a virtual census of payroll employment. Wages include bonuses, stock options, the cash value of meals and lodging, tips and other gratuities, and employer contributions to certain deferred compensation plans.

[16] See the Nathan Associates report "Building an Information Economy."

[17] According to the Semiconductor Industry Association, 75 percent of worldwide integrated circuit wafer fabrication capacity is located in the United States.

[18] Bureau of Labor Statistics. *Employment and Wages Annual Averages, 1996*. Washington, DC: U.S. Department of Labor (Bulletin 2494). Data reported are compiled for the Bureau's Covered Employment and Wages, or ES-202, program. They are compiled from quarterly tax reports submitted to state employment security agencies by employers subject to state unemployment insurance laws and from federal agencies subject to the Unemployment Compensation for Federal Employees program. Wages are reported compensation, including

bonuses, stock options, the cash value of meals and lodging, tips and other gratuities, and employer contributions to certain deferred compensation plans such as 401(k) plans.

[19] Hutheesing, N. 1997. Faster, cheaper, better—forever. *Forbes*, 7 July, 178.

[20] Behr, P. 1997. Virginia's Exotic Plant: A building that Breathes, a Team Obsessed with Clean, and a Futuristic Factory Set for Growth. *The Washington Post*, 15 September, financial section, F12.

[21] *Ibid*. p. 40.

[22] Industry R&D funds in 1987 and 1996 totaled $62,643 million and $113,450 million, respectively, according to the U.S. National Science Foundation, *National Patterns of R&D Resources*, as reported in the *Statistical Abstract of the United States: The National Data Book*, Table 980 in the 115th edition (1995) for 1987 and Table 962 in the 117th edition (1997) for 1996

[23] SIA. 1997. Available from http://semichips.org/news/pr120897.htm; Internet.

[24] The estimated average tax rate is based on 10-K reports of eight different companies: Advanced Micro Devices, Analog Devices, AMTEL, Cirrus Logic, Intel, International Rectifier, and VLSI Technology. Among these eight, tax rates as a percentage of sales varied from a low of zero percent to a high of 11.1 percent.

[25] According to the *1997 Statistical Abstract of the United States*, 1996 receipts from federal individual income taxes totaled $656.4 billion (Table 516, page 333) and total wages and salaries were $3,630.1 billion (Table 700, page 453). Therefore, the relevant measure of an average federal personal income tax rate for our purposes is $656.4 ÷ $3,630.1 or 18.1 percent.

[26] Average state personal income tax rates were calculated from state individual income tax collections in 1996 and wages by state. Tax revenues were reported in the *1997 Statistical Abstract of the United States*, Table 495, page 315. Wages were reported in *Employment and Wages Annual Averages, 1996*, Bureau of Labor Statistics, U.S. Department of Labor, Bulletin 2494, November 1997.

[27] See the *Source Book Statistics of Income 1993, Corporation Income Tax Returns*. Total corporate income tax revenue in 1993 was $119.9 billion; corporate business receipts totaled $10,865.5 billion. Therefore the average corporate income tax rate as a percentage of business receipts across all incorporated businesses was $119.9 ÷ $10, 865.5 or 1.1 percent. The tax base of our estimate equals the total impact on industry output (all goods and services produced) generated by semiconductor spending on materials and services.

[28] Chuvala, B. 1996. "Inside Business Silicon Valley Group: Explosive Growth for Area's Newest Employer." Available from http://www.newstimes.com/inside/silicon.htm; Internet.

[29] In the field of economics, this concept is referred to as consumer surplus. For any product there is a range of prices people are willing to pay to obtain the product. Consider a group of your friends who are considering the purchase of a computer. Ask each what he or she is willing to pay for a computer of a precise specification. Then arrange the responses from highest to lowest and plot them on a two-dimensional graph with price on the vertical axis and the person's name on the horizontal axis. Start with the person who is willing to pay the highest price. Then connect the points to form a downward sloping line that associates each name with a price. Now assume that this computer is available at a local store for a single price. Some of your friends will not purchase the computer because its price is higher than the price they are willing to pay. Others, however, will certainly purchase the computer because its price is lower than what they are willing to pay. Identify all the people who are willing to pay more than its price, calculate the difference between the amount each is willing to pay and the price, and sum the differences across people. It will equal the area of a triangle bounded by the plotted line, the vertical axis, and the horizontal line that crosses the vertical axis at the price of the computer. This measure is the consumer surplus for this computer among your friends. It is a sum they are willing to spend for the computer, but do not have to spend to obtain it. They can purchase the computer and have a surplus available for the purchase of other things. The fact that the price of the computer is lower than what they are willing to spend to purchase the computer leaves them better off than those who are willing to pay no more or no less than the price being charged. If the store were to lower the price of the computer, more of your friends would purchase the computer, and more important, the consumer surplus would increase.

[30] Flamm, K. 1997. More for Less: The Economic Impact of Semiconductors. San Jose, CA: Semiconductor Industry Association.

[31] Platzer, M.D. *Op. Cit*.

[32] Consumer Electronics Manufacturers Association.

[33] Krueger, A.B. How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984-1989. *Quarterly Journal of Economics*, CVIII(1), 1993.

[34] Council of Economic Advisors. 1998. *Economic Report of the President*. Washington, U.S. Government Printing Office. p. 58.

[35] Dickinson, G.W. 1996. Cars and Trucks: The Ultimate Consumer Electronics Products. Presented at the Automotive News World Congress, Detroit, MI. 9 January. Available from http://www.delco.com/ news/-speeches.html; Internet.

[36] *Ibid*.

[37] Armstrong, L and S. Hamm. 1998. The Office You Can Drive. *Business Week*, 9 February.

[38] Giga Information Group in London. Available from http://www.delco.com/autosmart/96_spring/shrink.html; Internet.

[39] Wiesenfelder, J. The Information Superhighway (This is not a metaphor.). Available from http://www.wired.com/wired/4.02/features/smart.cars.html; Internet.

[40] *Ibid*.

[41] Gordon, J.S. 1997. The next revolution. *Forbes*, 7 July, 162.

[42] Wayner, P. 1996. Ten reasons why microprocessors define the twentieth century more than any other achievement. *BYTE*, December. Available from wysiwyg://46/http://byte.com/art/9612/sec6/art1.htm; Internet.

[43] *Ibid*.

[44] *Time*. *Op. Cit*. page 51.

[45] Wayner. *Op. Cit*.