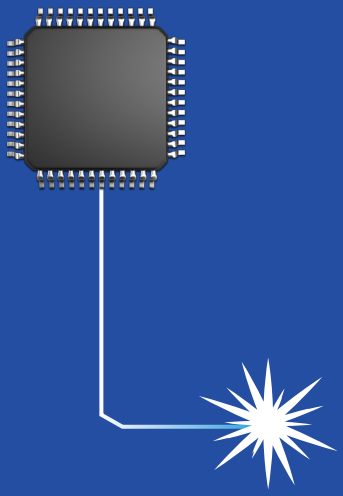
SPARKING INNOVATION

How Federal Investment in Semiconductor R&D Spurs U.S. Economic Growth and Job Creation

June 2020

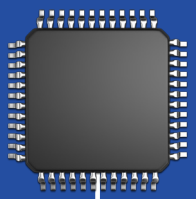
SIA SEMICONDUCTOR INDUSTRY ASSOCIATION



EXECUTIVE SUMMARY

For decades, federal government and private sector investments in semiconductor research and development (R&D) have propelled the rapid pace of innovation in the U.S. semiconductor industry, making it the global leader and spurring tremendous growth throughout the U.S. economy. This report analyzes the impact of federal investments in semiconductor R&D on U.S. economic growth, job creation, and our country's technology leadership. The report reaches the following key findings:

This report is based on research and analysis conducted by Nathan Associates Inc. on behalf of SIA.



FINDING 1. FEDERAL GOVERNMENT FUNDING FOR SEMICONDUCTOR R&D DRIVES ECONOMIC GROWTH AND PROMOTES AMERICA'S GLOBAL TECHNOLOGICAL LEADERSHIP

Federal government funding for semiconductor R&D offers an outsized return on investment through huge benefits across the entire economy. We find that each dollar invested by the federal government into semiconductor research has increased overall U.S. gross domestic product (GDP) by $16.50.

The multiplier effect of federal government investments in semiconductor R&D is due to the unique role of semiconductors in the modern, technology-driven economy. Advances in semiconductor technology have a positive impact on nearly every sector, including automotive, agriculture, bio-medical, and defense.

In addition, federal investments in semiconductor R&D incentivize, or "crowd in," greater private sector R&D investments and, in turn, spark innovation in the semiconductor industry and the many downstream industries enabled by semiconductors. These innovations lead to growth in the broader U.S. economy and promote America's global technology leadership.

FINDING 2. FEDERAL GOVERNMENT FUNDING FOR SEMICONDUCTOR R&D HAS LAGGED BEHIND PRIVATE SECTOR INVESTMENTS

Federal government investments in semiconductor R&D play a critical role in complementing existing private sector R&D and stimulating greater levels of private investment in new R&D. Unfortunately, annual federal investments have increased at a much slower rate than private sector investments.

Forty years ago, federal funding for semiconductor R&D was more than double private R&D funding. Today, the story is far different, as the private sector invests 23 times more in direct semiconductor research than the federal government. In 2019, private sector funding for semiconductor R&D totaled nearly $40 billion, while the federal government spent only $1.7 billion on core, semiconductor-specific R&D (along with an additional $4.3 billion in research in semiconductor-related fields).

FINDING 3. ADDITIONAL FEDERAL FUNDING FOR SEMICONDUCTOR R&D WOULD FURTHER INCREASE U.S. ECONOMIC GROWTH, CREATE NEW JOBS, AND HELP AMERICA LEAD IN THE TECHNOLOGIES OF THE FUTURE

As our economy becomes increasingly reliant on technology, chip innovation is becoming more complex and more expensive. Increased federal semiconductor R&D investments are required to sustain U.S. leadership in semiconductor technology and the key technologies of the future, including artificial intelligence, quantum computing, and advanced wireless networks.

We find that tripling federal investments in semiconductor-specific research (from $1.7 billion to $5.1 billion by 2024) and doubling federal investments in semiconductor-related research (from $4.3 billion to $8.6 billion by 2024) would:

- Add $161 billion to U.S. GDP by 2029;
- Create nearly 500,000 more jobs by 2029;
- Maintain U.S. technology leadership in the face of growing global competition.

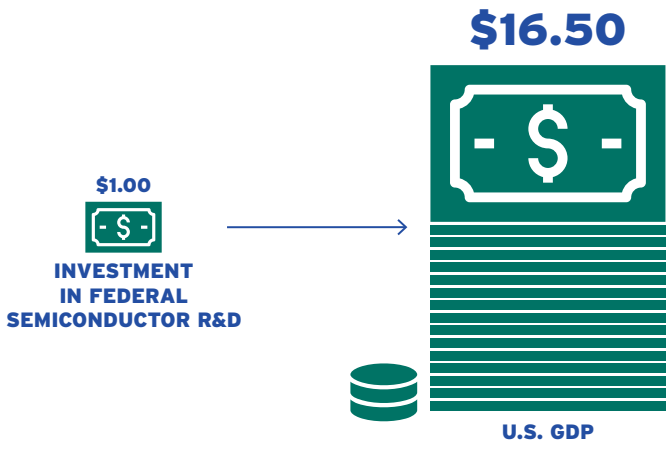
In short, increased funding of semiconductor research is a sound investment for the federal government and yields significant returns for the economy as a whole.

FINDING 1

FEDERAL INVESTMENTS IN SEMICONDUCTOR R&D DRIVE ECONOMIC GROWTH AND PROMOTE AMERICA'S GLOBAL TECHNOLOGY LEADERSHIP

Federal investment in semiconductor research yields significant and outsized dividends for the U.S. economy. **We estimate that each dollar invested in semiconductor research has resulted in $16.50 in increased GDP.**[1]

EACH ADDITIONAL DOLLAR INVESTED IN FEDERAL SEMICONDUCTOR RESEARCH INCREASES U.S. GDP BY $16.50.

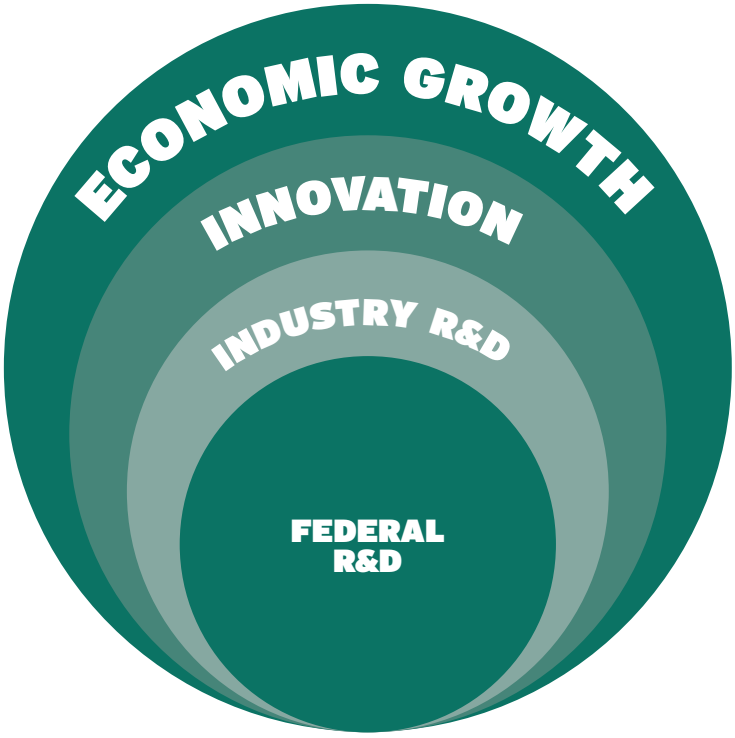


FEDERAL SEMICONDUCTOR R&D DEFINED

There is no official U.S. government summary of semiconductor research programs or related programs. A working group was recently formed under the auspices of the White House Office of Science and Technology Policy (OSTP) to coordinate semiconductor research programs across the federal government. In the absence of an official list, we created the list of programs set forth in the Appendix Table B-1.

Federal semiconductor R&D includes federal funding for fundamental theoretical and experimental research broadly in areas such as physical sciences and engineering, computing, nano-electronic computing, new designs/materials/architectures, fundamental microelectronics, Internet of Things (IoT), Artificial Intelligence (AI), advanced manufacturing processes, novel computing and storage paradigms. Also, this research focuses on examining foundational principles in physics, material science, quantum computing, applied mathematics, and engineering. Typically, this research is funded out of four agencies: the National Science Foundation, the Department of Defense, the National Institute of Standards and Technology, and the Department of Energy.

FIGURE 1. **FEDERALLY FUNDED RESEARCH SPARKS A CHAIN REACTION THAT SPURS PRIVATE INVESTMENT, CREATING A FOUNDATION OF INDUSTRY INNOVATION THAT LEADS TO INCREASED GROWTH IN THE BROADER ECONOMY**



The chain reaction showing how federal government research investments create increased GDP is depicted in Figure 1. Federal government R&D investments incentivize private sector R&D investments, which, in turn, spur greater innovation and growth throughout the U.S. economy.

Our analysis of the historical relationship between federal funding of semiconductor R&D and the private sector's investment in semiconductor R&D shows they are positively correlated[2], with increases in federal funding stimulating even larger increases in private investment.[3]

Private semiconductor industry investments, spurred by the initial federal investments, then spark innovation in other economic sectors, ultimately creating growth in the broader U.S. economy.

Due to this chain reaction, each dollar invested in federal semiconductor research has increased U.S. GDP by $16.50, based on recent historical data.

Given the pervasive role semiconductors play in enabling innovation throughout the broader economy and not just in the immediate downstream computer and electronics industry, it is likely our estimated impact on GDP is understated and the overall positive impact on GDP is significantly higher.

In addition to benefiting the U.S. economy, robust federal semiconductor research investments play a key role in maintaining U.S. semiconductor technology leadership, which further enhances U.S. competitiveness.

The U.S. semiconductor industry is the global leader with nearly half of global sales market share. Through its significant level of annual R&D investment, stimulated in part by federal funding, the U.S. semiconductor industry has been able to lead the world in innovating and creating leading-edge technologies. In turn, the United States has maintained a leadership position in information and communications technology and is well-positioned to play a leadership role in the "must-win" technologies of the future.

The future economy will be characterized by technologies that use sensors to collect immense amounts of data, networks to store and move the data, and advanced computers and systems to analyze and use the data in productive ways. Semiconductors are core to each of these functions, and we must make further advances in semiconductor technology to meet the needs of the technologies of the future.

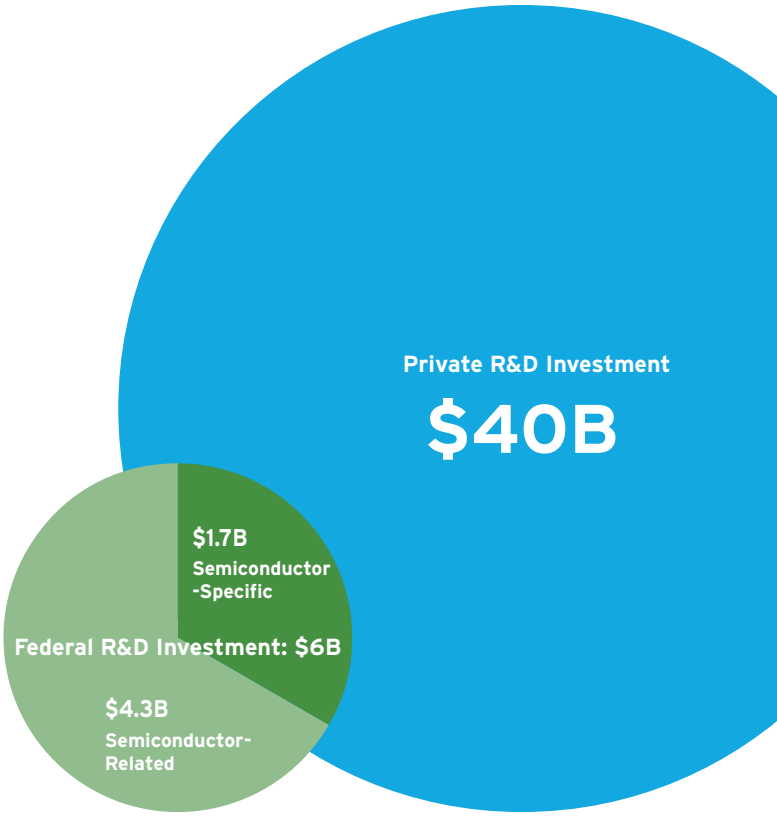
FINDING 2

FEDERAL INVESTMENTS IN SEMICONDUCTOR R&D HAVE LAGGED BEHIND PRIVATE INVESTMENTS

Although federal funding for semiconductor R&D provides a critical spark to drive innovation in the semiconductor industry and the related technology sectors, annual federal funding has lagged far behind private sector investment in semiconductor R&D. At the same time, key competitors are dramatically increasing their government research investments. **The U.S. risks losing its innovation edge and the global competition for technology leadership if under-investment persists.**[4]

The numbers speak for themselves. Forty years ago, federal investment in semiconductor R&D was more than double that of private investment ($1 billion federal to $0.4 billion private). Over several decades, investment by the private sector has grown dramatically. The U.S. semiconductor industry invests nearly 20 percent of revenue into R&D annually, among the highest rates of any industry, while growth of federal investments has been modest. Today, private investment is nearly $40 billion, vastly exceeding the federal government investments of $1.7 billion in semiconductor-specific R&D and $4.3 billion in research in semiconductor-related fields.

FIGURE 2. **FEDERAL INVESTMENTS IN SEMICONDUCTOR R&D ARE A FRACTION OF INDUSTRY INVESTMENTS.**



Source: Agency budget data extracted from official budget documents from NSF, DOD, DOE, and NIST; U.S. semiconductor industry R&D figures reported by SIA.

As a percentage of GDP, private investment in semiconductor R&D has increased nearly 10-fold over the last 40 years, while federal investment has remained flat.

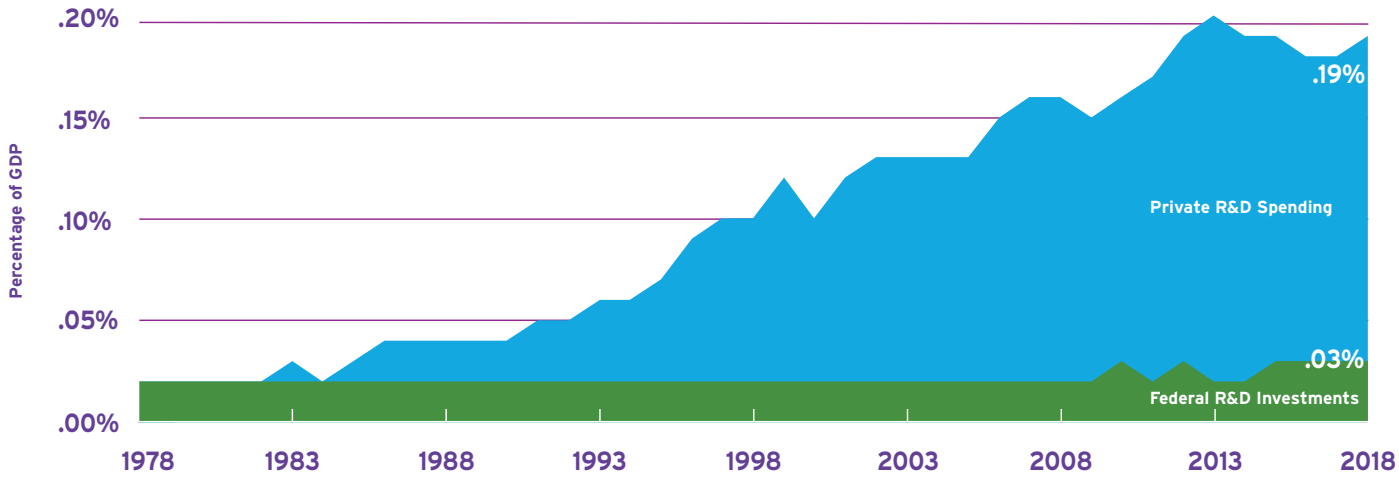
As a percentage of GDP, the difference in investment trends between federal and private R&D is stark. Private investment in semiconductor R&D as a percentage of GDP has increased nearly 10-fold over the last 40 years, while federal investment has remained flat. These trends are depicted in Figure 3.

In 1978, both federal semiconductor R&D and private semiconductor R&D were about 0.02 as a percent of GDP. While private sector semiconductor R&D has grown rapidly to 0.19 percent of GDP in 2018, federal semiconductor R&D has grown only marginally to 0.03 percent of GDP in 2018.

Since 2003, federal semiconductor R&D has averaged just 0.02 percent of GDP, and only 0.14 percent of total U.S. government research investments. By any measure, federal semiconductor R&D investment growth trends have lagged private industry levels.

Without substantially increasing federal funding, the historical pace of innovation established by the industry is at risk, creating an opportunity for our competitors to challenge our global leadership role. Additionally, the outsized economic benefits resulting from the positive chain reaction sparked by these federal investments is threatened.

FIGURE 3. AS A PERCENTAGE OF GDP, FEDERAL SEMICONDUCTOR AND RELATED RESEARCH HAS REMAINED FLAT OVER THE PAST 40 YEARS, WHILE PRIVATE INDUSTRY INVESTMENT HAS INCREASED 10-FOLD



Source: Calculated based on agency budget data extracted from official budget documents from NSF, DOD, DOE, and NIST; U.S. semiconductor industry R&D figures reported in the 1999 SIA Databook and the 2019 SIA Factbook; and GDP figures reported by BEA through its National Income and Products Accounts, Table 1.1.5 Gross Domestic Product (Annual – 1978 to 2018).

FINDING 3

ADDITIONAL FEDERAL INVESTMENTS IN SEMICONDUCTOR R&D WOULD FURTHER INCREASE U.S. ECONOMIC GROWTH AND JOBS AND HELP AMERICA LEAD IN THE TECHNOLOGIES OF THE FUTURE

While the U.S. semiconductor industry currently leads the world in global market share and innovation, overseas governments are seeking to displace U.S. leadership through huge government investments in both commercial manufacturing and scientific research.[5] These challenges pose risks to American semiconductor leadership and our ability to win the global race for the technologies that will define our future.

As advances in semiconductor technology become more complex and expensive, additional federal investment in research is needed to help discover the next breakthrough technologies that will allow the United States to successfully compete with global competitors and lead in the "must-win" technologies of the future, including artificial intelligence, quantum computing, and advanced wireless networks including 5G.[6]

Substantial increases in federal investments in semiconductor research and related fields are not only imperative for maintaining U.S. economic and technology leadership; these investments yield economic benefits for the economy as a whole. In short, investments in semiconductor research are a wise use of federal funds, generating substantial U.S. economic growth and job creation.[7]

This study measures the impact on U.S. GDP and job creation for two scenarios:

1. **Status Quo Scenario:** Federal funding for semiconductor R&D increases at the historic rate of 5 percent per year.
1. **Ambitious Funding Scenario:** Federal funding for semiconductor-specific R&D is tripled over the next five years to $5.1 billion and federal funding for semiconductor-related research is doubled over the next five years to $8.6 billion.[8]

Scenario 2 will advance semiconductor innovation and greatly strengthen the U.S. economy and America's global technology leadership. Under this scenario, the U.S. government would invest $50.8 billion in semiconductor R&D over a five-year period, which is $15.6 billion more than the status quo funding levels outlined in Scenario 1. What economic and technology benefits would this increase in federal R&D funding generate?

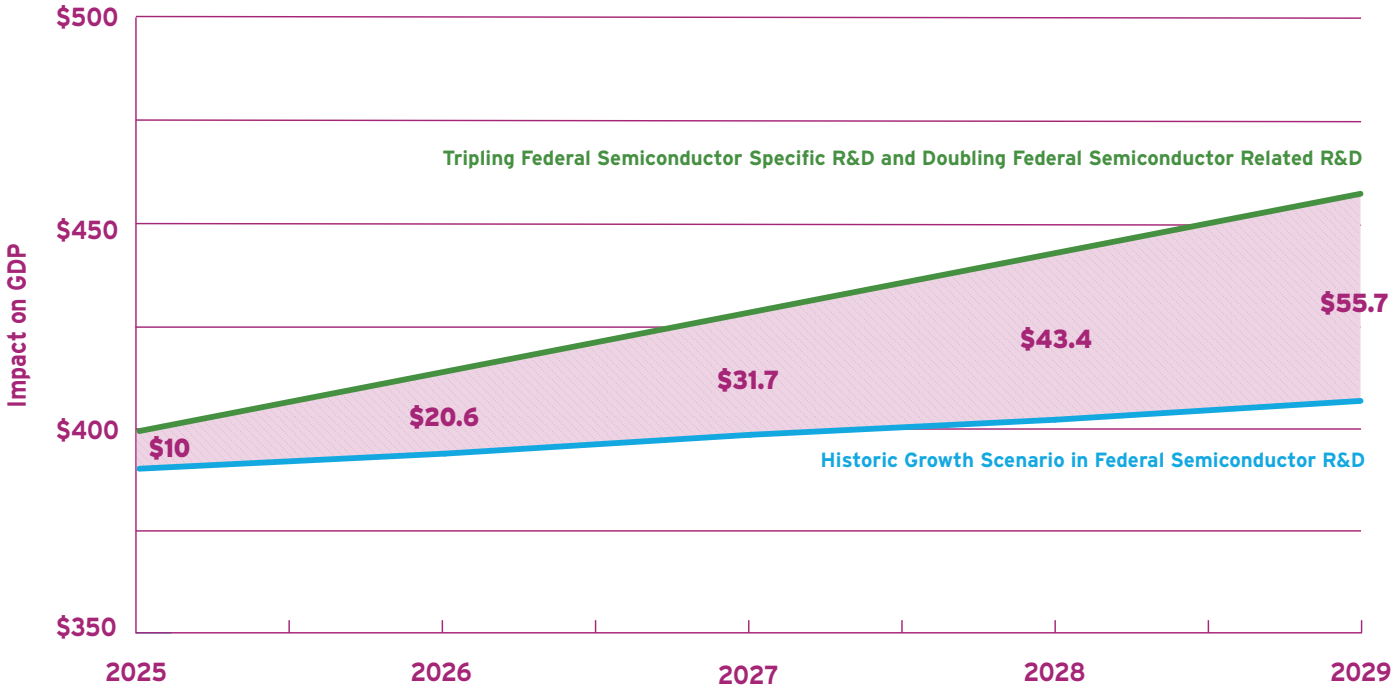
U.S. GDP

Applying very conservative assumptions,[9] we find that significantly increasing federal semiconductor R&D over the next five years would add a cumulative total of $2.144 trillion to U.S. GDP from 2025 to 2029. In comparison, maintaining status quo levels of federal funding for semiconductor R&D would add a cumulative total of $1.983 trillion to U.S. GDP from 2025 to 2029. The difference between these totals is $161 billion.

Therefore, the U.S. economy would gain an additional $161 billion in GDP by 2029 if federal investment in semiconductor R&D is significantly increased (Figure 4).[10]

FIGURE 4. **ESTIMATED IMPACT ON U.S. GDP OF INCREASED FEDERAL R&D FROM 2025 TO 2029 ($ BILLIONS)**

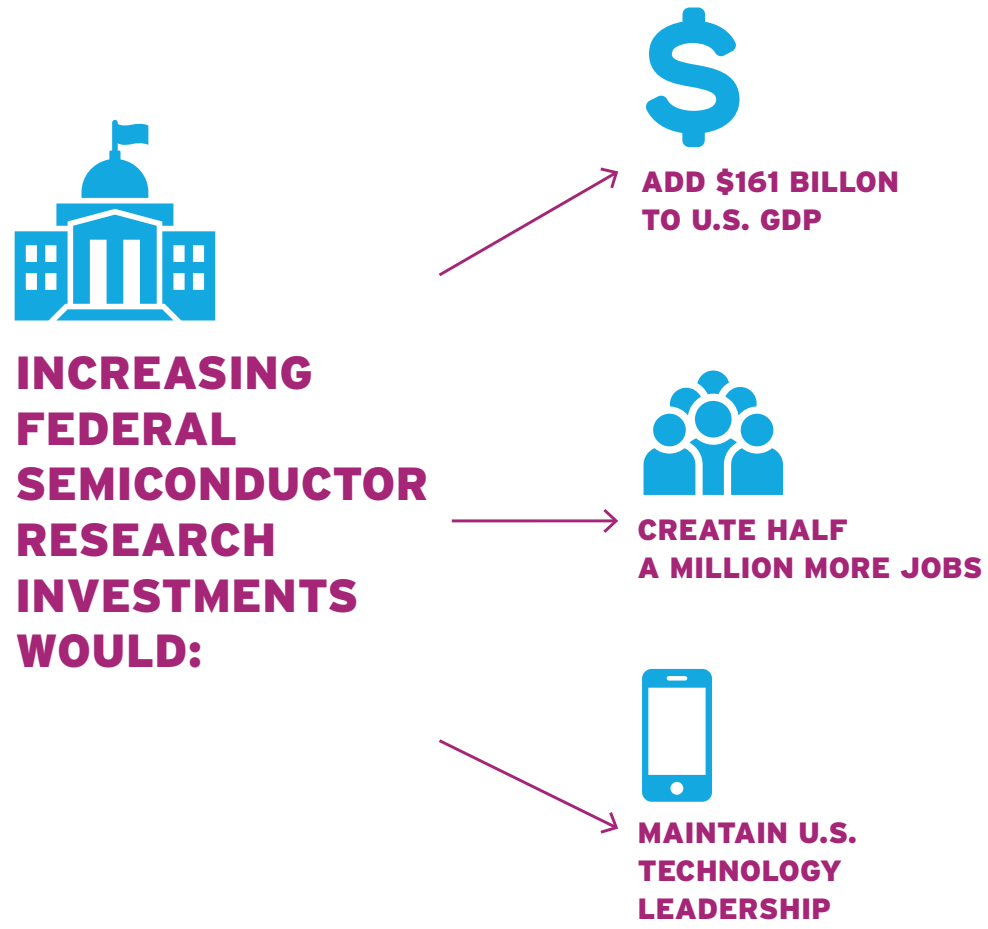
The estimated cumulative economic impact by 2029 from increasing federal R&D spending is **$161 billion**.



Source: Calculated by Nathan Associates.

If the U.S. government significantly increases federal investments in semiconductor R&D, the U.S. economy would gain an additional $161 billion in GDP over 5 years.

FIGURE 5.



Source: Calculated by Nathan Associates.

JOBS

Using the same conservative assumptions, increased economic activity due to these increased federal investments would result in a substantial increase in jobs.[10]

Every $1 million of goods and services sold by the computer and electronics industry leads to an increase of 2.5 jobs in the computer and electronics industry and 5.8 jobs in other upstream industries that supply goods and services to the computer and electronics industry.[11] The addition of $161 billion in GDP as a result of increasing federal investments in semiconductor R&D would result in incremental growth of 496,847 jobs in the next ten years. The total increase in jobs would be considerably higher if employment gains in other sectors of the economy were taken into account.

TECHNOLOGIES OF THE FUTURE

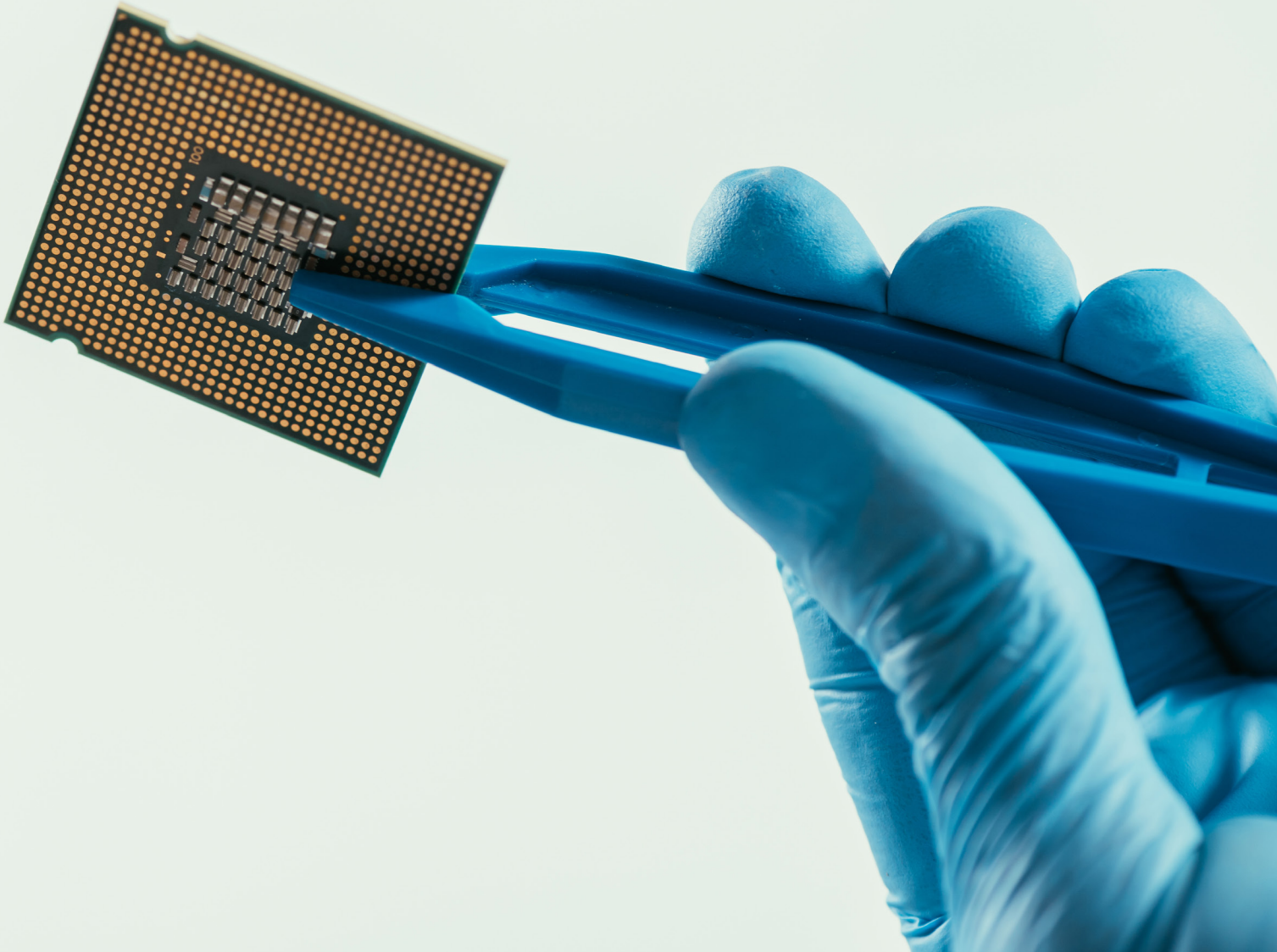
In addition to the economic benefits from increasing federal R&D funding, such increases will drive the innovation needed to enable the United States to lead in the key "must-win" technologies of the future. These include artificial intelligence to power self-driving cars and other autonomous systems, quantum computing to analyze massive volumes of data and enhance digital encryption, and advanced wireless networks to seamlessly connect people at unprecedented speeds. These core technologies will fuel future innovations in other fields essential to future economic growth, such as personalized healthcare, robotics, and intelligent products. The country that leads in these technologies of the future will reap incalculable economic benefits.

CONCLUSION

Now, more than ever, increased federal R&D investment is a key factor in sustaining and strengthening the global leadership position of the U.S. semiconductor industry. Federal funding of semiconductor R&D is necessary for the U.S. semiconductor industry to maintain the rapid pace of chip innovation, boost economic growth and job creation, and drive U.S. leadership in the must-win technologies of the future.

A significant increase in federal semiconductor R&D would have an enormous impact on the entire economy, adding $161 billion to GDP, creating nearly half a million new jobs, and ensuring America leads in AI, quantum computing, advanced wireless networks, and other key technologies of the future.

In short, increased funding of semiconductor research is a sound investment for the federal government and yields significant returns for the economy as a whole.



ENDNOTES

1 For a detailed definition of federal semiconductor R&D, please see Report Supplemental Appendix B (Methodology and Programs Used to Estimate Federal Investments in Semiconductor Specific and Related Research). A list of federal semiconductor research programs and related research is set forth in Appendix B Table B-1.

2 For more details and background on the positive relationship between federal and industry R&D and how increased federal R&D funding "crowds in" industry R&D spending, please see Report Supplemental Appendix E (Study Methodology), Part 1 (Estimating the Relationship between Federal Semiconductor R&D and Private Semiconductor R&D) and Report Supplemental Appendix F (Additional Background Information).

3 For historical examples of how initial federal R&D funding has led to increased funding in the commercial space and ultimately commercial innovations, please see Report Supplemental Appendix C.

4 Initial federal R&D support from space and defense programs was an important factor in the birth of the semiconductor and computer industries themselves. In fact, from 1950 to 1970 when the semiconductor industry was in its infancy, the federal government funded almost 50 percent of the R&D in semiconductors. See council on Foreign Relations, Independent Task Force Report No. 77. Innovation and National Security, Keeping Our Edge, 2019, P. 27.

5 For example, the Chinese government has announced efforts to invest over $100 billion over the next decade to catch up to the United States in semiconductor technology, artificial intelligence, and quantum computing.

6 Semiconductors enable these key "must-win" future technologies, including artificial intelligence to power self-driving cars and other autonomous systems, quantum computing to analyse massive volumes of data and enhance digital encryption, and advanced wireless networks to seamlessly connect people at unprecedented speeds. These core technologies will fuel innovation in other fields essential to future economic growth, such as personalized healthcare, robotics, and intelligent products.

7 Report Supplemental Appendix A provides a research framework that lays out the steps on how federal semiconductor R&D impacts overall GDP and jobs. Also, separate from the direct positive impact on GDP and jobs, federal semiconductor R&D has been shown to directly benefit the U.S. government itself in the form of computer pricing declines. For details on these benefits, please see Report Supplemental Appendix D.

8 For more information about proposed levels of federal semiconductor research investments, please see the SIA Policy Blueprint.

9 This report calculates the economic benefits of increased semiconductor research solely on GDP gains directly to the immediate downstream computer and electronics industry. While it is clear semiconductors enable many industries indirectly throughout the broader economy (e.g., transportation, health care, manufacturing, etc.), this report calculates the economic benefits exclusively through the direct downstream computer and electronics industry. The methodology in calculating the gain to the computer and electronics industry are set forth in Report Supplemental Appendix E.

10 GDP is assessed beginning in 2025 because it takes five years after R&D investments are made to see the full benefits to economic growth. Refer to Report Supplemental Appendix E (Study Methodology) for detailed study methodology. Also, please see Report Supplemental Appendix F (Additional Background Information) for more details on how the two investment scenarios change the trajectory of annual GDP growth from 2025-2029.

11 As mentioned earlier, this report takes a narrow approach to analyzing the positive economic impact of increased federal R&D funding on the economy by looking at the direct impacts to jobs and GDP to the immediate downstream computer and electronics industry only. Therefore, the total increased jobs and GDP figures in the report are conservative, given how pervasive semiconductors are in enabling other sectors indirectly throughout the broader economy. For further background on the impact on employment due to increased federal semiconductor R&D investment, please see Report Supplemental Appendix E (Study Methodology), Part 4C (Impact on Employment).

BIBLIOGRAPHY

Bloom, Nicholas, Charles I. Jones, John Van Reenen and Michael Webb. (2017). "Are Ideas Getting Harder to Find?" National Bureau of Economic Research (NBER) Working Paper No. 23782.

Borsuk, M. Gerald and Coffey, Timothy. (2003). "Moore's Law: A Department of Defense Perspective." Defense Horizons Number 30. A publication of the Center for Technology and National Security Policy. National Defense University.

Dominique Guellec & Bruno van Pottelsberghe de la Potterie. (2000). "The Impact of Public R&D Expenditure on Business R&D." OECD Science, Technology and Industry Working Papers 2000/4, OECD Publishing.

Dornbusch, Fraunhofer. (2018). "Global Competition in Microelectronics Industry from a European Perspective: Technology, Markets and Implications for Industrial Policy." Fraunhofer Center for International Management and Knowledge Economy IMW.

Handy, Jim. (2011). "How Big is a Nanometer?" Forbes. https://www.forbes.com/sites/jimhandy/2011/12/14/how-big-is-a-nanometer/#1208cd486fb0 (accessed August 27, 2019).

IB Computer Science Frankfurt International School. "Transistor Density - Smaller is Better." http://ibcomp.fis.edu/speed/transist.htm (accessed August 27, 2019).

IHS. (2015). "Celebrating the 50th Anniversary of Moore's Law."

Jorgenson, Ho, and Samuels. (2014). "Long-term Estimates of U.S. Productivity and Growth."

Khan, H. (2015). Scaling Moore's Wall: A Public-Private Partnership in Search of a Technological Revolution.

KPMG. (2017). "Evolving the D&A of semiconductor R&D: Leveraging data and analytics to create next generation R&D."

Luc L. G. Soete, Bart Verspagen & Thomas H. W. Ziesemer. (2019). "The productivity effect of public R&D in the Netherlands." Economics of Innovation and New Technology.

National Research Council. (2012). "Continuing Innovation in Information Technology." Washington, DC: The National Academies Press.

National Research Council. (2003). "Innovation in Information Technology." Washington, DC: The National Academies Press.

BIBLIOGRAPHY CONTINUED

National Research Council. (2002). "Information Technology Research, Innovation, and E-Government." Washington, DC: The National Academies Press.

National Research Council. (1999). "Funding a Revolution: Government Support for Computing Research." Washington, DC: The National Academies Press.

Platzer, Michaela D. and John F. Sargent Jr. (2016). "U.S. Semiconductor Manufacturing: Industry Trends, Global Competition, Federal Policy." Congressional Research Service R44544.

Semiconductor Industry Association (SIA). 2019 Factbook.

SIA. 1999 Databook.

SIA and Semiconductor Research Corporation. (2017). "Semiconductor Research Opportunities. An Industry Vision and Guide."

Semiconductor Industry Association. (2019). "Winning the Future: A Blueprint for Sustained U.S. Leadership in Semiconductor Technology."

Szarowská, I. (2017). "Does Public R&D Expenditure Matter for Economic Growth? GMM approach." Journal of International Studies, 10(2), 90-103.

Tassey, Greggory. (2012). "Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy." Economic Analysis Office working paper, U.S. National Institute of Standards and Technology (NIST). Science and Public Policy. 40(3): 293– 315.

The President's Council of Advisors on Science and Technology (PCAST). (2017). "Report to the President: Ensuring Long-Term U.S. Leadership in Semiconductors."

United States Government Accountability Office. (2014). Report to Congressional Requesters "Nanomanufacturing: Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health"

VerWey, J. (2019). "The Health and Competitiveness of the U.S. Semiconductor Manufacturing Equipment Industry" United States International Trade Commission Working paper ID-058.

Wikichip. "Technology Node." https://en.wikichip.org/wiki/technology_node (accessed August 27, 2019) .

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