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Report Supplemental: Appendices

SPARKING INNOVATION: HOW FEDERAL INVESTMENT IN SEMICONDUCTOR R&D SPURS U.S. ECONOMIC GROWTH AND JOB CREATION

SUBMITTED TO
Semiconductor Industry Association (SIA)

SUBMITTED BY
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APPENDIX A: Research Framework

In this section, we describe our research framework. Our analysis to estimate the impact of federal semiconductor R&D, overall GDP, and jobs contains the following steps:

STEP 1 - A: Estimate the relationship between federal semiconductor R&D and private semiconductor R&D.

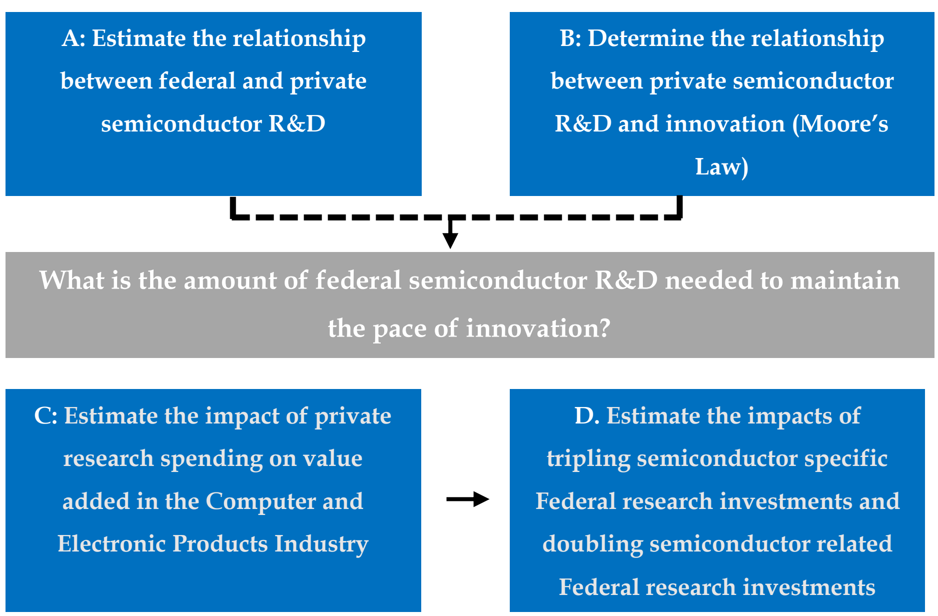
STEP 2 - B: Determine the relationship between private R&D spending and innovation (Moore's Law).

STEP 3 - Combine the results of steps 1 and 2 to estimate the federal semiconductor R&D investment required to maintain innovation (Moore's Law) in the semiconductor industry.

STEP 4 - C: Estimate the relationship between private semiconductor R&D and the value added (GDP) in the Computer and Electronics Products Industry.

STEP 5 - D: Using results from steps 3 and 4, estimate the impact of increasing federal semiconductor R&D on the value added in the Computer and Electronic Products Industry and other upstream industries, and on jobs.

Figure A-1: Approach to Estimating the Economic Impact of Federal Investments for Semiconductor and Related Research



APPENDIX B: Methodology and Programs Used to Estimate Federal Investments in Semiconductor Specific and Related Research

We estimate federal investments in semiconductor specific and related research in the United States from 1978 to 2018. In consultation with SIA, we identified two U.S. government departments – The U.S. Department of Defense (DOD) and the U.S. Department of Energy (DOE) - and two U.S government agencies – the National Science Foundation (NSF) and the National Institute of Standards and Technology (NIST) - that are involved in semiconductor specific or semiconductor related research. We used the SIA "Vision" Report (which was provided to us by SIA) as the basis for screening and identifying the programs which are semiconductor specific and semiconductor related. For each of these organizations, we examined funding at the program level using budget documents and identified relevant accounts and sub-accounts based on whether the program activity or research:

1. Supports research (basic/applied) in science and engineering disciplines.
2. Supports or relates to (i) Electronics/ Computer Systems, (ii) new technologies – IoT machine learning, AI, big data, (iii) Moore's Law, (iv) material research – e.g. silicon, (v) nanotechnology, and (vi) any other research related to semiconductors.
3. Supports research that may indirectly result in the technological advancement of the above (i) to (vi).

An illustration of our selection criteria is presented in Box B-1 below. Using this methodology, we find federal investment in FY2019 in semiconductor "specific" research was approximately $1.7 billion and investments in "related" research was approximately $4.3 billion. In total, federal investments in these two areas in FY2019 was estimated to be about $6 billion.

Box B-1: An Example of the Methodology Used to Select Federal Semiconductor R&D Programs, Using NSF

STEP 1: IDENTIFYING AND SELECTING THE ACCOUNTS

- We reviewed budget documents of NSF to
  a. understand the appropriation categories, and
  b. identify the activities that each account represents.
- NSF is budgeted into 6 accounts
  – Research & Related Activities (R&RA)
  – Education & Human Resources
  – Major Research Equipment & Facilities
  – Agency Operations & Award Management
  – National Science Board

Office of Inspector General

- Out of the 6 NSF accounts, we selected 1 account - Research & Related Activities (R&RA) based on the below mentioned description and criteria,
  a. Description: R&RA funds enable progress across the frontiers of scientific and engineering research and education.
  b. Criteria: Relates to foundational research in science and engineering disciplines.

STEP 2: IDENTIFYING AND SELECTING THE SUB-ACCOUNTS

- Out of the 10 sub-accounts within R&RA, we selected 4 sub-accounts based on the criteria mentioned above.
- The selected sub-accounts are:
  – Directorate for Computer and Information Science and Engineering (CISE)
  – Directorate for Engineering (ENG)
  – Directorate for Mathematical and Physical Sciences (MPS)
  – Directorate for Biological Sciences (BIO)
- For example, we selected sub-account (i) Directorate for Computer and Information Science and Engineering (CISE), because it satisfies the criteria that it relates to research in electronics/computer systems.

STEP 3: IDENTIFYING AND SELECTING THE SUB-SUB-ACCOUNTS

- After selecting the sub-accounts, we identify the sub-sub-accounts within each sub-account.
- For example, Directorate for Computer and Information Science and Engineering (CISE) includes the following 5 sub-sub-accounts:
  – Office of Advanced Cyberinfrastructure (OAC)
  – Computing and Communication Foundations (CCF)
  – Computer and Network Systems (CNS)
  – Information and Intelligent Systems (IIS)
  – Information Technology Research (ITR)
- We selected all of the sub-sub-accounts within CISE, based on our review of their description/objective given in the budget and applying the criteria for selection discussed earlier.
- For example, Information and Intelligent Systems (IIS) supports
  a. research that studies the interrelated roles of people, computers, and information,
  b. research and education in AI, data science, and human-computer interaction.
- The criteria for selection is that it relates to new technologies.

Table B-1: Programs Used to Estimate Federal Funding for Semiconductor Specific and Related Research

Sub-account	Sub-sub-account	FY19 Research in Related Fields ($ millions)	FY19 Semiconductor Research Funding ($ millions)
National Science Foundation (NSF)			
Engineering	Civil, mech, manufacturing Innovation (CMMI)	216.9	
Engineering	Electrical, Comms, & Cyber Systems (ECCS)	111.6	
Engineering	Engineering Education & Centers (EEC)	97.25	
Engineering	Industrial Innovation & Partnerships (IIP)	248.42	
Engineering	Emerging Frontiers & Multidisciplinary Activities (EFMA) / EFRI (pre-2016)	67.26	
Computer and Information Science and Engineering (CISE)	Office of Advanced Cyberinfrastructure (OAC) / ACI (pre-2018)	210.09	
Computer and Information Science and Engineering (CISE)	Computing and Communication Foundations (CCF)	183.03	
Computer and Information Science and Engineering (CISE)	Computer and Network Systems (CNS)	217.09	
Computer and Information Science and Engineering (CISE)	Information Technology Research (ITR)	123.14	
Computer and Information Science and Engineering (CISE)	Information and Intelligent Systems (IIS)	192.07	
Mathematical and Physical Sciences	Physics (PHY)	266.73	
Mathematical and Physical Sciences	Materials Research (DMR)	295.05	
Mathematical and Physical Sciences	Chemistry (CHE)	230.58	
Mathematical and Physical Sciences	Mathematical Sciences (DMS)	218.82	
Biological Sciences	Various	46	
Multiple	National Nanotech Coord Infrastructure	14.78	
National Science Foundation (NSF) – Sub-Total		**2,739**	

Agency	Program and Project Title / Project	FY19 Research in Related Fields ($ millions)	FY19 Semiconductor Research Funding ($ millions)
Department of Defense (DOD)			
Defense Advanced Research Projects Agency (DARPA)	**CCS-02: Math and Computer Sciences**: Machine Common Sense (MCS)	13.53	
Defense Advanced Research Projects Agency (DARPA)	**ES-02 Beyond scaling sciences:** Lifelong Learning Machines (L2M)		16.1
Defense Advanced Research Projects Agency (DARPA)	**CCS-02: Math and Computer Sciences:** Unconventional Processing of Signals for Intelligent Data Exploitation (UPSIDE)*		-
Defense Advanced Research Projects Agency (DARPA)	**CCS-02: Math and Computer Sciences:** Complexity Management Hardware (Formerly Cortical Processor*		-
Defense Advanced Research Projects Agency (DARPA)	**CCS-02: Math and Computer Sciences:** Focus Areas in Theoretical Mathematics (FAThM)*	-	
Defense Advanced Research Projects Agency (DARPA)	**CCS-02: Math and Computer Sciences:** 23 Mathematical Challenges*	-	
Defense Advanced Research Projects Agency (DARPA)	**CCS-02: Math and Computer Sciences:** Foundational Computer Science*	-	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Magnetic Miniaturized and Monolithically Integrated Components (M3IC)	8.8	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** SHort Range Independent Micro Robotics Program (SHRIMP)	4.13	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Atomic-Photonic Integration (A-PhI)	5	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Precise Robust Inertial Guidance for Munitions (PRIGM)	4.4	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Signal Processing at RF (SPAR)		7.7
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Direct On-Chip Digital Optical Synthesis (DODOS)*		-
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Semiconductor Technology Advanced Research Network (STARNet) (Microsystems Research Consortium before 2013)*		-
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Near Zero Energy RF and Sensor Operations (N-ZERO) (Basic component) *	-	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Joint University Microelectronics Program (JUMP)* (moved to ES-02 Beyond scaling sciences since 2019) *		-
Defense Advanced Research Projects Agency (DARPA)	**ES-02 Beyond scaling sciences:** Joint University Microelectronics Program (JUMP)		18
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Microscale Plasma Devices (MPD) *	-	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Micro-coolers for Focal Plane Arrays (MC-FPA) *	-	
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Beyond Scaling - Materials (Basic component) *(moved to ES-02 Beyond Scaling Sciences since 2019) *		-
Defense Advanced Research Projects Agency (DARPA)	**ES-02 Beyond scaling sciences:** Beyond Scaling - Materials (Basic component)		11
Defense Advanced Research Projects Agency (DARPA)	**ES-01: Electronic Sciences:** Beyond Scaling - Architectures and Designs (Basic component) *(moved to ES-02 Beyond Scaling Sciences since 2019) *	-	

Agency	Program and Project Title / Project	FY19 Research in Related Fields ($ millions)	FY19 Semiconductor Research Funding ($ millions)
Defense Advanced Research Projects Agency (DARPA)	**ES-02 Beyond scaling sciences:** Beyond Scaling - Architectures and Designs (Basic component)		6
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Molecular Systems and Materials Assembly (this was previously in Nanoscale/Bio-inspired and Metamaterials and Fundamentals of Nanoscale and Emergent Effects and Engineered Devices)	19.7	
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Fundamental Limits	25.22	
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Non-Equilibrium Materials	18	
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Basic Photon Science*		-
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Nanoscale/Bio-inspired and Metamaterials*		-
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Fundamentals of Nanoscale and Emergent Effects and Engineered Devices*		-
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Fundamentals of Physical Phenomena*		-
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** MesoDynamical Architectures (Meso)*		-
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Atomic Scale Materials and Devices*		-
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Enabling Quantum Technologies*		-
Defense Advanced Research Projects Agency (DARPA)	**MS-01: Materials Sciences:** Surface Enhanced Raman Scattering (SERS) - Science and Technology Fundamentals*		-
Defense Advanced Research Projects Agency (DARPA)	**TRS-01: Transformative Sciences:** Biological Complexity (BioCom)	11.94	
Defense Advanced Research Projects Agency (DARPA)	**TRS-01: Transformative Sciences:** Social Simulation (SocialSim)	13.01	
Defense Advanced Research Projects Agency (DARPA)	**TRS-01: Transformative Sciences:** Native Bioelectronic Interfaces*	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Precise Robust Inertial Guidance for Munitions (PRIGM) (Applied Research Component)	10.5	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Wafer-scale Infrared Detectors (WIRED)		15
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Modular Optical Aperture Building Blocks (MOABB)		20
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Atomic Clock with Enhanced Stability (ACES)		16
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Limits of Thermal Sensors (LOTS)	7.67	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Atomic Magnetometry for Biological Imaging in Earth's Native Terrain (AMBIIENT)	11.54	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Dynamic Range-enhanced Electronics and Materials (DREaM)	15	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** SHort Range Independent Microrobotic Platforms (SHRIMP)	4.5	

Agency	Program and Project Title / Project	FY19 Research in Related Fields ($ millions)	FY19 Semiconductor Research Funding ($ millions)
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Instinctual RF*	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Direct On-Chip Digital Optical Synthesis (DODOS) (Applied Research Component)		3
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Common Heterogeneous integration & IP reuse Strategies (CHIPS) *Formerly Fast and Big Mixed-Signal Designs (FAB) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Near Zero Energy RF and Sensor Operations (N-ZERO) (Applied Research Component) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Circuit Realization at Faster Timescales (CRAFT) *		-
Defense Advanced Research Projects Agency (DARPA)	ELT-01: Electronic Technology: Beyond Scaling - Materials (Applied Research Component) (moved to ELT-02 in 2019) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Beyond Scaling - Architectures and Designs (Applied Research Component) (moved to ELT-02 in 2019) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Wireless Autonomous Vehicle Power Transfer (WAVPT)	9.5	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Arrays at Commercial Timescales (ACT) (Applied Research Component) *	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Adaptive Radio Frequency Technology (ART) *	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Diverse & Accessible Heterogeneous Integration (DAHI) (Applied Research Component) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** IntraChip Enhanced Cooling (ICECool)*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Terahertz Electronics*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Nitride Electronic NeXt-Generation Technology (NEXT)*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Microscale Plasma Devices (MPD) (Applied Research Component)*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Micro-coolers for Focal Plane Arrays (MC-FPA) *	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Microscale Power Conversion (MPC) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Photonically Optimized Embedded Microprocessor (POEM) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Quantum Information Science (QIS) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Systems of Neuromorphic Adaptive Plastic Scalable Electronics (SyNAPSE) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Self-HEALing mixed-signal Integrated Circuits (HEALICs) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Efficient Linearized All-Silicon Transmitter ICs (ELASTx) *		-

Agency	Program and Project Title / Project	FY19 Research in Related Fields ($ millions)	FY19 Semiconductor Research Funding ($ millions)
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** High Frequency Integrated Vacuum Electronic (HiFIVE)*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Short-range Wide-field-of-regard Extremely-agile Electronically-steered Photonic Emitter and ReCEPver (SWEEPER)*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Electric Field Detector (E-FED)*	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Non-Volatile Logic*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Carbon Electronics for RF Applications (CERA)*	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Quantum Sensors*	-	
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Chip-to-Chip Optical Interconnects (C2OI) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Near-Junction Transport (NJTT) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Compound Semiconductor Materials on Silicon (COSMOS) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Advanced Microsystems Technology*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** High Frequency Wide Band Gap Semiconductor*		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-01: Electronic Technology:** Semiconductor-Tuned HTS Filters for Ultra-Sensitive RF ReCEPvers (SURF) *		-
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** Beyond Scaling - Materials		44.35
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** Beyond Scaling - Architectures		43
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** Beyond Scaling - Design		33
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** Common Heterogeneous integration & IP reuse Strategies (CHIPS)		15.5
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** System Security Integrated Through Hardware and firmware (SSITH)		22.79
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** Hierarchical Identify Verify Exploit (HIVE)		17.6
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** Circuit Realization at Faster Timescales (CRAFT)		9.4
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** Near Zero Energy RF and Sensor Operations (N-ZERO)		10
Defense Advanced Research Projects Agency (DARPA)	**ELT-02: Beyond Scaling Technology:** DARPA Electronics Resurgence Initiative		30
Defense Advanced Research Projects Agency (DARPA)	**MT-16: Beyond Scaling Advanced Technologies:** Beyond Scaling - Access		30.2
Defense Advanced Research Projects Agency (DARPA)	**MT-16: Beyond Scaling Advanced Technologies:** Millimeter Wave Digital Arrays (MIDAS) *		-

Agency	Program and Project Title / Project	FY19 Research in Related Fields ($ millions)	FY19 Semiconductor Research Funding ($ millions)
Defense Information Systems Agency	**JA1:** Joint Artificial Intelligence Center (JAIC) *		-
Office of the Secretary of Defense (OSD)	**Trusted and Assured Microelectronics:** 647: Microelectronics Innovation for National Security and Economic Competitiveness (MINSEC) Innovation and Development		428.75
Office of the Secretary of Defense (OSD)	**Trusted and Assured Microelectronics:** 822: Microelectronics Innovation for National Security and Economic Competitiveness (MINSEC) Enhancement and Demonstration		80.86
Department of Defense (DOD) – Sub-Total		182	878
Department of Commerce - National Institute of Science and Technology (NIST)			
NIST	Lab programs – (nanoelectronic COmputing REsearch (nCORE)) [1]		9.42
NIST	Standards coordination and special programs - (nanoelectronic COmputing REsearch (nCORE))[2]		1.19
NIST	Manufacturing USA	15	
Department of Commerce - National Institute of Science and Technology (NIST) – Sub-Total		15	11
Department of Energy (DOE)			
Energy and Water Development, and Related Agencies	Energy efficiency - Advanced Manufacturing - R&D Projects	99.1	14
Energy and Water Development, and Related Agencies	Energy efficiency - Advanced Manufacturing - R&D Consortia	166.9	
Energy and Water Development, and Related Agencies	Energy efficiency - Advanced Manufacturing - Technical Partnerships	40	
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - Mathematical, Computational, and Computer Sciences Research - Applied Mathematics		28.21
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - Mathematical, Computational, and Computer Sciences Research - Computer Science		22
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - Mathematical, Computational, and Computer Sciences Research - Computational Partnerships		4.77
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - Mathematical, Computational, and Computer Sciences Research - Next Generation Networking for Science	0	
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - High Performance Computing and Network Facilities - High Performance Production Computing		104
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - High Performance Computing and Network Facilities - Leadership Computing Facilities		339

[1] This relates to the funding for the nanoelectronic COmputing REsearch (nCORE) program which is a part of the Lab programs. Based on discussion with SIA, we assumed a 1.5 percent share of total funding for lab programs ($628.13) as funding for the nCore portion.

[2] This relates to funding for nCore program which also receives funding from the Standards coordination and special programs funds. Based on discussion with SIA, we assumed a 1.5 percent share of total funding for Standards coordination and special programs ($79.07) as funding for nCore portion.

Agency	Program and Project Title / Project	FY19 Research in Related Fields ($ millions)	FY19 Semiconductor Research Funding ($ millions)
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - High Performance Computing and Network Facilities - Research and Evaluation Prototypes		24.45
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - High Performance Computing and Network Facilities - High Performance Network Facilities and Testbeds		84
Energy and Water Development, and Related Agencies	Advanced Scientific Computing Research (ASCR) - Exascale Computing Project (ECP)		232.71
Energy and Water Development, and Related Agencies	Basic Energy Sciences - Material Sciences	395.74	
Energy and Water Development, and Related Agencies	Advanced Research Projects Agency - Energy (2020 budget proposes elimination of this program)	366	
Energy and Water Development, and Related Agencies	Weapons Activities - Advanced Simulation and Computing - Advanced Technology Development and Mitigation	89.07	
Energy and Water Development, and Related Agencies	Weapons Activities - Advanced Simulation and Computing - Computational Systems and Software Environment	146.65	
Energy and Water Development, and Related Agencies	Weapons Activities - Advanced Simulation and Computing - Construction	47	
Department of Energy (DOE) – Sub-Total		1,350	853
	FY 2019 Funding for Semiconductor Related Programs (to be doubled) and Semiconductor Specific Programs (to be tripled)	4,287	1,742
	Total Federal Funding for Semiconductor Specific and Related R&D for FY2019	6,029	

Note: Programs with a * were funded in years prior to 2019. There was no funding for these programs in 2019.

APPENDIX C: Examples of Federal Funding for Semiconductor Research Leading to Commercialization

DARPA's critical role in development and advancement of semiconductor technology

The Defense Advanced Research Projects Agency (DARPA) of the U.S. Department of Defense has played a key role in the development and advancement of semiconductor technology over the years through its support for basic research in semiconductor technology.

- VLSI program:
    - One of DARPA's earliest investments in the advancement of integrated circuit technology was an ambitious effort called the Very Large-Scale Integrated Circuits (VLSI) program.
    - During the 1970s and 1980s, VLSI brought together entire research communities to create significant advances in computer architecture and system design, microelectronics fabrication, and the overall cycle of design fabrication, testing, and evaluation.
    - These R&D commitments helped overcome early barriers to the transistor-scaling trends that Gordon Moore articulated.
    - The progress achieved under VLSI helped propel the field of computing, furthering U.S. military capabilities and enhancing national security, all the while helping to usher in a new era of commercial applications.
    - Among the resulting technologies from the VLSI program were Reduced Instruction Set Computing (RISC) processors, which have provided the computational power undergirding everything from supercomputers and the NASA Mars Pathfinder to today's cell phones and mobile devices.
    - Because of the development of RISC processors, the performance of graphics hardware grew 55 percent per year, essentially achieving a doubling in performance every 18 months.
- Metal Oxide Silicon Implementation Service (MOSIS):
    - Established by DARPA in 1981.
    - Provided low-cost fabrication of custom and semi-custom microelectronic devices. This enabled researchers to have direct access to fabrication facilities which they otherwise would not have.
    - Facilitated a steady pace of innovation in design and manufacturing of semiconductors.

- Semiconductor lithography:
    - DARPA funded a program that ushered in state of the art in semiconductor lithography. Working with academia and industry, the program advanced the development of new lens materials and photoresists capable of pushing past technical barriers that had previously limited the technology to 248-nanometer (nm) lithography and of supporting new-generation technology produced with 193-nm lithography.
    - These advances in miniaturization and circuit density had a dramatic effect on the semiconductor industry. The new lithography capabilities quickly became mainstream and industry players used it for advanced commercial and military microelectronics.
- Microelectromechanical systems, or MEMS:
    - In the 2000s, DARPA funded a large number of programs that developed MEMS technology and created tiny structures that move and flex rather than just conduct electrons.
    - MEMS motion sensors and actuators are the heart of certain chips which contain millions of micro-mirrors that project movies onto theatre screens.

Examples of Government Semiconductor R&D that led to product innovations

The federal government has played a critical role in overcoming challenges in semiconductor innovation through its support for exploratory research. The following investments have led to successful product innovations that are used today.

- The DOE-funded National Extreme Ultra Violate Lithography Program (NEUVLP) from 1994-1996 helped provide the foundation for advances in optical lithography that enabled the industry to continue to innovate. The NEUVLP spurred the commercial market to invest in making EUVL commercially viable which it became in 2000. EUVL technology extended the pace of Moore' Law and has enabled more powerful commercial products such as PCs and smartphones over the past 20 years.
- A DARPA-funded contract in 1996 to develop electronic switches enabled scientists at leading universities to research a new transistor design known as FinFET. This led to further DARPA and industry research from 2000-2006 and eventually to commercialization of the technology in 2011 to shrink transistor features sizes from 32 to 22 nanometers. Without this breakthrough, industry innovation would have stalled, and the world would be without the new and innovative commercial products enabled by advanced semiconductors.
- Wide Band Gap semiconductor materials development by DoD (initially ONR and then DARPA through the WBGS-RF program in the early 2000s) helped to rapidly advance an unproven material technology,

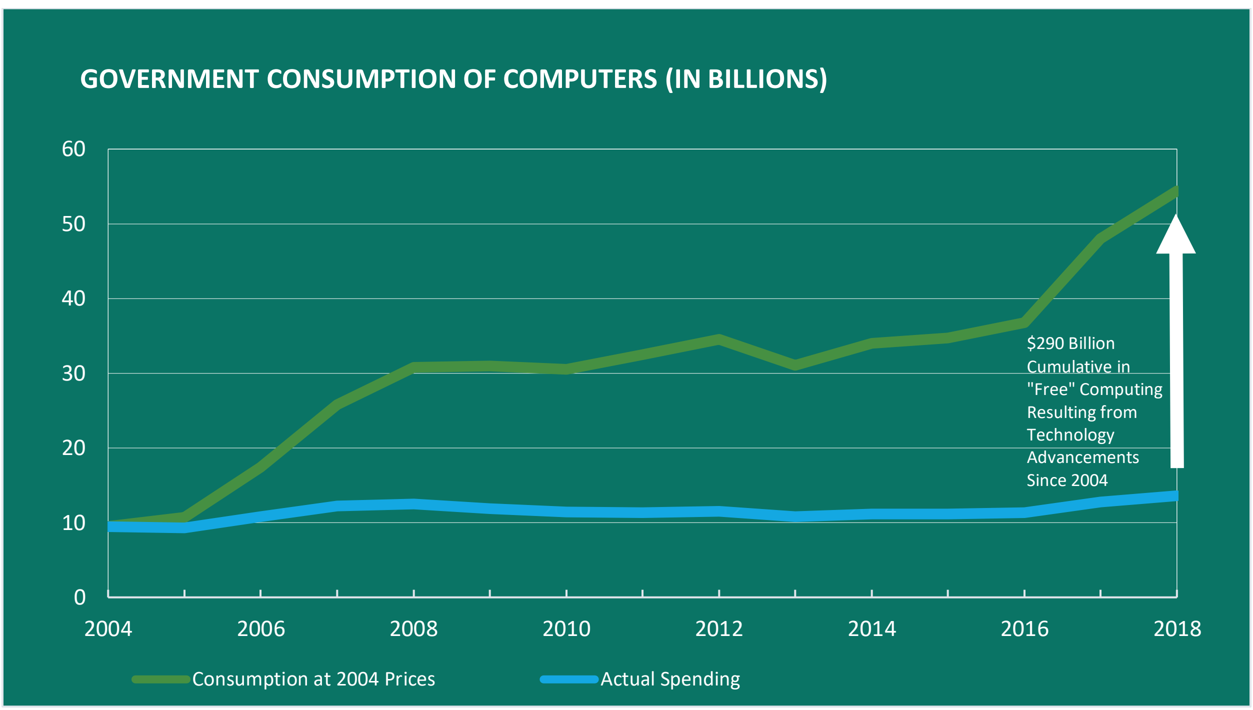
gallium nitride (GaN), into an industrially relevant one that is now a part of all major RF semiconductor device manufacturers' portfolios and is an emerging market where the U.S. semiconductor industry is dominant. GaN is also in high-power-management semiconductors, and it makes blue-green lasers and LEDs possible. Without it much of today's high-end electronics such as LED TVs would not exist.

- Gallium arsenide (GaAs) transistor innovation by DoD (OSD and DARPA), through the Microwave and Millimeter Wave Integrated Circuit (MIMIC) program in the late 1980s, provided a key piece to the commercial sector as it sought to establish newly developed cellular phone technology in the 1990s. GaAs transistors enabled handheld phones to establish the critical communications link to cell towers, and to this day most smartphones contain a small piece of GaAs to perform this critical function. This program helped propel the U.S. semiconductor industry to become the dominant driver of the wireless revolution.

APPENDIX D: Benefits of Federal Semiconductor R&D: Computer Pricing Declines Allow Government to Do More with Less

The U.S. government itself is an important beneficiary of the advances in semiconductor technology. The national research labs, scientific agencies, and government departments such as DoD, DoE, FDA, USDA, etc., critically rely on electronic equipment embedded with the latest semiconductor technology to conduct their research activities. Not only does this research enable the United States to maintain its leadership position in terms of economic growth and development, but also it is crucial for national security, disaster control and relief, among others. Innovation in semiconductors that has reduced computing cost while increased computing power has resulted in significant benefits to the government in terms of cost savings. The consumption spending by the government on computers from 2004 to 2018, if estimated at 2004 prices of computers, shows that the government saved $290 billion due to technological advancements from semiconductor innovation.

Figure D-1: Benefits to Government in Terms of Cost Savings on Computer Purchases



Source: U.S. Bureau of Economic Analysis, National Income and Product Accounts, 2018. Section 9, other tables, table 9.2U.

APPENDIX E: Study Methodology

1: Estimating the Relationship between Federal Semiconductor R&D and Private Semiconductor R&D

In order to estimate the impact of federal semiconductor R&D on private semiconductor R&D, we use an econometric model that is derived from the research of Guellec & Pottelsberghe (2000) and Sebastian Hamirani (2017). Model 1 is the mathematical representation of the relationship between the level of private semiconductor R&D, and other factors that influence it, including Federal semiconductor R&D.

Model 1: $\ln PRD_t = \beta_{\text{Cons}} + \beta_{FRD} \ln FRD_{t-5} + \beta_{Sales} \ln Sales_{t-1} + \beta_{\text{Unem}} \ln Unem_{t-1} + \beta_{CTR} \ln CTR_{t-1} + \beta_{IMP} \ln IMP_{t-1} + \varepsilon_t$

We have used the Ordinary Least Square (OLS) technique to estimate the relationships in this model. $\boldsymbol{PRD}$ is Private R&D spending on semiconductor and related research, $\boldsymbol{FRD}$ is Federal R&D investments on semiconductor and related research, $\boldsymbol{Sales}$ is Annual Sales revenue in the semiconductor industry, $\boldsymbol{Unem}$ is Unemployment in the Computer and Electronics Industry (CEI), a proxy for unemployment in the Semiconductor Industry, $\boldsymbol{IMP}$ is Semiconductor Industry Intermediate Purchase Index. The model is estimated using the natural logarithm of the variables ('ln' that precedes the variables indicates that the variables are measured in natural logarithms). $\boldsymbol{\beta}$, $\boldsymbol{\varepsilon}$, and $\boldsymbol{t}$ represent regression coefficient, error term, and indicator for time, respectively. Table E-1 shows the description and data source of the variables used in the model.

Table E-1: Description of Variables and Data Source for Model 1

Variable	Description	Years	Data Source
PRD	Private R&D spending on semiconductor and related research	1998 - 2018	2019 SIA Factbook, Slide 20
		1978 - 1997	1999 SIA Databook, p. 41
FRD	Federal R&D investments on semiconductor and related research	2003-2018	Annual Budget documents of Departments of Commerce, Defense, and Energy and National Science Foundation.
		1978-2002	Extrapolated based on available historical data. We discuss the extrapolation method below.
$Sales$[3]	Annual Sales revenue in the semiconductor industry	1978 - 1997	1999 SIA Databook, p. 46
		1998 – 2018	2019 SIA Factbook, Slide 21
$Unem$	Unemployment in the Computer and Electronics Industry (CEI), a proxy for unemployment in Semiconductor Industry	2000-2018	Bureau of Labor Statistics (BLS)
IMP	Semiconductor Industry Intermediate Purchase Index	1987-2016	Bureau of Labor Statistics (BLS)

The results of our econometric analysis are presented in Table E-2, below. Our results indicate that there is a positive relationship between the 5th lag of FRD and PRD with a coefficient of 0.42, which is statistically significant at the 10 percent significance level. This shows that a one percent increase in the FRD in the current period leads to a 0.42 percent increase in the PRD in 5 years from the current period.

- Similarly, a 1 percent increase in $Sales$ level in the current period leads to a 0.746 percent increase in PRD in the next year.
- The first lag of $Unem$ in the computer industry has no significant impact on PRD.

[3] While Guellec & Pottelsberghe (2000) used Value Added (Sales-Intermediate Input), we have used Sales and IMP due to data unavailability.

- The first lag of IMP has a significant and negative impact on PRD. A 1 percent increase in IMP leads to a 0.38 percent decrease in PRD. Such a negative relationship can be attributed to either increasing cost or decreasing productivity.

Table E-2: Relationship between Federal Semiconductor R&D and Private Semiconductor R&D

Independent Variable	Coefficient
Fifth Lag of Log of Federal R&D Spending (E)	0.424***
Lag of Log of Semiconductor Sales	0.746***
Lag of Log of CEP Unemployment	0.093
Lag of Log of Corporate Tax Revenue as a % GDP	-0.000
Lag of Log of Semiconductor Industry Intermediate Purchase Index	-0.376*
Constant	-4.838*
Observations	17
Adjusted R-squared	0.925

* p<0.10 ** p<0.05 *** p<0.01

These results show that federal semiconductor R&D is different, vital and complementary to private R&D spending in the semiconductor industry and spurs private spending on semiconductor research, indicating there is a "crowding in" effect.

2: Estimating the Relationship between Private Semiconductor R&D and Innovation in the Semiconductor Industry

The semiconductor industry's research efforts towards technological innovation have for decades been targeted to achieve Moore's Law. Nicholas Bloom et al. (2019) use the Solow growth model to study the relationship between private research spending and innovation in the semiconductor industry from 1971 to 2014.

$$Solow's\ Growth\ Model: Growth\ =\ Research\ productivity\ X\ Number\ of\ researchers$$

(Nominal semiconductor R&D expenditures of 30 semiconductor firms and 11 semiconductor equipment manufacturers from all over the world deflated by the nominal wage of high-skilled workers were used as the proxy for number of researchers).

The key findings by Nicholas Bloom et al. 2019 are as follows:

- Moore's Law (left side of the equation) corresponds to a constant exponential growth rate of around 35% per year.
- According to the analysis of the data on private semiconductor R&D expenditure, research effort has increased by a factor of 18 from 1971 to 2014.
- To maintain equality of the equation, research productivity must have fallen by a factor of 18 (or at an average rate of 6.8% per year).
- A fall in research productivity by 6.8% per year implies that after 10 years, research productivity will be halved in the semiconductor industry.
- In order to maintain the same exponential growth as Moore's Law, private research spending must double every 10 years.

2A: The Level of Private Semiconductor Research Spending Required to Maintain the Pace of Innovation in the Semiconductor Industry

Therefore, PRD has to be doubled, in order to maintain the current pace of innovation in the semiconductor industry or Moore's Law. We have estimated in **Model 1** that a 1 percent change in FRD today, will result in a 0.424 percent change in PRD in the next 5 years. Since the impact of FRD on PRD is realized 5 years later, we considered the period between 2024-2034 to double PRD as given below,

$$\frac{PRD_{2034} - PRD_{2024}}{PRD_{2024}} = 100\%$$

For a 100% change in PRD between 2024-2034, FRD should increase by approximately 236% from 2019-2029 as given below,

$$\frac{FRD_{2029} - FRD_{2019}}{FRD_{2019}} = \frac{100}{\beta_{PRD}} = \frac{100}{0.424} \approx 236\%$$

Therefore, federal semiconductor R&D must increase by 236% (i.e. close to triple) over the next ten years, to ensure that private R&D spending doubles over the period 2024 to 2034. This is required to simply maintain innovation in the industry in line with Moore's Law.

3: Estimating the Relationship between Private Semiconductor R&D and Value Added by the Computer and Electronic Products Industry

We used the Cobb-Douglas production function to analyze the impact of private R&D spending on semiconductor and related research on the Computer and Electronics Industry (CEI) value added to the GDP. Our model is based on Szarowska (2017) and Soete et al (2019). CEI value added reflects the contribution made by the industry to GDP.

Model 2: $\ln CEVA_t = \beta_{Cons} + \beta_{PRD} \ln PRD_t + \beta_{Unem} \ln Unem_{t-1} + \beta_{Cap} \ln Cap_{t-1} + \varepsilon_t$

We have used the OLS technique to estimate the model. In this model, ln, β, ε, and t represent natural log, coefficient, error term and year, respectively. $\boldsymbol{CEVA}$ is Computer and electronics industry value added (same as the GDP of CEI), $\boldsymbol{PRD}$ is Private R&D spending on semiconductor and related research, $\boldsymbol{Unem}$ is Unemployment level in CEI, $\boldsymbol{Cap}$ is Capital Expenditure in the semiconductor industry. Table E-3 shows the description and data source of the variables used in this model.

Table E-3: Description of Variables and Data Source for Model 2

Variable	Description	Years	Data Source
$CEVA$	Computer and electronics industry value added	1997-2017	Bureau of Economic Analysis (BEA)
PRD	Private R&D spending on semiconductor and related research	1998 - 2018	2019 SIA Factbook, Slide 20
		1978 - 1997	1999 SIA Databook, p.41
$Unem$	Unemployment level in CEI	2000-2018	Bureau of Labor Statistics (BLS)
Cap	Capital Expenditure in the semiconductor industry	1982-2018	2019 SIA Factbook, Slide 24

The results of the analysis indicate a positive association between private R&D spending on semiconductor and related research and computer and electronics value added. Table E-4 illustrates the results of the above-mentioned regression model. The summary of the results is;

- There is a positive relationship between PRD and $CEVA$, which is significant at 1 percent. A 1 percent increase in FRD leads to a 0.5 percent increase in $CEVA$.
- The first lag of Cap has a negative and significant impact on $CEVA$ with a coefficient of -0.182. This result indicates that an increase in physical capital expenditure leads to a reduction in value added.
- The first lag of $Unem$ has a negative and significant impact on $CEVA$ with a coefficient of -0.063.

Table E-4: Relationship between Private Semiconductor R&D and Computer and Electronic Products Industry Value added

Independent Variable	Coefficient
Log of Private R&D Spending in the Semiconductor Industry	0.501***
Lag of Log of CEP Unemployment	-0.0625***
Lag of Log of Semiconductor Capital Expenditure	-0.182***
Constant	11.68***
Observations	17
Adjusted R-squared	0.959

* p<0.10 ** p<0.05 *** p<0.01

4: Estimating the Impact of Increasing Federal Semiconductor R&D on The Computer Industry, Other Upstream Industries and Jobs

4A: Impact on Value Added by Computer and Electronics Products (CEP) Industry

We forecast the impact of federal semiconductor R&D on value addition by the computer and electronics products industry (*CEVA*), indirectly through private semiconductor R&D (PRD) using the results obtained through our regression analysis. The baseline for FRD is 2019 (enacted budget) (the latest year for which data on federal research investments is available) and that for both PRD and $CEVA$ is 2018. We forecast these variables until 2029 and compare the changes in these variables in the following two scenarios based on changes in FRD,

- Federal semiconductor R&D increases at the historic growth rate of 5%;
- Federal R&D funding for semiconductor specific research is trebled and that for semiconductor related research is doubled in five years.

In the following paragraphs we describe each of the scenarios in detail;

Scenario 1: Forecasting using the current levels of FRD

We forecast FRD for the years 2020-2029 using the CAGR of FRD between the years 2010 and 2019. Then, using the regression results of the first model (**Model 1 and Table A-2**),[4] we calculate the impact of the percentage change in PRD due to a percentage change in FRD. As per the model, FRD in the current period affects PRD five years later; for example, a dollar invested through FRD in 2019 will impact PRD in 2024. The arithmetic calculations for PRD are as follows;

$$PRD_t = PRD_{t-1} * \left(1 + \left(\left(\frac{FRD_{t-5} - FRD_{t-6}}{FRD_{t-6}}\right) * \beta_{FRD}\right)\right)$$

Following the forecasting of PRD until the period 2029, we forecast the contemporaneous effect of PRD on $CEVA$ based on the regression results from **Model 2 (Table E-2)**. These calculations are given below.

$$CEVA_t = CEVA_{t-1} * \left(1 + \left(\left(\frac{PRD_t - PRD_{t-1}}{PRD_{t-1}}\right) * \beta_{PRD}\right)\right)$$

Scenario 2: Forecasting when FRD for semiconductor specific research is tripled and FRD for semiconductor related research is doubled in five years.

In this scenario, we forecast the impact of tripling[5] FRD on PRD, and subsequently $CEVA$. First, we triple the FRD (multiply by 5) in 2024. Second, we use the 5-year CAGR for the period 2019-2024, to fill the years 2020-2023. Thus, we obtain the FRD series for the years 2019-2024. Using this series, we forecasted the impact of tripling on

[4] Only the marginal impact of FRD is considered in forecasting PRD in both the scenarios.
[5] While some programs of FRD are tripled, others are doubled. In order, to capture this effect, we have split PRD and $CEVA$ based on the proportions of doubling and tripling of FRD. Then, finally we added the two split values across all the variables for each year.

PRD and $CEVA$ for the years 2024-2029 using the same methodology as Scenario 1. For the years 2019-2024, the values PRD and $CEVA$ are same as that of Scenario 1.

4B: Impact on Value Added by Upstream Industries

We estimate the impact on value added by upstream industries to the computer and electronic products industry under two scenarios.

We use the 2017 Make table of the Input-Output Accounts from the Bureau of Economic Analysis (BEA) to identify the upstream industries that supply goods and services to the CEP industry. These are: Miscellaneous professional, scientific, and technical services; Other transportation equipment; Wholesale trade; Computer systems design and related services; Miscellaneous manufacturing; Electrical equipment, appliances, and components; Machinery; Plastics and rubber products; Chemical products; Fabricated metal products; Nonmetallic mineral products; Primary metals; Construction; Motor vehicles, bodies and trailers, and parts; Furniture and related products; Printing and related support activities; Paper products; Wood products; and Textile mills and textile product mills.

To calculate the direct impact, we use the percentage share of inputs from these upstream industries to total output of the computer industry. We then multiplied this proportion to the proportion of output to value added in the computer and electronics industry. To this we multiplied the estimated value addition by the computer and electronics industry for both scenarios – the historical growth scenario, and the tripling and doubling of Federal semiconductor R&D scenario.

4C: Impact on Employment

We used the employment multipliers obtained from literature[6] to estimate the addition of direct, indirect and induced jobs as a result of the increase in value added by the computer and electronics products (CEP) industry.

These multipliers are based on final demand for outputs of that particular industry/sector and are available for the sub-sectors of the CEP Industry, namely: Computer and peripheral equipment manufacturing; Communications equipment manufacturing; Audio and video equipment manufacturing; Semiconductor and other electronic component manufacturing; Navigational, measuring, electromedical, and control instruments manufacturing; and

[6] Bivens Josh, "Updated Employment Multipliers for the US Economy." Economic Policy Institute. January 23, 2019. https://www.epi.org/publication/updated-employment-multipliers-for-the-u-s-economy/.

Manufacturing and reproducing magnetic and optical media. We calculated the total employment multiplier for the CEP industry as the weighted average of the employment multipliers of these 5 sub-sectors. We then assumed sales obtained from 2012 Input-Output Accounts of BEA as the proxy for final demand in order to estimate the addition of jobs.

The addition of direct jobs in the CEP industry per million-dollars of demand (sales is considered as proxy for demand) is estimated as 2.5, while the addition of indirect jobs in CEP industry per million-dollars of demand (sales is considered a proxy for demand) is estimated as 5.8.

We then calculated the sales in the CEP industry as a result of the increase in value added by the CEP industry (based on the difference in value add of CEP industry between tripling and historical growth scenario) based on the ratio of value added to sales for 2017.

The addition of direct jobs in all industries (based on the difference in value added of the CEP industry between tripling and the historical growth scenario) is calculated by multiplying the estimated sales as a result of the increase in value added by the CEP industry and the employment multiplier for direct jobs in the CEP industry per dollar demand. Similarly, we calculate the addition of indirect jobs in all industries (based on the difference in value added of the CEP industry between tripling and the historical growth scenario) by multiplying the estimated sales as a result of the increase in value added by the CEP industry and the employment multiplier for indirect jobs per dollar demand.

APPENDIX F: Additional Background Information

FEDERAL SEMICONDUCTOR R&D SPURS PRIVATE SEMICONDUCTOR R&D

Historic trends in federal and private semiconductor R&D investment show they are positively correlated. In fact, not only are the contemporaneous movements correlated, but current private semiconductor R&D is highly correlated with federal semiconductor R&D from five years ago.

There is an inherently symbiotic relationship between federal and private semiconductor R&D. Federally funded research focuses primarily on exploratory basic research. The private sector builds on federally funded fundamental research and undertakes R&D that is applied in nature and has the potential to result in the development of a marketable product.

There is clear evidence of “crowding in”—whereby federal semiconductor R&D attracts more private semiconductor R&D rather than cannibalizes it. This is not surprising. There are ample examples of private semiconductor R&D leading to the commercialization of many semiconductor products and processes, triggered by federal research support. For instance, reduced instruction set computing processors that optimized the performance of computers were originally conceptualized at IBM but could not be realized until the Department of Advanced Research and Projects Agency of the U.S. Department of Defense funded additional research as part of its Very Large-Scale Integrated Circuit (VLSI) program. Appendix C presents additional examples of semiconductor products and processes that were triggered by federal research support. Appendix D shows the benefits to the Government in terms of savings on consumption spending on computers as a result of innovation in semiconductor technology.

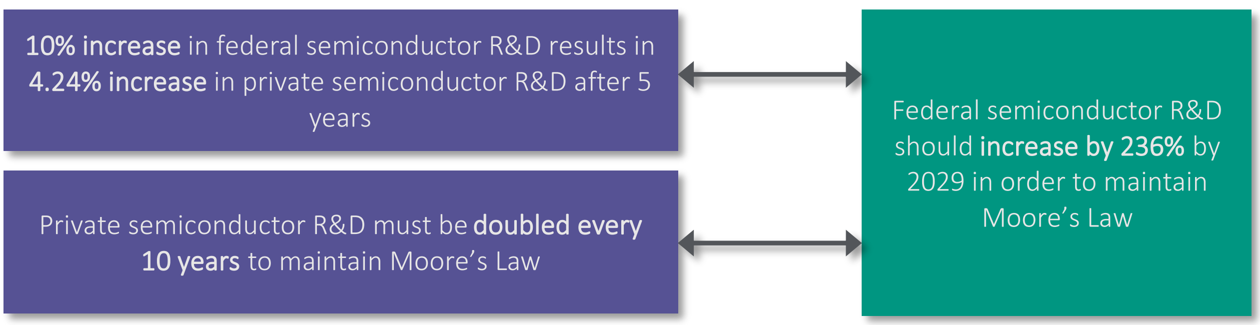
CHALLENGE OF MAINTAINING HISTORICAL RATES OF INDUSTRY INNOVATION

Semiconductor technology has grown rapidly in the last five decades. The pace of innovation in the industry is characterized by Moore’s Law, which states the number of transistors on a single semiconductor chip doubles every two years. R&D in the semiconductor industry is therefore focused on increasing chip power by packing as many transistors as possible on a single chip while continuously reducing its size. Indeed, the speed at which a processor executes instructions has increased from 750 KHz to 200 MHz, while the size of a chip has decreased from microns (millionth of meter) to nanometers (billionth of meter).

However, it is becoming harder and more expensive to increase chip power while minimizing its size. Between 1994 and 2014, research productivity in the semiconductor industry—measured by the growth rate in innovation and intensity of private research—fell by a factor of 18, or by 6.8 percent every year. At this rate of decline, research productivity in the semiconductor industry will be halved in 10 years. Consequently, private semiconductor R&D has to double every 10 years to maintain the pace of innovation at levels dictated by Moore's Law.

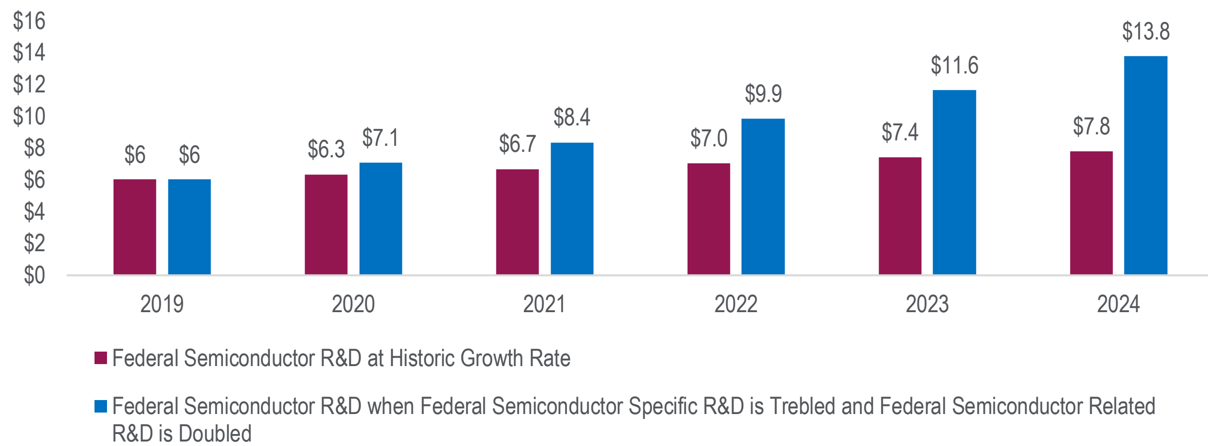
In our estimation, Federal semiconductor R&D investment must increase by 236 percent in the next decade to stimulate a doubling of private R&D funding required to maintain the pace of innovation. Stated differently, Federal semiconductor R&D investment has to more than triple for the semiconductor industry to double its R&D spending and maintain its historic levels of innovation. Please see Appendix E for detailed calculations on these estimates.

Figure F-1: Federal Semiconductor R&D Investments Required to Maintain the Industry's Historic Rate of Innovation



COMPARISON OF ANNUAL FEDERAL R&D SPENDING BASED ON HISTORICAL SPENDING AND THE PROPOSED SPENDING

Figure F-2: Increase in Federal Semiconductor R&D (in billions of USD) in Two Scenarios



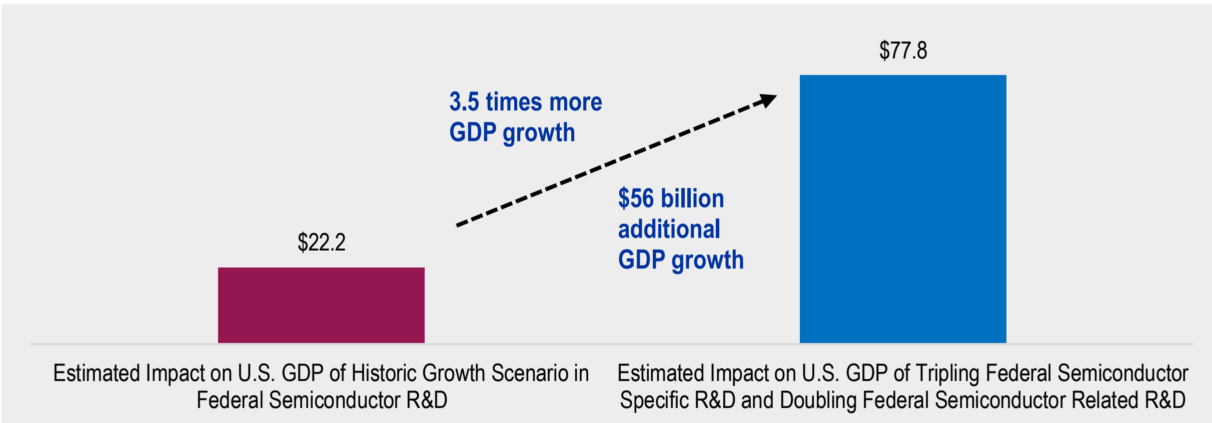
INCREASING FEDERAL SEMICONDUCTOR R&D INVESTMENTS WOULD RESULT IN 3.5 TIMES MORE U.S. GDP GROWTH

As a result of significantly increasing federal investment in semiconductor R&D, the GDP in the computer and electronics products industry and related upstream industries would grow from $383 billion in 2024 to $461 billion in 2029, a growth in GDP of $77.8 billion ($62.5 billion in the computer and electronics products industry and $15.3 billion in the upstream industries).

In contrast, if federal semiconductor R&D grows at the historic rate of 5%, GDP in the computer and electronics products industry and related upstream industries would grow from from $383 billion in 2024 to just $406 billion in 2029, a growth in GDP of $22.2 billion ($17.8 billion in the computer and electronics products industry and $4.4 billion in the upstream industries). Therefore, GDP grows 3.5 times more between 2024 and 2029 as a result of tripling semiconductor *specific* R&D and doubling semiconductor *related* R&D, i.e., an additional growth in GDP of approximately $56 billion over five years from 2024 to 2029. (Figure F-3). This additional growth is 0.3% of current

(2018) U.S. GDP of $20.5 trillion[7] and 20% of the GDP of the computer and electronics industry of $281 billion (2018).

Figure F-3: Incremental Growth in U.S. GDP from Tripling of Federal Semiconductor Specific R&D and Doubling of Federal Semiconductor Related R&D (in billions of USD)



[7] U.S. Bureau of Economic Analysis, "Gross Domestic Product, Third Quarter 2019 (Second Estimate), Corporate Profits, Third Quarter 2019 (Preliminary Estimate)" News Release, November 27, 2019, Available at https://www.bea.gov/system/files/2019-11/gdp3q19_2nd.pdf (accessed November 15, 2019).