BEYOND BORDERS

THE GLOBAL SEMICONDUCTOR VALUE CHAIN

How an Interconnected Industry Promotes Innovation and Growth

SIA SEMICONDUCTOR INDUSTRY ASSOCIATION

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SUBMITTED TO
Semiconductor Industry Association
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May 2016

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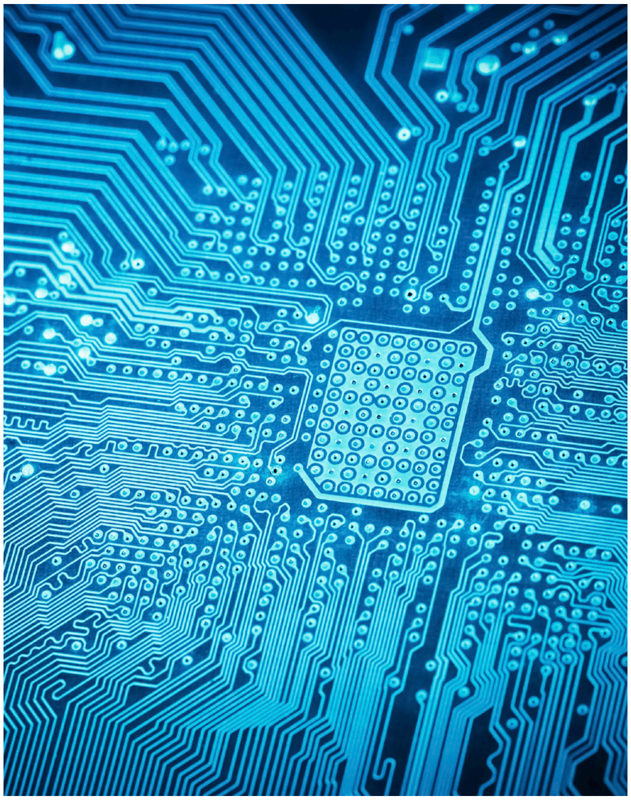
ABBREVIATIONS

ASE	Advanced semiconductor engineering
CAD	Computer-aided design
DG	Director General
EDA	Electronic design automation
FGP	Factory-less goods producers
GVC	Global value chain
HS	Harmonized System
IC	Integrated circuit
IDM	Integrated device manufacturer
IOT	Internet of Things
IP	Intellectual property
NAICS	North American Industrial Classification System
NES	Not elsewhere specified
ODM	Original design manufacturers
OECD	Organization for Economic Cooperation and Development
OSAT	Outsourced semiconductor assembly and test
PC	Personal computer
PwC	PricewaterhouseCoopers
R&D	Research & development
SEMI	Semiconductor Equipment and Materials International
SMIC	Semiconductor Manufacturing International Corp.
SOC	System-on-chip
SOP	System-on-Package
SPIL	Siliconware Precision Industries Co. Ltd
TI	Texas Instruments
TSMC	Taiwan Semiconductor Manufacturing Co.
UK	United Kingdom
UMC	United Microelectronics Corp.

1 INTRODUCTION



Semiconductors, also known as integrated circuits, microchips, or just "chips," drive the digital economy.[1] Containing thousands of miniature electronic components all connected together, semiconductors are the "brains" of all modern electronics, from consumer products including televisions, laptop computers, tablets, and mobile phones, to more sophisticated equipment used in aerospace, business operations, industrial applications, and national defense. Just like the complex and interconnected nature of a semiconductor itself, the semiconductor industry, with US$335.2 billion in global sales in 2015, is distinguished by a highly specialized, globally dispersed, and interconnected value chain. This value chain and a host of supporting activities form a complex and global semiconductor ecosystem.[2] Countries that participate in this global value chain or supporting activities reap countless benefits, including increased employment and export opportunities. The benefits compound with greater and lasting participation in that global ecosystem.

The ubiquity of semiconductors explains in part why the ecosystem is global. The extreme complexity of the industry provides a deeper explanation. The nonstop, consumer-driven demand for more and better capabilities, features, reliability, and speed requires a heavy investment in research and development (R&D), design, and efficient, low-cost manufacturing, testing, assembling and packaging, and distribution. These same pressures also affect the supporting activities, such as the production of semiconductor manufacturing equipment, development of design software and semiconductor intellectual property cores ("IP cores" or "IP blocks"), and provision of raw materials.[3] **These pressures have led semiconductor companies to develop business models that look beyond national borders to achieve efficiencies to compete in the marketplace.**

Over the years, demands for new technology innovations that rely on chips have become even greater: Simple scaling and cost reductions based on Moore's Law will soon no longer be enough to improve device performance. The industry is rapidly moving into new areas such as brain-inspired computing, the Internet of Things, energy-efficient sensing, automated devices, robotics, and artificial intelligence calling for new breakthroughs. A globally interdependent industry that pools the best each participant has to offer provides the best path to the future.

Yet, because the industry is so dynamic and a key driver of economic growth and technological innovation, a country may be tempted to create and operate a fully domestic industry by attempting to reproduce the entire value chain within its own borders. This report shows that trying to do so not only ignores the experience of several economies that have successfully participated to their benefit in the global value chain, but also risks undermining domestic industry capabilities and competitiveness.

The first section of this report describes how the semiconductor value chain and ecosystem evolved globally for economic, technological, and market reasons. Based on economic principles and case studies, the second section of the report summarizes the benefits of the current ecosystem and the risks of confining value chain activities to a single country. Because the evidence does favor a globally dispersed, but hightly interconnected and integrated ecosystem for the semiconductor industry, the report's conclusion describes policy choices that support maintenance of, and participation in, this existing ecosystem. The alternative of going it alone as a nation does not make sense from an economic or technological veiw point.

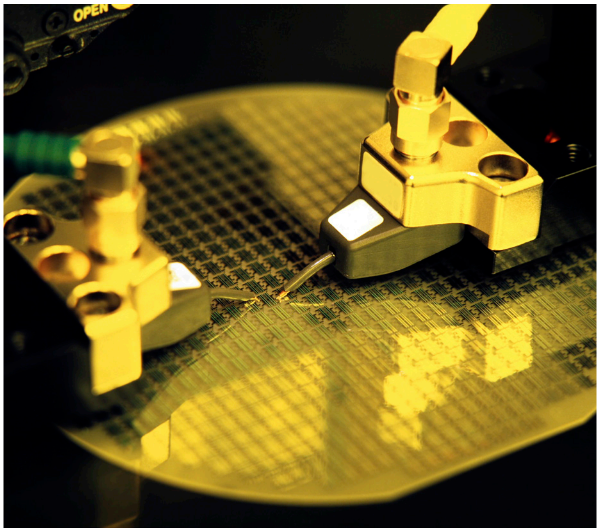
Readers desiring a more thorough understanding of semiconductor types and applications can find that information in the Appendix.

2 A DEEPLY GLOBAL INDUSTRY

Semiconductors are complex products critical to the function of everyday consumer electronics, communications and computing devices, and increasingly sophisticated equipment used in all economic sectors: aerospace, automotive, financial, medical, and retail, to name a few. End-users depend on a globally integrated supply chain comprising these activities: R&D, design, manufacturing, assembly, testing, packaging, and distribution. Carrying out each activity requires great specialization and offers a chance to add significant value. The supply chain thus becomes a value chain, with each activity contributing to the overall competitive edge of the final product.[4] The actors in the value chain form part of a semiconductor ecosystem also populated by materials suppliers, design service providers, developers of "IP cores" or "IP blocks," and makers of equipment to manufacture semiconductors.

Few industries, if any, have a value chain and ecosystem so complex, geographically widespread, and intertwined. For example, one U.S. semiconductor company has over 16,000 suppliers worldwide. More than 7,300 of its suppliers are based in 46 different American states and more than 8,500 of its suppliers are located outside of the United States. Many of those suppliers are small businesses in multiple industries that provide a variety of goods and services including chemical gases, materials, construction services, foundry services, capital equipment, spares, control and life systems, computing hardware, market research, technical consulting, and media services. The industry is uniquely structured to derive maximum benefit from the diverse and varied skills of human resources and locational advantages of participating countries. Canada, European countries, and the United States tend to specialize in semiconductor design, along with high-end manufacturing. Japan, the United States, and some European countries specialize in supplying equipment and raw materials. China, Taiwan, Malaysia and other Asian countries tend to specialize in manufacturing, assembling, testing and packaging. Canada, China, Germany, India, Israel, Singapore, South Korea, the United Kingdom, and the United States are all major hubs for semiconductor R&D. Major semiconductor companies have located facilities in countries as far flung as Costa Rica, Latvia, Mexico, South Africa, and Vietnam.

This international structure evolved over decades and is still changing. In the 1950s, individual companies tended to engage in all stages of production and operated in one country. The industry is now characterized by an ever-diversifying range of business models and relationships crossing national and regional boundaries. Technological advances and competition have driven this evolution.



Even companies that remain vertically integrated produce in multiple countries and not all are as integrated as in the past. For instance, for a subset of their products or technologies, they may turn to other companies for some specialized design or production. A significant number of these specialist companies operate throughout the world.

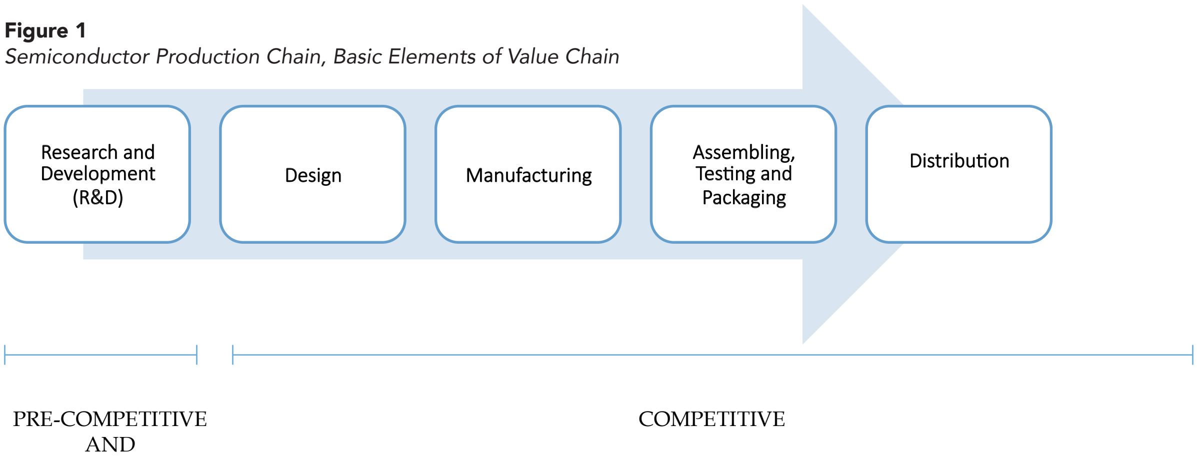
This global ecosystem benefits all participants and their global economies. Countries experience increased employment, derivative innovation, export opportunities and overall economic growth. Benefits accrue at all segments of the value chain, including those segments involving lesser investments in R&D and plant and equipment. The contribution of a country to the value of semiconductors increases as the country's economy and the skills of its workforce grow and the country moves up the value chain. Newer countries join the value chain and start to move up. The global value chain thus expands and spreads the benefits that come with it. Companies, wherever based, benefit from productivity gains, cost efficiencies from specialization, and gains from improved technology and increased knowledge.

2.1 A Global Value Chain: Forged by Complexity and Competition

To understand how and why this value chain evolved, it is important to understand the complexities of semiconductor production. This makes it possible to analyze the unique enhancements in each activity in the value chain and each of the supporting activities. This analysis also makes it possible to understand the role of competition.

Semiconductor production begins with R&D and ends with distribution (figure 1, exhibit 1). After research and before distribution come design, manufacturing, and assembly, testing, and packaging. Although research and distribution are not strictly speaking production activities, this report includes them in the production chain because of their critical importance and their role in the value chain.

Figure 1
Semiconductor Production Chain, Basic Elements of Value Chain



Research and development (R&D) activities, as figure 1 above shows, can be precompetitive or competitive. R&D is precompetitive when industry participants, government, and academia cooperate to promote technological innovation. Competitive R&D on the other hand comprises activities undertaken by individual companies in an attempt to innovate and compete in the market through better products. All other activities in the value chain also are carried out by companies that actively compete with each other by pursuing innovations and cost efficiencies. Exhibit 1 further describes each stage of production.

Exhibit 1
Stages of Semiconductor Production

Research and Development (R&D): This critical stage chain drives the industry's rapid technological advancement. Researchers constantly seek to increase the processing capability and speed of semiconductor devices while reducing their cost, following Moore's Law.* Research is increasingly moving toward "more than Moore" with a focus on innovations in packaging and technologies to surpass the physical limits of semiconducting materials. The semiconductor industry is one of the most R&D intensive industries in the world, with industry-wide investment rates ranging between 15-20 percent of sales.

Design: In the design stage, companies conceive new products and specifications to meet customer needs, then lay their design foundation. Research outcomes are a key input to the design stage, which relies heavily on highly skilled engineers and human capital.

Manufacturing: This stage involves production of the designed chips. This stage demands advanced technical and chemical/material proficiency and utmost precision. It is characterized by high fixed costs and the need for constant facility improvement to keep up with technological advances. Successful manufacturers require high capacity utilization (90 percent) and large-scale operations.

This is the final stage in the making of a semiconductor device, necessary to connect a chip or IC. This stage has higher material and higher labor costs than the manufacturing stage. It appears at the end of the production cycle and prepares the product for shipment to the market.

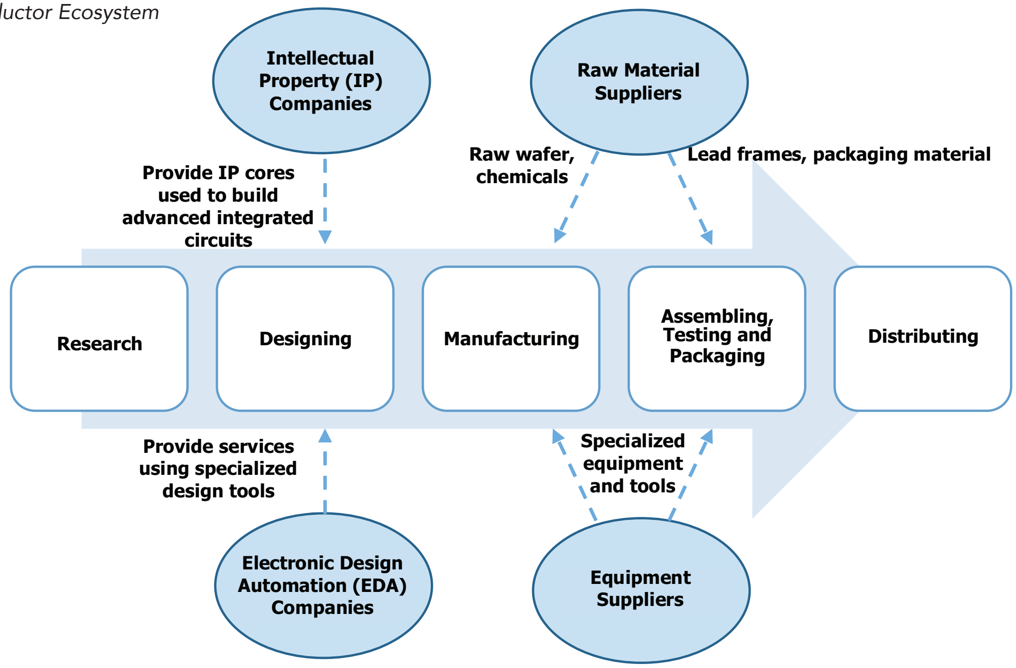
Distribution: Finished semiconductor devices are shipped to distributors or through direct sales to equipment manufacturers for use in electronic goods. Efficient logistics are essential in this stage.

*Named after Intel cofounder Gordon E. Moore. Moore's Law postulates that the number of transistors embedded in an integrated circuit doubles every 2 years, while the price remains the same. The number of transistors defines capability (e.g., processing capabilities, speed, and memory). (Refer to the Appendix for details on transistors and integrated circuits.)

Sources: SIA 2016 Databook, Jeremy Millard, et al, Study on Internationalisation and Fragmentation of Value Chains and Security of Supply (Brussels: European Commission, DG Enterprise and Industry, February 2012).

Each stage of production is highly specialized and competitive. For participants in the supply chain to succeed, they must offer better features or cost advantages. These features or advantages must incorporate continuously evolving consumer preferences and differentiate the participant's contribution to the supply chain. Participants in the supply chain thus turn it into a value chain. The end product containing a semiconductor becomes more competitive in the market.

Figure 2
The Semiconductor Ecosystem



2.2 Supporting Activities: Completing the Ecosystem

Specialized companies whose activities support the value chain—in an industry characterized by unprecedented technological advancement—complete the semiconductor ecosystem. The contribution of these companies is essential to producing semiconductors that are competitive in price, quality, performance, and consumer preference. The main types of supporting companies in the semiconductor ecosystem are:

- IP companies that develop and license predesigned "blocks" of circuits that semiconductor companies then integrate into their own broader chip designs as a subset of their own chips.[5,6];
- Electronic design automation (EDA) companies that provide computer-aided design (CAD) and other design services[7];
- Materials companies that produce wafer-fabrication and packaging materials; and
- Equipment manufacturers that produce specialized equipment and machine tools for manufacturing, assembly, testing, and packaging.

Figure 2 illustrates the ecosystem, showing where supporting companies interact with the value chain.

2.3 Differentiation: Driven by Demand

Differentiation in human and financial resource requirements across various stages of production is a distinguishing feature of the semiconductor industry. This differentiation is based on factors such as pace of innovation, technology requirements, scale of production, and operational efficiency. For instance, semiconductor design requires teams of skilled engineers, while the manufacturing stage is capital intensive and requires advanced technological expertise: a capacity utilization rate of as high as 90 percent is considered to be "healthy" for semiconductor manufacturers.[8] Assembly, testing, and packaging is more labor intensive, requiring less technical skill, although this paradigm is shifting because of advances in packaging technology. Those advances will require more skilled labor.

Through differentiation, companies perform the tasks they do best and assign the rest to other companies better equipped for that work, thereby gaining a competitive advantage.[9] Demand for rapid innovations, combined with the efficiencies resulting from specialization, enables companies to compete successfully.

2.4 Operating Models: Responding to Change

Different levels of specialization and functional delineation in the value chain have led to the emergence of two key operating models in the semiconductor industry: IDM, for integrated device manufacturer, and fabless-foundry. Figure 3 diagrams these two models along with the industry participants, including R&D companies, and identifies some companies representing different activities in the value chain.

In the IDM model, one company carries out all stages of production—design, manufacturing, and assembly, testing, and packaging. In the fabless-foundry model, production is split: Design companies focus on design and contract out manufacturing (fabrication), and are thus "fabless." Foundry companies concentrate on contract manufacturing. A third group of companies, though not part of the fabless-foundry name, perform assembly, testing, and packaging. This third group is known as outsourced semiconductor assembly and test companies, or OSATs.

Figure 3
Operating Models in the Semiconductor Industry

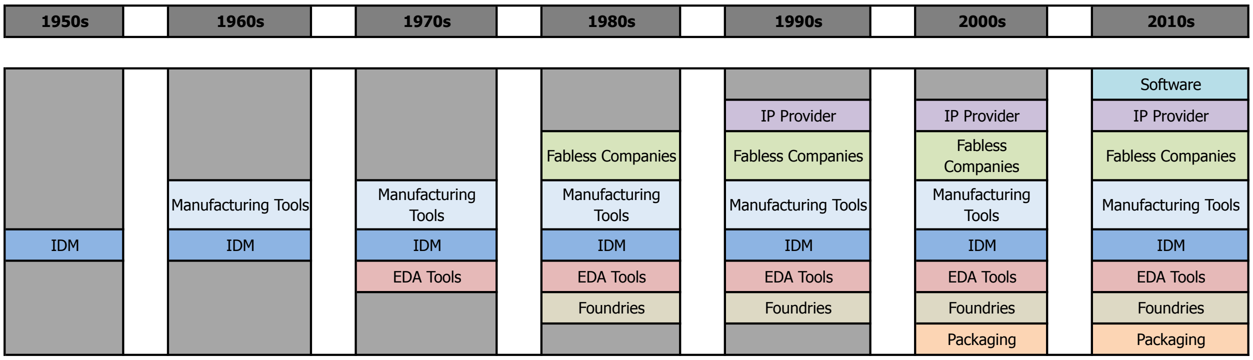
Research and Development (R&D)	Fabless-Foundry Model			Distribution (to OEMs / ODMs)*
	Design (Fabless) AMD, Broadcom, MediaTek, Spreadtrum, Qualcomm	**Manufacturing (Foundries)** Global Foundries, HH Grace, SMIC, Tower Jazz, TSMC, UMC	**Outsourced Assembly and Test (OSAT)** Amkor, ASE, ChipPAC, JCET, J-Devices, Power-tech, SPIL	
	IDM Model			
CEA-Leti, IMEC, ITRI, SEMATECH, Semiconductor Research Corporation	**Integrated Device Manufacturer (IDM)** Infineon, Intel, Micron, Renesas, Samsung, Texas Instruments			Allied Electronics, Arrow Electronics, Avnet, Digi-Key, Mouser Electronics

** Original Equipment Manufacturers (OEMs)/Original Design Manufacturers (ODMs) buy semiconductors to integrate into consumer end-products*

The IDM model derives efficiencies from vertical integration. The fabless-foundry model derives efficiencies from delineation of tasks and specialization. The fabless companies focus on design and innovation and avoid heavy investment in setting up, maintaining, and upgrading foundries. Foundries try to achieve high capacity utilization and efficiency by servicing many fabless companies in the market. OSATs focus on achieving operational efficiencies by also serving many companies to ensure a profitable capacity utilization rate, just as foundries must. Figure 4 highlights the functional evolution in the semiconductor industry over the years toward a diversity of business models and industry relationships.

Figure 4

Functional Evolution of the Semiconductor Ecosystem (1950s–2010s)



Note: The individual colored blocks are only a representation of the participants present in the semiconductor value chain at various points in time. They are not indicative of their relative market sizes.

Source: Heide, Marcel, et al., Study on the changing role of Intellectual Property in the semiconductor industry—including non-practicing entities, (European Commission DG Communication Networks, Content & Technology, Report prepared by TNO and CWTS, 2014), 6.

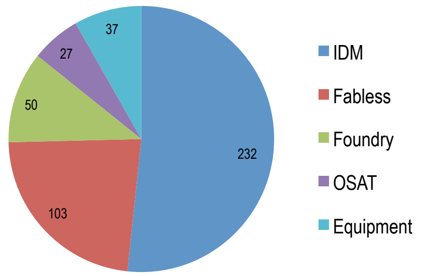
IDMs had the largest revenue share of the semiconductor industry in 2014. However, while IDMs will continue to play an important role, the fabless-foundry model is gradually becoming a larger portion of the industry as technology changes and products become even more complex. Between 2009 and 2014, fabless, foundry, and OSAT companies have shown a higher compound annual growth rate (CAGR) than IDMs

In the past decade, IDMs have been acquiring more characteristics of the fabless-foundry model. Several IDMs contract with other companies to manufacture chips while performing all other remaining tasks internally. This is commonly called fab-lite. Many IDMs become fab-lite due to the constant and costly need to upgrade manufacturing facilities to keep up with technological advances.

The growth in vertical specialization in semiconductors since 1985 reflects the influence of both market-related and technological factors. The expansion of markets for semiconductor devices enabled vertically specialized semiconductor design and production firms to exploit economies of scale and specialization, consistent with the predictions of [George] Stigler and [Adam] Smith. Scale economies lowered production costs, expanding the range of potential end-user applications for semiconductors and creating additional opportunities for entry by vertically specialized firms. The increasing capital requirements of semiconductor manufacturing provided another impetus to vertical specialization, since these higher fixed costs make it necessary to produce large volumes of a limited array of semiconductor components in order to achieve lower unit costs. The design cycle for new semiconductor products also has become shorter and product lifecycles more uncertain, making it more difficult to determine whether demand for a single product will fully utilize the capacity of a fabrication facility that is devoted exclusively to a particular product and increasing the risks of investing in such "dedicated" capacity. Since foundries tend to produce a wider product mix, they are less exposed to these financial risks.

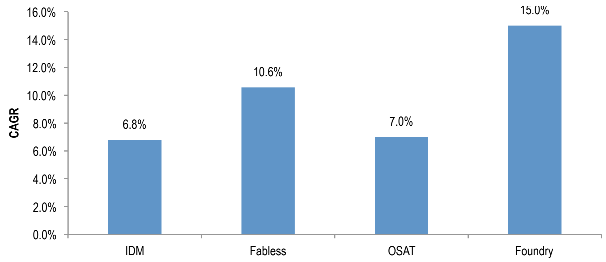
—Jeffrey T. Macher and David C. Mowery, "Vertical Specialization and Industry Structure in High Technology Industries," Business Strategy Over the Industry Lifecycle, Advances in Strategic Management, Volume 21 (2004), 331–332.

Figure 5
Revenue by Semiconductor Sector (2015), US$ Billion



Source: Semiconductor Industry Association; World Semiconductor Trade Statistics; SEMI, "SEMI Reports Global Semiconductor Equipemnt Sales of $36.5 billion," http://www.semi.org/en/semi-reports-2015-global-semiconductor-equipment-sales-365-billion; IC Insights, Research Bulletin, "U.S. Companies Continue to Capture Bulk of IDM and Fabless IC Sales," http://www.icinsights.com/news/bulletins/US-Companies-Continue-To-Capture-Bulk-Of-IDM-And-Fabless-IC-Sales/; IC Insights, Research Bulletin, "Leading Edge Leads the Way in Pure-Play Foundry Growth," http://www.icinsights.com/news/bulletins/Leading-Edge-Leads-The-Way-In-PurePlay-Foundry-Growth/; PR Newswire, "Advanced Packaging Market and OSAT Industry 2015 Review Report for Global and Chinese Regions," http://www.thestreet.com/story/13269917/1/advanced-packaging-market-and-osat-industry-2015-review-report-for-global-and-chinese-regions.html

Figure 6
Growth (CAGR) in the Semiconductor Ecosystem, (2009–2015)



Source: Semiconductor Industry Association; World Semiconductor Trade Statistics; EE Times, "Fabless Chip Companies Ranked by 2013 Sales," http://www.eetimes.com/document.asp?doc_id=1322324&page_number=2; EE Times, "Foundry Sales Growing Faster Than Chip Market," http://www.eetimes.com/document.asp?doc_id=1324902&page_number=1; PR Newswire, "Advanced Packaging Market and OSAT Industry 2015 Review Report for Global and Chinese Regions," http://www.thestreet.com/story/13269917/1/advanced-packaging-market-and-osat-industry-2015-review-report-for-global-and-chinese-regions.html

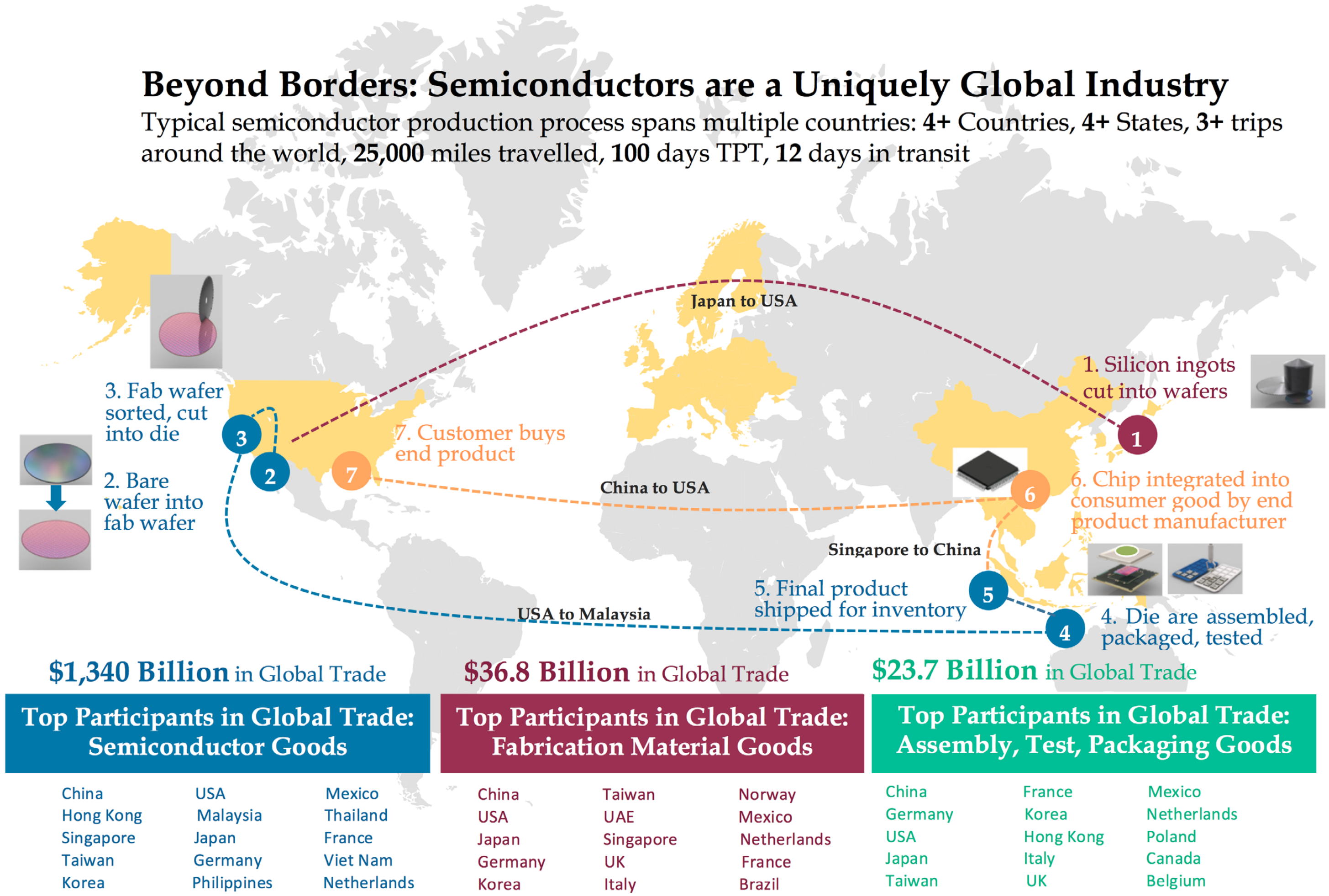
Thus, from a time in the early 1960s when individual firms performed all functions in-house and used a "combination of homemade equipment and scientific lab equipment,"[10] the industry has evolved into an entire semiconductor ecosystem. Firms enhance competitiveness through increasing specialization in only certain segments of the value chain including the support activities. This ecosystem is together enhancing the overall competitiveness of semiconductors in capabilities, consumer preferences, and price.

2.5 Here, There, Everywhere: Geographic Dispersion of the Value Chain

The semiconductor value chain began to cross national boundaries in 1961 when the U.S. company Fairchild Semiconductor, facing increased market and technological competition, began assembling chips in Hong Kong. The advantages of this move included lower costs, availability of qualified engineering and technical personnel, advanced infrastructure, proximity to consumer markets, and low tax rates and duties, increasing the competitiveness of the U.S. company.[11] This allowed the firm to continue to rapidly increase its investment into R&D that was essential to creating new technologies. The value chain became increasingly dispersed as the benefits grew. Today, a majority of the wafer capacity of U.S.-based firms is located in the Americas, while 30 percent lies in the Asia-Pacific, 9 percent in Europe, and 9 percent in Japan.[12,13] Exhibit 2 at the end of this section summarizes the factors promoting a global value chain.

A variety of data make it possible to gauge the extent to which the value chain transcends national and regional boundaries. These include information on revenue and trade flows for various products and raw materials. Figure 8, based on share of revenue, illustrates international dispersion of the semiconductor value chain for the IDM and the fabless-foundry models.[14]

Figure 7
Example of the Global Nature of the Semiconducor Value Chain



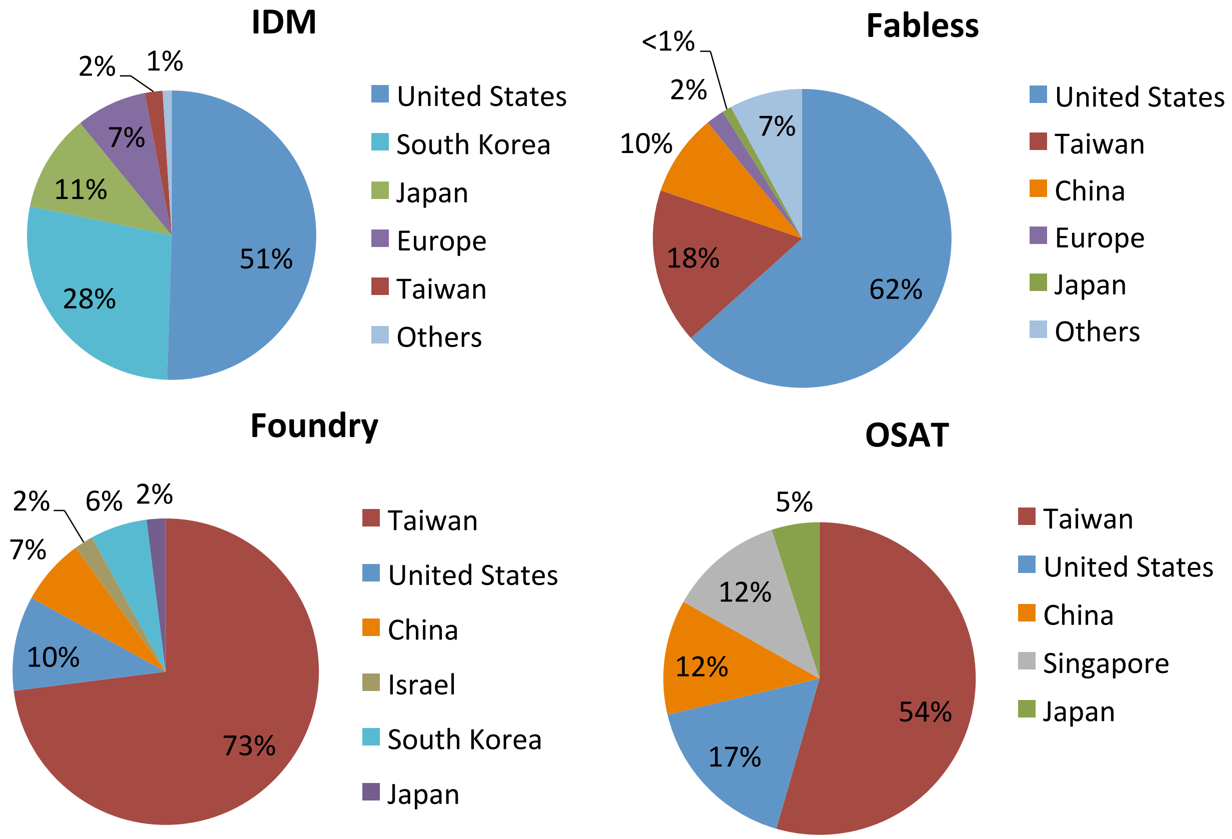
Source: UN Comtrade and Taiwan Customs Administration, Ministry of Finance; Year of 2014

Semiconductor goods defined by HS Codes: 8541 (Diodes, Transistors, and Similar Semiconductors); 8542 (Electronic Integrated Circuits)

Fabrication materials goods defined by HS Codes: 280429 (Rare gases other than Argon); 280430 (Nitrogen); 280461 (Silicon (>99.99% pure)); 280469 (Silicon (<99.99% pure)); 28047 (Phosphorus); 851680 (Resist); 903141 (Photomasks)

Assembly, test, packaging goods defined by HS Codes: 3506 (Glues and Adhesives); 854710 (Ceramic Packaging)

Figure 8
Internationalization of the Semiconductor Value Chain (% of total revenue, 2015)



Source: IC Insights, Research Bulletin, "U.S. Companies Continue to Capture Bulk of IDM and Fabless IC Sales," http://www.icinsights.com/news/bulletins/US-Companies-Continue-To-Capture-Bulk-Of-IDM-And-Fabless-IC-Sales/; Gartner, "Worldwide Semiconductor Foundry Market Grew 4.4 Percent in 2015, According to Final Results by Gartner," http://www.gartner.com/newsroom/id/3281630; Company reports.

Note: The IDM and fabless charts describe the share of IC revenue across the entire global market. The charts for foundry and OSAT describer the share of semiconductor revenue across the top 10 companies in their respective sectors.

IDMs are mainly concentrated in the United States, South Korea, Japan, and Europe, in that order. Several IDMs also have dispersed segments of the value chain geographically, (although still within the firm) to realize cost advantages (see Figure 9). In the fabless-foundry model, countries' roles differ according to the activities performed. For instance, the United States and Taiwan lead in the design segment of the value chain, while Asian countries, particularly Taiwan, largely concentrate on manufacturing and assembly, testing, and packaging.[15] Besides Taiwan and United States, there are several other countries involved in the fabrication segment of the semiconductor value chain, either as pure-play[16] foundries (e.g. Israel and China) or as wafer manufacturing plants of IDMs (e.g., Ireland and Singapore).[17] Assembly, testing, and packaging are also performed in several countries including Taiwan, United States, China, Singapore, and Japan.[18]

Delineation and globalization of production are also apparent in activities supporting the semiconductor value chain. The United States and Japan[19] are the two leading suppliers of semiconductor manufacturing equipment, with 44 percent and 32 percent market shares, respectively.[20] The Netherlands has a strong presence as a maker of high-end equipment to

Figure 9

Geographic Dispersion of the SemiconductorValue Chain by Six IDMs

manufacture integrated circuits.[21,22] Japan is the foremost supplier of materials, including wafer fabrication materials and packaging materials such as lead frames and bonding wires, providing more than 50 percent of the world supply of semiconductor production materials.[23] The United States and several European countries also engage in materials supply.

2.5.1.1 Integrated Circuits, Silicon: an Expanded World Market

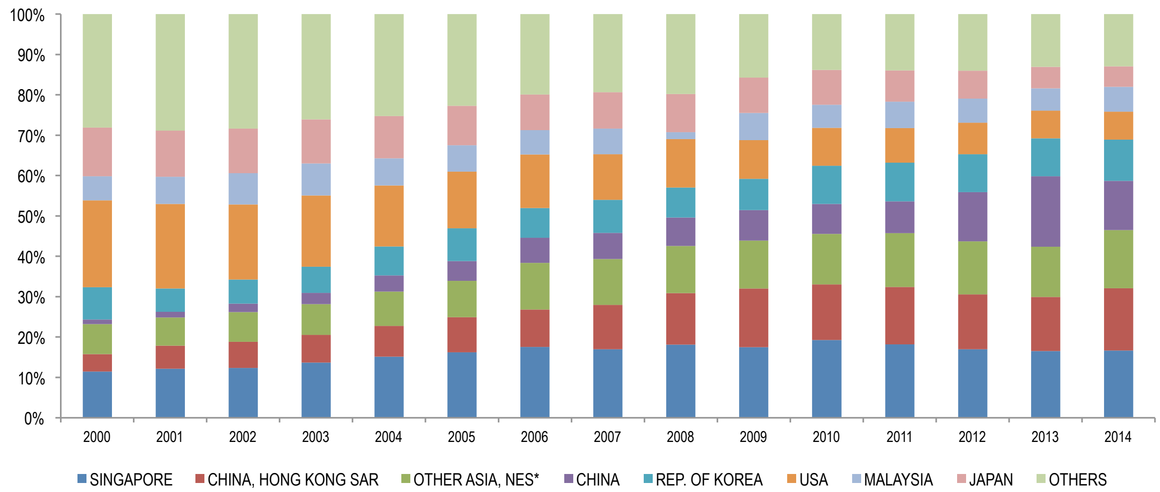
As the next two figures demonstrate, export markets have created growth opportunities for many exporters. And while it appears that some countries have lost market share—the United States and Japan, for example—it must be remembered that the size of the market has grown. Subsequent discussions will show that a diversity of suppliers is a net plus for all, because numerous suppliers can step in to add more and more specialized value to enhance the competitiveness of the end product.

Figure 10 illustrates the share of the major countries in the export of integrated circuits (ICs) from 2000 through 2014. This figure demonstrates that many nations export electronic integrated circuits, and the global participation has increased since 2000. This clearly shows the global nature of the industry, with no one country standing alone.

Analysis of data on imports of silicon—the primary raw material for chips—also highlights how increasingly interconnected the semiconductor ecosystem has become, evidence of growth amid an expanding value chain. Figure 11 gives the share of different countries in silicon imports from 1995 to 2014. Silicon imports are a good indicator of semiconductor manufacturing in a country. Semiconductor manufacturing has become a truly international enterprise over the past 20 years

The various discussions and data presented in this section highlight the evolution and extent of geographic dispersion in the semiconductor global value chain. At the same time, the discussions in this section also point toward the potential for newer countries, for example in South America and Africa, to enter the semiconductor global value chain by undertaking activities of semiconductor production in which they have a competitive advantage, such as affordable human resources and low cost of production. As the countries that currently participate in the semiconductor global value chain experience economic growth and as their skill and technological capabilities and cost structures change, they will move up the value chain, making room for new entrants. Also, as segments of the value chain become increasingly specialized due to rapid innovations, new sub-segments or supporting activities will emerge in the value chain—just as semiconductor design further specialized into EDA companies and IP block companies—providing opportunities for new countries and companies to enter the semiconductor global value chain.

Figure 10
Share of Global Exports of Electronic Integrated Circuits

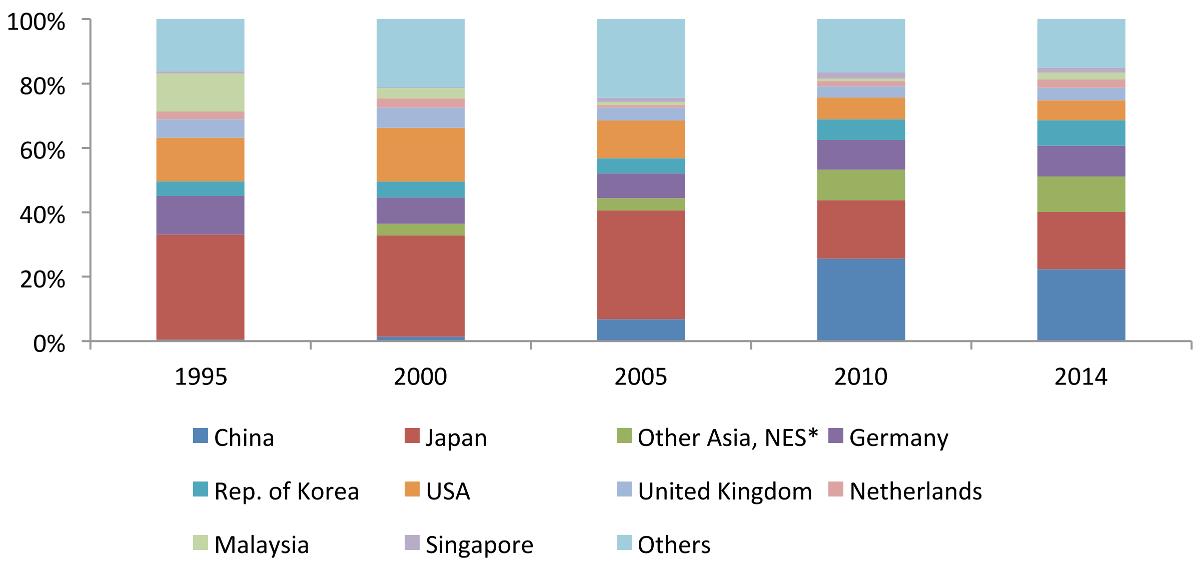


Source: UN Comtrade (Code: 8542)

*NES: Not elsewhere specified

Note: Singapore has a high share of exports as a major transshipment hub for semiconductors.

Figure 11
Shares of Global Imports of Silicon



Source: UN Comtrade (Code: 8542)

*NES: Not elsewhere specified

Exhibit 2
Factors promoting a global value chain for semiconductors

Relative advantage of countries in undertaking certain activities: The semiconductor global value chain enables countries to focus on activities where they have a competitive advantage and trade for other goods and services. In the semiconductor global value chain, countries "trade in tasks" within specific segments of the value chain. Generally, countries with abundant labor perform labor-intensive tasks (e.g., assembly and testing), while countries with skilled labor (process knowledge) primarily undertake technology-intensive tasks (e.g., manufacturing), and developed economies focus on knowledge-intensive tasks (e.g., design). A country's comparative advantage is not static, but will constantly adjust as some activities grow and some decline, and as a country's economic and structural policy environment changes.

Trade-facilitating conditions: The emergence of global value chains has also been facilitated in the recent years by advancement in information and communications technology, improving the quality and reducing the cost of global communications and business operations through real-time interaction and resource sharing. Technological advancements have also facilitated development of international standards for technology, product descriptions, and protocols. Increased trade liberalization and the resultant increased access to worldwide resources and markets have also contributed to the emergence of a semiconductor global value chain. Another promoting factor has been the reduction in costs associated with international trade (port costs, freight and insurance costs, tariffs and duties, transportation and communication costs, and so on).

Positive business environment: Elimination of tariffs, provision of tax benefits such as R&D credits, provision of grants, establishment of industrial clusters, protection of IP, and government investment in skill development are all incentives that prompt firms to move their operations to countries to improve their competitiveness. At the same time, changing perceptions of the stability and openness of markets, concerns about intellectual property protection, rising costs and a range of other factors also prompt firms to "back-shore" or relocate activities. A positive and stable business and policy environment is a key factor in firms' decision to invest and engage in economic activities in a country.

Proximity to end-use markets: Increased demand for electronic products in emerging markets especially in Asia has pushed semiconductor companies to move production facilities closer to these markets.

Physical characteristics of semiconductors: Semiconductor manufacturing involves physically distinct stages of production which allow for geographic dispersion of the production process. Further, the high value to weight ratio of semiconductors allows easy and economical transportation during the various stages of production.

3 GLOBAL APPROACH: CLEAR-CUT BENEFITS

As the preceding section shows, the semiconductor value chain became geographically dispersed for an array of economic and technological reasons, as a result of business decisions made over time in response to specific situations. This globally integrated value chain contributes to a steady stream of innovation—fueled by demand and large-scale spending on R&D—and to the availability of increasingly sophisticated and affordable products. This section details the benefits to industries, consumers, and entire economies of participating in the global value chain, citing economic principles and examples from numerous industries, including the semiconductor industry. The benefits of participation can also be demonstrated through a "but-for" analysis: but for a global value chain, what position would industries, consumers, and national economies be in? Recent history has numerous examples of the risks to industries of economies that have insulated themselves from the global market. This section also categorizes costs and risks of a nationalistic approach.

3.1 Benefits of Participating in the Global Value Chain

3.1.1 Greater Efficiency, Higher Productivity

The most obvious benefits from division of tasks across countries are efficiency gains and higher productivity as companies concentrate efforts on areas where they can excel, with each region adding maximum value on a competitive basis, in a way that naturally controls the risks of overcapacity and oversupply.

The first step toward the global semiconductor value chain—the decision by market players to establish facilities in Asia in response to intense inter-industry competition—was based on this consideration. As benefits of a global value chain became more apparent, U.S.-based activities gravitated to R&D, design and high-end manufacturing, while the availability of more-skilled and less-skilled labor drew other manufacturing, assembly, and testing to Asian countries. The higher value-added activities are still spreading: U.S. companies have been initiating R&D development activities—especially focusing on the design stage of the value chain—in the United States and other regions such as India, Israel, Malaysia, and Singapore as skill levels there have risen and governments have introduced policies supporting such specialized participation in the global value chain. [24,25,26] Suppliers of electronic design automation (EDA) services in China, India, Malaysia, Singapore,

South Korea, and Taiwan have harnessed their competitive advantages in designing through the use of EDA tools and have experienced high revenue growth in response to global demand.[27] In short, the allocation of tasks across countries based on competitive advantages enables companies to operate more efficiently and compete more effectively in the world market. It is important to note that "increasing foreign presence does not necessarily involve the closure or physical offshoring of existing production from advanced economies, but does often imply the creation and expansion of affiliates abroad."[28] This behavior by companies ultimately benefits national economies around the world where companies place jobs and often invest in local universities, science centers, and other contributors to the semiconductor ecosystem.

3.1.2 Economic Growth, Lower Consumer Prices

Another major benefit from participating in the global value chain is the positive impact it has on overall economic development of every participating nation. The positive impacts are measurably direct, as in exports and sales, or may be more diffuse, promoting productivity and lowering consumer prices. The activity does not have to occur within a geography to benefit that geography. It can occur anywhere in the world, with some of the benefits (e.g., revenues) coming back to the parent company to fule more innovation.

For instance, by tapping into the global value chain, South Korea has seen its share of worldwide semiconductor sales increase from about 6 percent in the early 1990s to 17 percent in 2014. Taiwan's share has increased from almost zero in the early 1990s to 7 percent in 2014, and China's share has increased from almost zero in the early 2000s to 4 percent in 2014. The U.S semiconductor market share has remained roughly steady at around 50 percent for the past 20 years, yet the industry's contribution to the U.S. economy, as measured by growth in real value added, has accelerated amid globalization, increasing 265 percent from 1987–2011. The pace exceeded that of any other manufacturing industry. Value added jumped to US$65 billion from US$50.3 billion from 2007–2011, growing far faster than GDP as a whole. Among manufacturing industries, only petroleum refineries and pharmaceutical preparation makers contributed more to U.S. GDP in 2007 and 2011.[29]

The Taiwanese semiconductor industry is also making significant contribution to Taiwan's GDP through estimated exports worth US$61.2 billion in 2014—demonstrating a 16.3 percent year-over-year increase.[30]

Deeper global value chain integration resulting from participation in trade liberalizing agreements has also been critical in spurring economic growth, especially for developing countries. The 1997 Information Technology Agreement (ITA) – a multilateral trade pact that eliminated tariffs on a wide range of electronic products – is a key example. Several ITA countries saw their shares of ICT goods exports increase dramatically in the years following ITA implementation.[31] For example, China's share of global exports of IT products rapidly expanded from 2.2 percent in 1996 to 27.5 percent in 2012, surpassing both the EU and the US to become the leader in overall ITA trade in 2005.[32]

R&D spending, spurred by participation in the global value chain and rewarded by increased global sales, cannot be discounted as a driver of economic growth.[33] In 2015, the worldwide semiconductor industry spent a record US$56.4 billion on R&D.[34] R&D expenditures of the U.S. semiconductor industry grew at an average annual rate of about 33 percent during 1994–2014, and R&D spending as a share of sales ranged from 15-20 pecent for U.S. semiconductor firms over the last 10 years—an unprecedented ratio among manufacturing industries in the United States.[35]

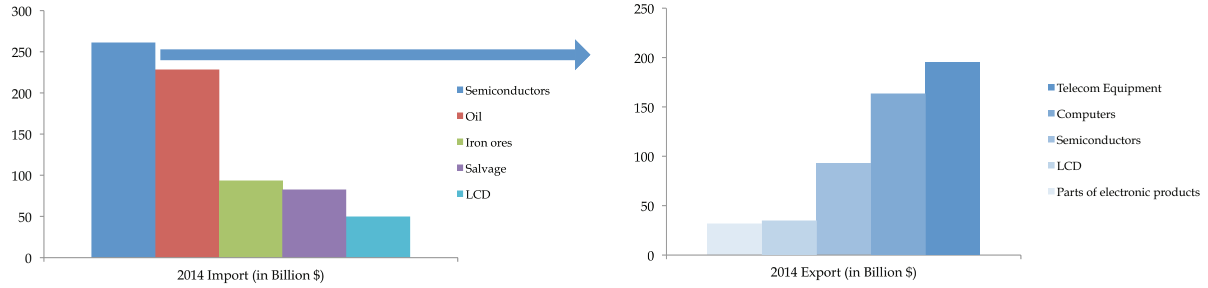
The technological advances that R&D spending brings about have created significant value through price and productivity. The benefit to consumers can be estimated as the difference between the price that consumers were willing to pay for a semiconductor and the lower price that they actually paid. For instance, economist Kenneth Flamm estimated that "in 1995, the value of a year's price decline was worth $12 billion to consumers," meaning "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."[36] If the automobile industry had had similar improvements in price and performance to semiconductors over three decades, "a Rolls-Royce would cost only US$40 and could circle the globe eight times on one gallon of gas—with a top speed of 2.4 million miles per hour."[37]

3.1.3 Access To Large And Growing Markets Worldwide

The international diffusion of the semiconductor value chain is not driven by cost and efficiency considerations alone. Access and proximity to markets and customers is another very important reason for joining this value chain.

In particular, the market for semiconductors[38] in the Asia-Pacific has quadrupled over the past 15 years—from US$39.8 billion in 2001 to over US$194 billion in 2014.[39] China alone accounts for 29.4 percent of all single-country sales of semiconductors.[40] Other statistics from Chinese sources put Chinese consumption of semiconductors at 56.6 percent of the global market, making semiconductors China's leading import.[41] It is important to note that a large percentage of this consumption is re-exported to customers around the world, not domestically consumed, after the semiconductor is incorporated into an end product.[42] In fact, China's top five exports (in terms of revenue) are electronic end products that use semiconductors, and semiconductors themselves are China's third largest export. Without its large imports of high-quality semiconductors, China would not be the exporting powerhouse it is today (Figure 12).

Figure 12
Relationship between China's Semiconductor Imports and Top Five Exports (in Revenue)



Source: UN Comtrade Database. HS Codes Semiconductors (8541+8542), Oil (2709), Iron Ore (2601), Salvage (9999), LCD (9013), Telecom Equipment (8517), Computers (8471), Parts of electronic products (8473).

While China's semiconductor market is significant, there are several other large and important markets for semiconductors, including Taiwan and Japan, which imported US$34.2 billion and US$24.5 billion worth of semiconductors in 2013, respectively.[43] The United States is also a huge semiconductor consumer market, with sales of semiconductors, including imported semiconductors, to electronic equipment makers in the United States amounting to US$69.3 billion in 2014.[44]

Through proximity and access to customers overseas, participation in the world value chain helps companies capture foreign markets and exploit new demand opportunities and growth centers.

3.1.4 Innovation, Advancements In Technology

If there's any doubt about the advances made in the semiconductor industry, consider these passages: "The rate of progress since the first silicon transistor in 1947 has been enormous, with the number of transistors on a single chip growing from a few thousand in the earliest integrated circuits to more than two billion today."[45] As for price, "in 1954, five years before the IC [integrated circuit] was invented, the average selling price of a transistor was US$5.52. Fifty years later, in 2004, this had dropped to 191 nanodollars (a billionth of a dollar)."[46]

The semiconductor industry is highly complex and characterized by rapid technological advancements requiring huge costs for upgrading and adopting new technology along the value chain (including demand by customers). Adaptation to the complexity of the industry and to changes in process technology and wafer sizes occurs most efficiently when the semiconductor industry around the world works in concert—and participation in the global value chain greatly facilitates this.

For instance, the eventual planned transition from 300mm diameter to 450mm diameter silicon wafers requires new manufacturing equipment and materials to develop the prerequisite manufacturing technologies. A company participating in the global value chain will purchase newly developed equipment from the companies specializing in 450 mm manufacturing technologies, whereever they are located because those companies will be the most competitive in producing the equipment. Similarly, the countries specializing in production of semiconductor manufacturing equipment cannot function without relying on the world's value chain—they will need enough global demand for the new wafer size to justify developing the equipment for the new wafer size.

Further, a worldwide value chain also facilitates important collaboration between companies and countries to help the industry successfully adopt new technologies. This is evident from the vast number of collaborative R&D consortia that have developed over the years[47] that bring together government, industry, academia, and global companies. One example is the Facilities 450 Consortium (F450C), which is bringing together selected companies from across the world to enable optimized 450mm high-volume semiconductor facility design, construction and operation. The F450C cooperative model leverages industry alignment and collaboration as a critical enabler.[48]

Similarly, the Global 450 Consortium (G450C) is a public-private partnership program initially launched by New York State in partnership with several global companies to "develop cost-effective test wafer fabrication infrastructure, equipment prototypes and high-volume tools to enable a coordinated industry transition to 450mm wafers."[49] Likewise, Imec—set up as a not-for-profit organization by the Belgian government to strengthen the nation's microelectronics industry—works in association with universities, private firms, and governments to conduct R&D in nanoelectronics and semiconductors through initiatives such as setting up laboratories and training programs for engineers.[50]

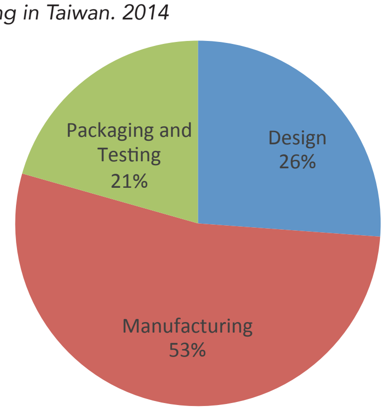
3.1.5 Movement Up The Value Chain

Participation in the semiconductor global value chain provides access to international networks, global markets for goods and capital, knowledge, and technology that might be unavailable to a domestic value chain. Such access typically result in accelerated development of human resources and skills. Increased human resources and skills enable all countries to move up the global value chain and reap greater economic benefits. As countries' relative advantage in performing tasks changes due to changes in skills and cost structures, countries will move up the value chain, allocating the lower value tasks they previously performed to other countries that might now be better equipped to undertake them. The value chain acquires new participants as a result. Taiwan and China illustrate this dynamic, as discussed below.

3.1.5.1 Taiwan: From Assembly to Design

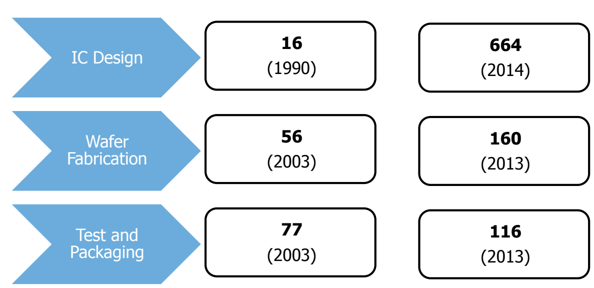
Taiwan's semiconductor industry has moved steadily up the value chain since the 1960s, when the U.S. firms located assembly plants there.[51] Today, Taiwan is very involved in semiconductor device design as well as manufacturing (figure 13 below). It is the third-largest semiconductor manufacturer in the world, behind only the United States and South Korea, and leader in the foundry segment of the global value chain. Driven by strong demand from China for mobile chips, Taiwan's integrated circuit design sector is also growing at a fast pace. Taiwan is the second-largest participant in semiconductor

Figure 13
Share of Revenue of IC Design, Manufacturing and Packaging and Testing in Taiwan. 2014



Source: Taiwan Semiconductor Industry Association, Overview on Taiwan Semiconductor Industry (TSIA, 2015 Edition), 4.

Figure 14
Growing Number of Semiconductor Enterprises in China



Source: PricewaterhouseCoopers, A Decade of Unprecedented Growth, China's Impact on the Semiconductor Industry 2014 Update, (PWC, 2015) device design, just after the United States, accounting for 22.2 percent of the global semiconductor device market as measured by revenue. There were about 245 fabless companies in Taiwan in 2014.

Taiwanese semiconductor companies are expected to follow the example of many Taiwanese makers of personal computers. The personal computer makers, because of rising production costs, are setting up manufacturing facilities in mainland China. As costs in China rise, the next manufacturing destinations are likely to be Cambodia, Indonesia, and Laos. Taiwanese firms are also allocating R&D to countries such as India and China due to availability of talented human resources in these countries.

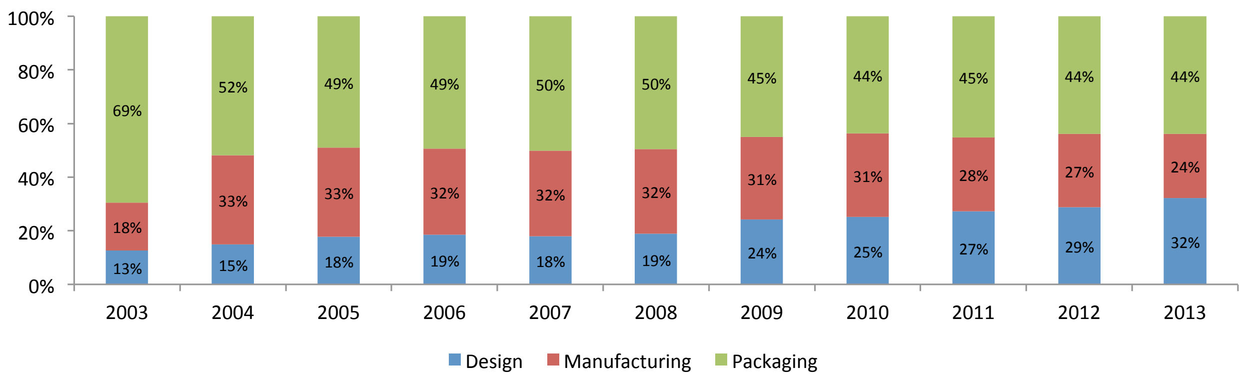
3.1.5.2 China: Expands to Become Integral Part of Value Chain

China's share of worldwide semiconductor revenue has multiplied as a result of China's participation in the global value chain for semiconductors, growing from roughly 2 percent of global revenue in 2000 to 13.4 percent in 2014.[52,53] Production of integrated circuits in China soared, increasing from 3.5 billion units in 1984 to 71.4 billion units in 2012. The number of design enterprises, wafer fabrication facilities, and assembly, test, and packaging companies in China has also risen significantly (figure 14). Employment in China has gained as a result: 1.28 million people worked in integrated circuit design enterprises in China in 2013, up 14 percent from a year earlier, the result of a 12.5 percent increase in the number of integrated circuit design enterprises in China from 2012–2013.

Foreign investment and establishment of facilities have greatly contributed to the industry's growth in China, with Taiwan playing a significant role: 34 percent of investment by Taiwanese firms in China is in IT. Within the semiconductor industry, as Taiwan grew stronger in fabless design after 2000, several Taiwanese fabless companies invested in China, largely to gain access to design engineering skills. The Taiwanese companies trained design engineers in China—an extensive knowledge transfer. In 2004, according to a survey by the Shanghai Municipal Corporation, 22

Figure 15

Distribution of Value Chain Activities in China as Share of Total Value (2003–2013)



Source: PricewaterhouseCoopers, A Decade of Unprecedented Growth, China's Impact on the Semiconductor Industry 2014 Update percent of 124 design houses in Shanghai were partially backed by Taiwanese investment, 17 percent were wholly owned Taiwanese operations, and 5 percent were Sino-foreign joint ventures. At least 7 of the 10 largest Taiwanese fabless companies have design centers in China.

China has moved up the value chain to become not just a base for assembly, test and packaging operations but also for fabrication and design. Also, several countries including the United States, Europe, Japan, Korea, and Taiwan have established industry bases and R&D centers in China. Figure 15 shows the decrease in low-value activities for China and a corresponding increase in activities higher up the value chain, specifically IC design.

3.2 Risks of a One-Nation Value Chain

The semiconductor industry has evolved into a global value chain in response to changing market conditions including advances in information and communications, technology, trade facilitation; declining transportation costs; differences in skill endowments and cost structures around the world; and increasing competition and demand for electronics. While one could look directly at the benefits that such globalization of the value chain has bestowed, as done in the previous section, another perspective would be to identify and analyze the costs associated with a "what if" scenario. In other words, what would be the costs if the value chain remains within national boundaries or if the government today attempts to establish an entire end to end domestic semiconductor industry within it's own borders? The results of such an examination follow.

3.2.1 Misdirection Of Investments, Leading To Higher Costs, Prices

A fully domestic semiconductor value chain would encompass all activities in the value chain and ecosystem. Given the array of segments and different resource requirements for each segment, significant investment cost must be incurred to create even a part of this value chain. These costs ultimately affect prices, and the effort necessarily would result in a technological lag because of a lack of focus and specialization impairs innovation and reduces the efficient use of resources (that is, one country cannot be leading edge in all steps in the value chain).

A fabrication facility illustrates the cost considerations. For instance, setting up a new advanced technology fabrication facility can cost between US$5billion–US$10 billion and take 1–2 years to complete.[54] Additionally, to stay competitive, the fab is likely to need retooling every 2 to 3 years, again involving significant costs. As a result of these constraints, few companies build their own chip plants.[55]

Table 1 presents the key cost and time variables for selected companies in each segment of the semiconductor value chain.[56] These variables highlight the significant amount of investment in financial and human resources for a country to have capabilities similar to those of a global leader in each segment. For instance, the largest fabless company in the world as measured by total equity—Qualcomm—spent nearly US$5 billion in research and development in 2013. The foundry TSMC had property, plant and equipment worth US$26.57 billion in 2013. And SPIL, an OSAT, employed close to 22,795 people in 2013. It is difficult for any country to make this kind of investment in each segment of the semiconductor value chain by itself.

Most of the companies in the semiconductor industry were set up several decades ago. They spent significant time and resources developing expertise in their areas of interest, which enabled them to reach their positions of global leadership today. The opportunity cost—both in terms of time and resources—of such investments is enormous. Investment resources most likely are finite: major investment in one industry can very well mean another industry or segment of the infrastructure is underfunded. Also, domestic investment in all aspects of the industry can fail to leverage cost efficiencies that might prevail in other parts of the world, diminishing the competitiveness of locally produced semiconductors and of products that contain semiconductors.

Investing in establishing every segment of the value chain domestically misdirects a country's scarce resources. This is highlighted by the fact that each segment of the semiconductor industry requires different resources to achieve operational efficiency, product quality, and advances in technology. For instance, investment in R&D and design is different from the financial and human resource investment required to set up and maintain production facilities. By choosing to domestically develop all activities including R&D, design and production, a country would forgo gaining from advances made in other geographies.

Table 1
Key Cost Data for Selected Semiconductor Companies (2013), US$ million

Type of company	Company	Founded in		Total Equity	R&D Expense	Property, Plant and Equipment	No. of Employees
		Year	Country				
Fabless	Broadcom[57]	1991[58]	USA	8,371	2,486	593	12,400[59]
	Mediatek[60]	1997[61]	Taiwan	5,933	803	192	7,065
	Qualcomm[62]	1985[63]	USA	36,087	4,967	2,995	31,000
	Marvell Technology Group[64]	1995[65]	USA	4,676	1,157	356	7,355
	AMD[66]	1969	USA	544	1,201	346	10,671
Foundry	TSMC[67]	1987[68]	Taiwan	27,962	1,608	26,573	40,483
	UMC[69]	1980[70]	Taiwan	7,028	419	5,443	17,784
Assembly, Test and Packaging	SPIL[71]	1984[72]	Taiwan	1,897	104	1,676	22,795
	Amkor[73]	1968[74]	USA	965	65	2,007	20,900
IDMs	Intel[75]	1968[76]	USA	58,256	10,611	31,428	107,600
	Micron[77]	1978[78]	USA	10,006	931	7,626	30,900
	Infineon[79]	2000[80]	Germany	4,116	572	1,744	26,725
	Toshiba[81]	1939[82]	Japan	1,047	4.89	62	4,055

Moreover, developing an isolated domestic value chain in those segments of the value chain in which the country does not have an advantage diminishes the competitiveness of it's whole domestic chain.

Specifically, cost of engaging in the activities in which the country is less competitive will be relatively higher and reduce national industrial competitiveness as compared with that of other countries that participate selectively in the global value chain. As a result, the total cost of operating the domestic value chain will be higher, not just in monetary terms, but in technology and competitiveness in all other segments of the value chain. This influences the price of the final product, and a higher-priced, less-advanced product adversely affects the competitiveness of the whole value chain by returning less profit than can be reinvested in technology innovation.

Governments and industries can invest wisely by encouraging firms to join the existing global value chain and invest in activities in which the domestic industry has a competitive advantage.

3.2.2 Knowledge Transfer And Technological Advancements

Being a part of the global value chain and interacting closely with companies of other countries makes it possible to more easily gain lawful access to sophisticated technology and highly critical process knowledge.[83] Legal knowledge transfer ensures the constant stream of innovation that benefits industries, consumers, and entire economies. A study of 56 Taiwanese semiconductor companies found that "knowledge transfer could develop semiconductor firms' core competence," which could later be built upon to develop competitive advantage.[84]

The alternative is to attempt to develop knowledge from the ground up, which is highly inefficient and very difficult in complex and dynamic industries like semiconductor design and manufacturers, and thus makes achieving success at the leading edge only a remote possibility. Even with deep pockets for investment, the country is also highly unlikely to be able to catch up to the latest technology and expertise in the international market. It may have access to a good domestically developed technology, but it is unlikely to be the best and latest technology, developed by another country specializing in that segment of the global value chain.

Technological change in one stage of the value chain has a cascading effect as well as an upstream effect on the technologies in other stages. Change in a chip design, for example, will be reflected and incorporated in the manufacturing, assembly, and testing segments of the value chain. Changes in chip design will also have a dramatic effect on the design and functionality of downstream products made with semiconductors. Manufacturing technology is constantly upgraded to keep up with wafer size, which has evolved from 13mm in diameter in the 1960s to 300mm in the 2000s, and is now moving toward 450mm. In this scenario, raw wafer suppliers must upgrade their technology to supply larger wafers to manufacturers. A global value chain with various companies regardless of geographic location focused on specific segments of the value chain is able to respond to such rapid changes in technology. When the entire value chain is confined to one geography, however, the country must focus on upgrading all stages of the value chain at once, a suboptimal and most likely impossible prospect.

3.2.3 Lost Export Opportunities

An uncompetitive domestic value chain reduces export opportunities for the host country, for both semiconductor products and much more seriously in downstream products. A semiconductor produced in a self-contained supply chain "bubble," cut off from leading-edge technology inputs, is likely to be neither price nor performance competitive in the international market, limiting semiconductor export opportunities.

Further, a country that isolates itself off from the global value chain may very well make the concurrent mistake of imposing domestic standards rather than adopting international standards, leading to domestic products that are incompatible with end products made for the

Exhibit 3
Galápagos Syndrome in Japan and United States

Japan provides a classic example of the danger of unique domestic standards and isolation from global markets. While a very open and liberal trading partner today, for much of the previous five decades, significant parts of Japan's market was mostly closed to foreign competitors, and Japan consistently imposed proprietary national standards, such as wireless communication standards, mobile data standards, and frequency bands, quite different from those used in other parts of the world.* To be sure, Japan's industry made astounding advancements in technology during this time, but these products were often incompatible with overseas conditions. This "Galápagos syndrome" put the existence of the Japanese firms at risk after they dominated their domestic market because it rendered them incapable of competing outside the Japanese market. NEC, a former leader in Japan's mobile phone market, left the industry in 2013. The company, among other reasons, failed to create enough business outside Japan. NEC thereby lacked the scale to compete globally and was exposed to domestic shocks. At the same time, many foreign companies adopting global standards (e.g., the Android operating system) are making headway into the domestic Japanese mobile phone market.

The U.S. wireless phone market also struggles with its own "Galápagos syndrome" in which various U.S. carriers operate with different network standards, often incompatible with each other. For instance, a Sprint phone does not work on an AT&T or Verizon network and vice versa, and the iPhone designed for compatibility with AT&T does not work with T-Mobile's 3G network. This lack of compatibility means that U.S. carriers must individually build parallel networks at great capital expense, with the effect of limiting consumer choice in the United States and leading to quality issues for customers in the form of poor network coverage. The non-standardization of networks domestically and the failure to align them with global standards has also kept international brands away from investing in the U.S. wireless phone market. As a result, U.S. operators have been unable to expand to international markets successfully, missing out on significant opportunities abroad.

* For instance, Japanese phone makers innovated and adopted unique standards for second –generation (2G) and third-generation (G) wireless technologies in the 1990s and 2001 respectively, a technology still non-existent overseas.

Source: Eurotechnology Japan, "Galapagos effect: how can Japan capture global value from Japan's technologies and new business models?" Eurotechnology Japan (2013), http://www.eurotechnology.com/insights/galapagos/(accessed March 3, 2016); Jon Russell, "End of the galapagos era? Japan's tech and Internet habits have never been more Western," Next Web (November 28, 2013). http://thenextweb.com/asia/2013/11/28/end-of-the-galapagos-era-japans-tech-and-internet-habits-have-never-been-more-western/ (accessed February 26, 2016); Horace Dediu, "The American Wireless Galapagos Syndrome: How the industry set itself up for a rout," Asymco (March 23, 2011). http://www.asymco.com/2011/03/23/the-american-wireless-galapagos-syndrome-how-the-industry-set-itself-up-for-a-rout/ (accessed April 11, 2016).

international market. The cost of imposing domestic standards over international standards is not only the loss of export opportunities, but also the likelihood of creating lesser-quality and lower-performing products, creating inferior internationally competitive semiconductors and infusing downstream industries with inferior and higher cost products.

A unique or discriminatory domestic standard might provide short-term stimulus to a domestic industry as it reduces sales of foreign products or technology. Long-term growth suffers, however. The opportunities provided by a domestic market, even one as large as China's or India's with more than 1.2 billion consumers each, cannot compare with the opportunities afforded by global participation, especially in the information and communications technology (ICT) or related industries. By one estimate, "90 percent of global ICT markets lie outside of China."[85] Missing those outside markets will mean loss of business and economic growth opportunities for the home country and its domestic companies in the long run.

This high risk must be a central concern of any national authority deciding to attempt a move toward self-sufficiency: creating a "national industry," as opposed to a strong industry participating in the global value chain, can only lead to undermining that country's capability to develop leading-edge semiconductors in all categories, but perhaps more importantly to the erosion of downstream industries, as described in exhibit 3 to the left.

Over recent decades, adherence to international standards has gained importance in the semiconductor industry. Standards apply to semiconductor technology, product quality and specifications, and testing and packaging, for example. Although standards are not compulsory, countries should follow them to be able to successfully export semiconductor products and semiconductor-containing products.

3.2.4 Erosion Of Downstream Industries That Rely On Global Sourcing

Semiconductors are critical components of almost all electronic products today. As a result, the global value chain based on semiconductors extends throughout much of every economy, into many industries—automotive, communications, consumer electronics, information technology, and medical devices, to name a few. An economy that isolates itself from the global value chain risks damaging these downstream industries—each of which may have outsized contributions to a national economy through skill and level of employment, as well as levels of trade and investment—by restricting their access to the highest quality, most cost effective, and most innovative products in the global marketplace. As an OECD report put it, "Today, success in international markets depends as much on the capacity to import high-quality inputs as on the capacity to export."[86]

Isolation from the global value chain, or limited participation in it, limits global sourcing of competitive inputs. An isolated country could severely and negatively affect its domestic downstream producers of finished products using semiconductors, especially in instances where these industries are the nation's top exporters. This in turn would have a profoundly negative effect on the nation's entire economy, not just in terms of exports but more broadly in other critical components, including foreign investment, domestic production, GDP growth, and domestic employment.

Simply put, a country that limits imports of a critical input to its top export products in favor of a lower quality and/or more expensive domestic product would soon find its top export products losing ground in the world market. That country's downstream companies would very likely relocate manufacturing to other countries that did allow the sourcing of critical semiconductor inputs from around the world. This development would ultimately result in a reduction of (1) exports of leading electronic products containing semiconductors; (2) domestic industrial production; (3) foreign investment; and (4) employment.

Some countries have highlighted the gap between domestic consumption and production of semiconductors as a reason for promoting development of a domestic semiconductor industry. Again, as shown above, this perspective fails to take into account the downstream exporting industries that rely on imports of semiconductor inputs. While it is beyond the scope of this paper to analyze the entire global value chain beyond semiconductors, import substitution[87] and self-sufficiency policies in the semiconductor sector have the potential to severely impede the very semiconductor-enabled downstream industries that form an important part of a nation's economy.

Exhibit 4
Steel: From Overcapacity to Crisis

One of the most historic and prominent examples of non-market overcapacity has been global steel manufacturing. With a current annual production of 1.6 billion tons, estimates of overcapacity in the steel industry vary from 300–600 million tons. [1,2] This has led to falling capacity utilization levels in the industry. In November 2015, utilization levels fell to 73.5 percent, much below the healthy utilization rate of 85 percent. Prices declined significantly. "Overcapacity had driven down prices by—10 percent at an annual average by July 2013," thereby harming profitability in the industry.[3] Almost all major countries at some point have been severely affected. The steel crisis of 1997–2000 affected the U.S. economy due to surging imports from countries such as Russia, Korea, Brazil, and Japan where large capacity build-up developed due to heavy government subsidies and other policy support, pushing capacity far in excess of consumption demand. [4] Restructuring of the U.S. industry has led to a closure of many factories with many companies driven into bankruptcy and workers being let go. [5] While North America has adjusted its capacity levels through industry restructuring and stricter anti-dumping policies, the European Union is still struggling with an overcapacity of 40 million tons. [6] Global overcapacity continues to distort even markets such as the United States that have successfully overcome overcapacity, because any attempts by domestic manufacturers to increase prices is countered through an increase in imports. Despite the overcapacity and slowdown in demand because of the financial crisis of 2008, new capacity is planned in many countries, especially Asian countries, Middle East and Latin America, anticipating higher demand in future years. [7]

Sources: [1] Mark O'Hara, "Massive Overcapacity in the Steel Industry In 2015," Market Realist (January 7, 2015), http://marketrealist.com/2015/01/massive-overcapacity-plague-steel-industry-2015/ (accessed February 26, 2016); [2] World Steel Association, World Steel in Figures 2015, 7; [3] & [6] Yann Lacroix, Major overcapacity in the global steel industry (Euler Hermes Economic Research, October 10, 2013), 2-3; [4] & [5] Alan H. Price, Government Intervention and Overcapacity: Causes and Consequences (Wiley Rein LLP Research, July, 2013), Prepared for American Iron and Steel Institute and Steel Manufacturers Association, 2-3.; [7] OECD, Excess Capacity in the Global Steel Industry and the Implications of New Investment Projects (OECD Publishing, OECD Science, Technology and Industry Policy Papers No. 18, , 2014), 10 – 11.

3.2.5 Threat Of Overcapacity

As stated above, one of the risks of creating and operating a totally domestic semiconductor industry is the misdirection of investments, distorting the prices of semiconductor products. Another risk of misdirected investments is the threat of creating overcapacity—excess supply in the domestic as well as the global market. Such overcapacity leads to declining prices, lost jobs, and a threat to the financial viability of an industry, a threat that in the long run may also affect the entire global economy. As an example, exhibit 4 below provides a glimpse of the overcapacity in the steel industry.

The overcapacity story often begins with capacity additions in a particular industry to initially cater to important domestic demand. In the steel industry, many non-OECD countries added capacity to support construction and manufacturing industries and to build infrastructure at home.[88] The industry is mostly supported by the government through favorable policies and incentives such as subsidies and easy access to finance and other approvals. However, usually unchecked, the capacity additions continue to increase irrespective of growth in demand and lead to overcapacity in the domestic market and flooding in the international markets.

It is also extremely difficult to roll back this overcapacity due to high closure costs, uncertain market conditions, and future expectations of pick-up in demand. Government actions also make this difficult especially when the intention is to ensure "self-sufficiency" in the industry or when the industry is of strategic importance or to avoid unemployment and other social problems.[89]

Thus, a country aiming to build an entirely domestic semiconductor value chain with the sole purpose of attaining "self-sufficiency" in every dependant industry or to support a flourishing industry (for instance, consumer electronics), may lead to the creation of excess supply in the semiconductor market domestically as well as globally. Similar to steel, given the strategically important nature of the semiconductor industry, the country will find it difficult to adjust this overcapacity later. Further, technologies in the semiconductor industry become outdated at an extremely fast pace and investing heavily in every segment of the value chain will likely create overcapacity once the technology is outdated. Thus, it makes more economic sense for countries to invest in only certain segments of the value chain in which they are competitive and which they can upgrade and expand based on rational judgement of domestic and global demand.

3.2.6 Undiluted Risk

Investing in a predominantly national value chain in the semiconductor industry is akin to cutting off the industry from global advances wherever they occur. Given that the industry experiences rapid technological change, companies unable to keep abreast risk losing their investments in the value chain. If technological advances or innovation result in the semiconductor chip being replaced by a new alternative, for example, then a country that has guided industry investments heavily in a particular direction of chip production will be affected only to the extent of this particular technology. But a geography that has invested in all the stages of the value chain will experience greater losses, as this technological shift will affect not only the chip production stage but also the design, material production, design tools, and assembly and testing activities also present in that geography, not to mention downstream industries that depend on availability of the latest breakthroughs in semiconductor design and manufacture. Moreover, in a global value chain, the risk will be shared by investors who are spread across the world; in a national value chain, a greater share of the risk is likely to be borne domestically.

If natural disaster or economic shock strikes a country hosting a domestic semiconductor value chain and ecosystem, the repercussions will extend through the entire value chain and the industry could come to a standstill. This could harm production and exports of semiconductors as well as semiconductor-containing finished products. After the 2011 earthquake-tsunami-nuclear power shutdowns in Japan, the country's IDMs suffered. Japanese IDMs are part of vertically integrated conglomerates that make electronic goods. A significant portion of demand for the IDMs' semiconductors was harmed by damage to the facilities of electrical goods manufacturers.[90] Where there is global sourcing, shared risk mitigates supply shocks, and prevents disruption to the supply chain when a single factory explodes, as happened in the 1993 Sumitomo accident that destroyed a substantial portion of the world supply of silicon ingot.

Thus, where there is participation in the global value chain, only a portion of the semiconductor production may be affected, and the domestic production and overall industry may be quickly stabilized through sourcing outside national boundaries. The global disruptions of the 2011 Japan earthquake were mitigated mainly due to the global nature of the semiconductor industry along with efforts of the Japanese government to restore power supply. Several countries including Taiwan and South Korea were able to fill the void and respond to this disaster by stepping up their supply of semiconductors to meet the shortage of exports from Japan.[91] Thus, companies that had dispersed their value chains globally were able to deal with the crisis much more effectively, as their entire value chain was not affected by the earthquake.[92]

4 CONCLUSION AND RECOMMENDATIONS

The semiconductor industry is extremely complex. Products constantly improve through technological advances, production now requires numerous distinct and divergent processes, and there is constant demand for more speed, reliability, capabilities, and features. Given this complexity and the forces of competition, the semiconductor industry has evolved into an increasingly specialized and complex value chain, with different firms focusing on more specialized, activities within the production process. This delineation extends through the entire ecosystem. Participation in this worldwide ecosystem has been demonstrated to be an essential part of success for individual firms and the industry as a whole.

The current semiconductor ecosystem and value chain are dispersed geographically, with companies specializing in specific activities based on their inherent advantages. The result is a truly global and interdependent semiconductor value chain and ecosystem that have benefited the industry by spurring innovation and technological advancements. It has also benefited the participating countries (and firms within them) by providing competitive employment and opportunities for growth and expansion.

Today, the basic technology of semiconductors is changing, and soon growth in the industry will continue be driven by extraordinary levels of innovation; simple scaling and cost reductions based on Moore's Law will no longer be the only basis for improved device performance and functionalities. The industry is rapidly moving into new areas such as real-time communication, the Internet of Things (IOT), energy-efficient sensing, and other semiconductor-enabled applications, calling for further breakthroughs.

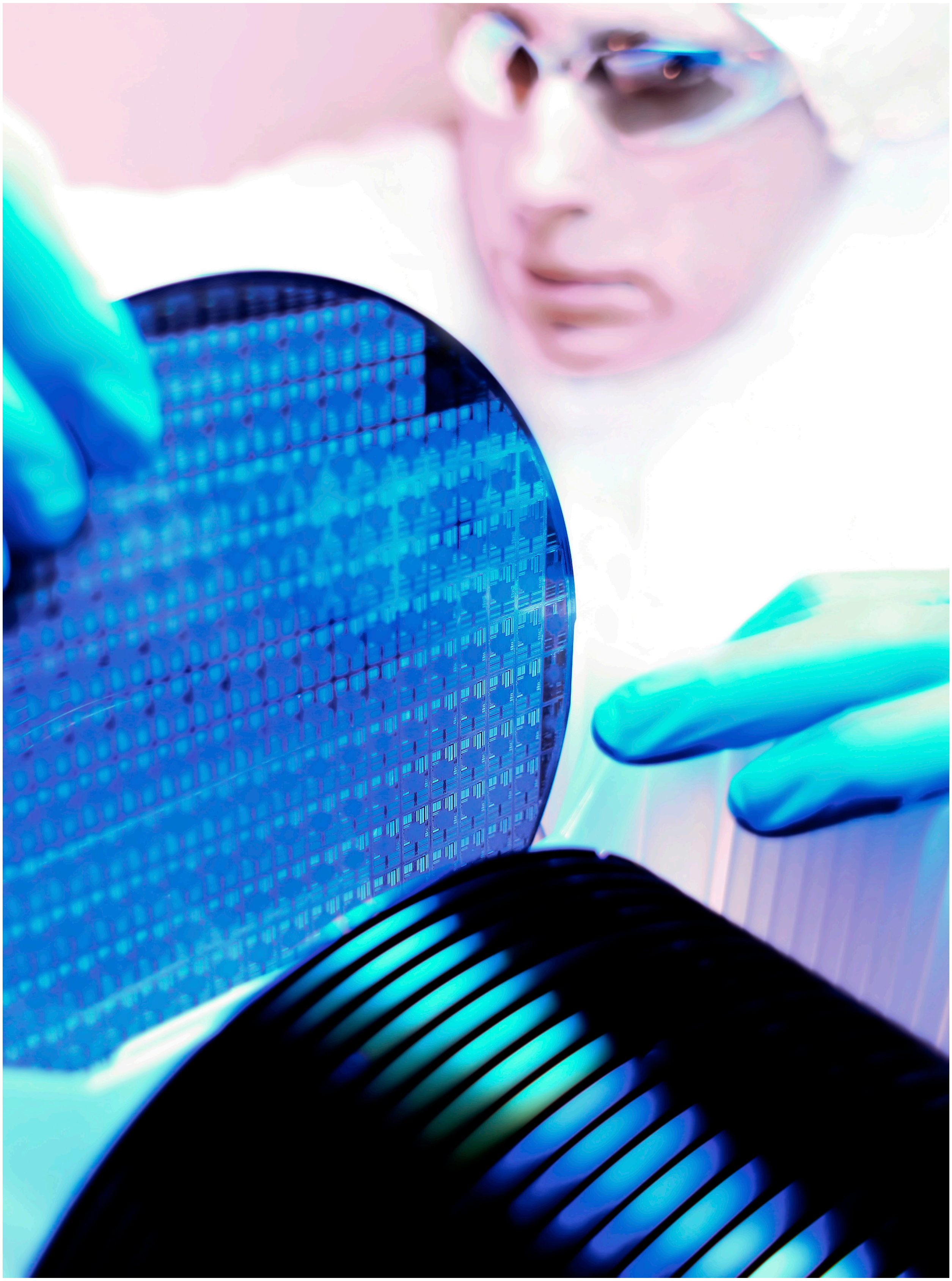
As the history of the past 50 years along with economic fundamentals demonstrate, innovation accelerates and is profitable when the industries within each country specialize in tasks they can best perform, and in which participants collaborate across the entire value chain, share knowledge, and exploit each other's relative advantages. This is different from most other less complex industries where simply adding productive capacity or implementing protectionist measures may be enough to enable an emerging industry to be competitive.

Cooperation could be further enhanced. Some potential areas include (1) additional government funding of precompetitive R&D to overcome the increasing technological challenges faced by the industry; (2) development of a skilled pool of engineers and scientists through focused education programs and R&D funding; and (3) joint work on creating manufacturing improvements—including partnerships among device manufacturers, tool suppliers, and materials suppliers to develop new manufacturing processes and equipment, process chemicals, and other innovations.

Development and adoption of global standards would facilitate the efficient functioning of the global value chain. Applying common global standards instead of varying domestic standards makes integration of different segments of the value chain in different countries efficient and attainable. Such standards are critical for emerging applications such as IOT where interoperability is their core value.

Governments can create policies that facilitate integration into global value chains. These include policies that support open to international trade (removal of tariff and non-tariff barriers), establish a transparent and predictable investment environments and ensure sound legal systems and intellectual property protection.

Such steps would be far more effective than an insular strategy, which risks wasting precious resources and time, hinders the ability of semiconductor and downstream industries from moving to the next level of innovation and growth, and ultimately impedes a nation's economic growth. The greater opportunities lie with full-fledged participation in the global value chain of one of the world's most dynamic and vital industries.



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APPENDIX: SEMICONDUCTORS

Semiconductors are materials with the electrical properties of both conductors and insulators, making it possible to control the flow of electric current in each direction. While other semiconductor materials exist, such as germanium and gallium arsenide, silicon is the most widely used. Semiconductor materials are used to make devices, which are in turn used in nearly all electronic applications today. These devices replaced the vacuum tubes of old, given their lower cost and power requirements, greater reliability and processing speeds.

The key types of semiconductor devices are:

1. Integrated Circuits (ICs): An integrated circuit is an arrangement of electrical circuits and components including resistors, capacitors, diodes, and transistors,[93] which are directly embedded onto the surface of the semiconductor chip. Used in nearly all electronic devices today, ICs can be subdivided into three categories:

   a) Logic semiconductor devices: These perform certain logical or thinking operations on the inputs provided to them, from which they then produce an output. Micro components are the most significant type of logic semiconductor devices and include microprocessors or central processing units (CPUs) used in computers, smartphones, and similar devices.

   b) Memory semiconductor devices: Memory semiconductor devices store information. They can be volatile[94] (e.g., dynamic random access memory, or DRAM, used in personal computers) or nonvolatile[95] (e.g., NAND flash memory, used in USB drives and solid-state hard drives.

   c) Analog semiconductor devices: Analog semiconductor devices are used to convert analog (i.e., continuous) information into digital format (0s and 1s) and vice versa. When recording a song to an MP3 player, for example, the song (continuous audio information) is converted to digital form for storage, then converted back to analog form to listen to it.

Figure A-1
Semiconductor sales by type (2014)

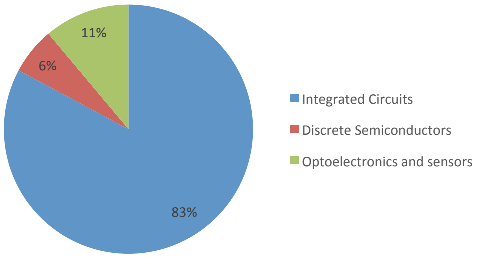
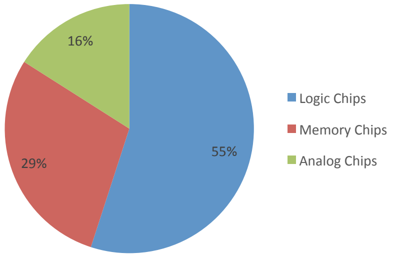
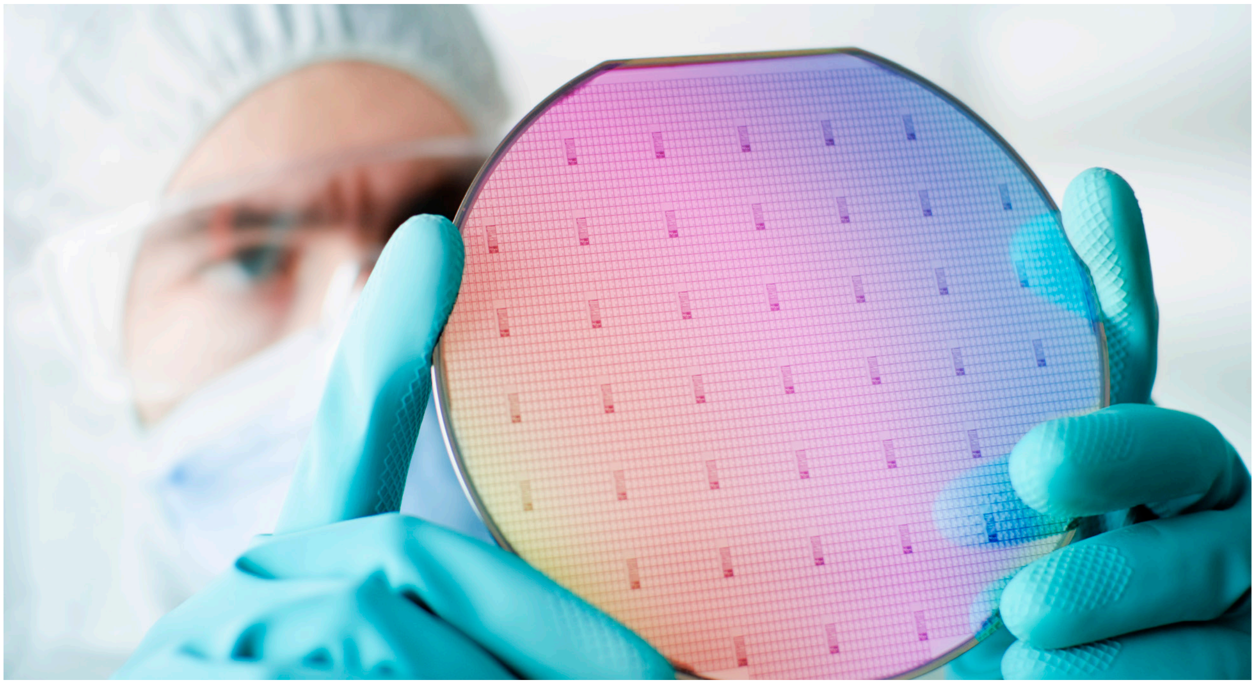


Figure A-2
Integrated Circuit Sales by Type (2014)



Source: Wong, D. and Chanda, A. (October 2015). Semiconductor Industry Primer 2015. Equity Research. Wells Fargo Securities, LLC



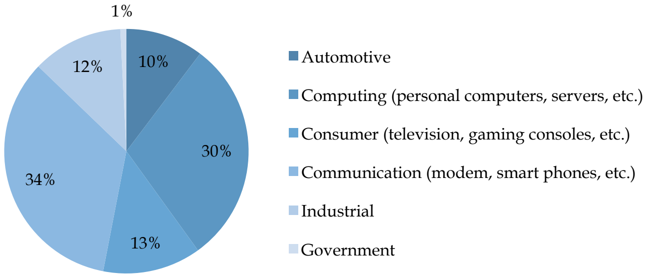
2. Discrete Semiconductors: These are single individual semiconductors used in electronic devices primarily to control electric current. Types include transistors, rectifiers, and diodes.

3. Optoelectronics and sensors: These semiconductors are mainly used for generating or sensing light, for example, in traffic lights or cameras.

In 2014, ICs accounted for 83 percent of semiconductor sales, followed by discrete semiconductors at 11 percent and optoelectronics and sensors at 6 percent. Within ICs (Figure A–2), the share of logic semiconductor devices was the highest in sales (55 percent) in 2014, followed by memory and analog semiconductor devices.

Figure A-3 presents semiconductor sales in 2014 based on the type of applications. Computing applications such as PCs, laptops, and servers had the largest share of revenues in 2014, followed by communications-related equipment such as smartphones.

Figure A-3
Semiconductor sales by application (2014)



Source: Semiconductor Industry Association and World Semiconductor Industry Statistics, Semiconductor Industry End-Use Report 2016.

ENDNOTES

[1] "Semiconductors" technically refers to semiconducting materials, but this report will frequently use the term as a shorthand for "semiconductor chips" or will use the term "chips."

[2] "Global Semiconductor Sales Top $335 Billion in 2015," Semiconductor Industry Association, February 1, 2016, http://www.semiconductors.org/news/2016/02/01/global_sales_report_2015/global_semiconductor_sales_top_335_billion_in_2015/.

[3] This report will often refer to value chain even when discussing the entire ecosystem. This is a convenience but also reflects the linear connection of each segment of the value chain and its direct relationship with the production chain. What is said about the value chain should apply to the entire ecosystem.

[4] A supply chain consists of nodes through which a product passes on its journey from producer to ultimate customer. Raw material production, manufacturing, marketing, and sales are common nodes in a supply chain. In a value chain, value is added at each node to meet consumer preferences and requirements. Value addition is not a requirement in a supply chain; however, in a value chain, it becomes the key competitive advantage for the company.

[5] Ilkka Tuomi, The Future of Semiconductor Intellectual Property Architectural Blocks in Europe, ed. Marc Bogdanowicz (JRC Scientific and Technical Reports, JRC European Commission, Institute for Perspective Technological Studies, 2009), executive summary and 11.

[6] These companies charge a one-time license fee to product developers and receive royalties once the product enters the market. The use of these blocks reduces design cost and lead time.

[7] Reduces design time and cost.

[8] David Wong and Amit Chanda, Equity Research: Semiconductor Industry Primer 2015, (Charlotte, NC: Wells Fargo Securities, October 2015), 19.

[9] Deborah K. Elms and Patrick Low, eds, Global Value Chains in a Changing World, (World Trade Organization, Fung Global Institute, and Temasek Foundation Centre for Trade & Negotiations, 2013), 26–27. According to Michael Porter's theory on competitive advantage, firms waste resources (time and money) on certain stages of production and support activities in which they do not have a competitive advantage and hence, they should focus only on tasks they perform best and pay others to do the rest.

[10] Craig Addison, "SEMI Oral History Interview," Semiconductor Equipment and Materials International, http://www.semi.org/en/About/P036368 (accessed April 6, 2016).

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[12] Americas refers to Central America, North America, and South America.

[13] U.S. Semiconductor Industry: 2015 Factbook, Semiconductor Industry Association, 7.

[14] While IDM revenue reflects all activities within the value chain (design, manufacturing, assembly, packaging, and testing) as they are carried out internally by the IDM companies, design revenue in the fabless-foundry model is captured by fabless.

[15] It is important to note that within these countries, individual companies also have their own competitive advantages in scale, process knowledge, technology ownership and others.

[16] Foundries that manufacture only.

[17] For instance, three of the top 10 pure-play foundries in the world (by revenue) are located in Israel and China—TowerJazz (Israel), Semiconductor Manufacturing International Corporation (SMIC), and Shanghai Huahong Grace Semiconductor Manufacturing(China). Intel—the world's largest IDM company—also has substantial manufacturing in Israel and China.

Singapore is home to 14 wafer fabrication plants including those of leading IDMs such as Micron and NXP, as well as those of leading foundries such as Global Foundries, United Microelectronics Corporation (UMC) and Taiwan Semiconductor Manufacturing Company (TSMC). Smaller IDMs such as ON Semiconductor and fab-lite companies such as Infineon have fabrication facilities in Malaysia.

Source: Gartner, "Worldwide Semiconductor Foundry Market Grew 16.1 Percent in 2014, According to Final Results by Gartner," Gartner, (April 13, 2015), http://www.gartner.com/newsroom/id/3027717 (accessed February 29, 2016) ; Solid State Technology, "Top 12 semiconductor foundries of 2012," Electroiq (August 21, 2012), http://electroiq.com/blog/2012/08/top-12-semiconductor-foundries-of-2012/ (accessed February 29, 2016); Intel Corporation, Annual Report 2014 (Santa Clara, CA: Intel Corp.), 10; Cho Jin-Young, "Chips in China: Samsung Electronics, Intel Expanding Semiconductor Manufacturing Facilities in China," Business Korea (October 22, 2015), http://www.businesskorea.co.kr/english/news/industry/12589-chips-china-samsung-electronics-intel-expanding-semiconductor-manufacturing (accessed February 29, 2016); and Singapore Government, "Electronics: Industry Background," Future Ready Singapore, Singapore Government https://www.edb.gov.sg/content/edb/en/industries/industries/electronics.html (accessed February 29, 2016).

18 For instance, Singapore has 15 semiconductor assembly and test units, including some of the world's top OSAT companies such as Advanced Semiconductor Engineering (ASE), and Amkor. Leading IDMs such as Texas Instruments have assembly and test plants in the Philippines, while Intel has its assembly and test operations based in Malaysia, China, and Vietnam.

Source: Singapore Government, "Electronics: Industry Background," Future Ready Singapore, Singapore Government, https://www.edb.gov.sg/content/edb/en/industries/industries/electronics.html (accessed February 29, 2016); and David Lammers, "TI's Evolving Manufacturing Strategy," Semiconductor Manufacturing & Design Community, http://semimd.com/lammers/2011/11/04/ti%E2%80%99s-evolving-manufacturing-strategy/ (accessed February 29, 2016).

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20 Indrek Grabbi and Dorothea Blouin, Semiconductors and Semiconductor Manufacturing Equipment: A market assessment tool for U.S. Exporters (U.S. Department of Commerce—International Trade Administration, July 2015), 9.

21 Semiconductors can be broadly divided into integrated circuit semiconductors, discrete semiconductors, and optoelectronics and sensors. Integrated circuits are the most popular type of semiconductors, with a revenue share of 83 percent in 2014. (See Appendix).

22 Grabbi and Blouin, 9. Other supplier countries for integrated circuit manufacturing equipment include South Korea (<3% share), Germany (<3% share), China (<0.5% share), Taiwan (<3% share), Singapore (<3% share) and some European countries (<0.5% share each).

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24 Research and development activities related to manufacturing process are also shifting outside of the United States as they are usually likely to be conducted close to the manufacturing locations (i.e., in countries where the new wafer fabrication facilities are moving).

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[94] A volatile memory chip loses its memory when power is disconnected

[95] A non-volatile memory chip can keep its memory when power is disconnected

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