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Trade and Labor in the U.S. Semiconductor Industry

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Abstract

The pattern of international trade, employment, and wages within the U.S. semiconductor industry shifted significantly during 2006–16. We examine the aggregate trends in these economic variables over this 10-year period, broken into 5-year segments, using detailed data on labor market outcomes by occupation, and data on trade flows by country. China and Vietnam became far more important in U.S. semiconductor trade as both import and export markets. These shifts in trade flows are reflected in the increase in earnings of workers in the U.S. semiconductor industry. Average earnings in the industry rose over the last decade, mostly due to a shift in the workforce to engineers and the technicians that support them. These trends in the semiconductor industry are broadly consistent with the predictions of the model of international trade in tasks found in Grossman and Rossi-Hansberg (2008).

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Introduction

Semiconductors are intermediate inputs in various manufactured goods that require computing, digital memory, or electronic functions. These are advanced goods, and the semiconductor manufacturing industry is well known for the complexity of its global supply chains. The front end of semiconductor production is highly technical, involving the high-value-added manufacturing of semiconductor wafers; it is often performed in the United States or other high-income countries. A large share of these semiconductor wafers is then exported. Subsequent back-end production—mostly relatively low-value-added testing, assembly, and packaging—is often performed in countries with lower wages. The finished semiconductor is then sold to manufacturers in the United States or elsewhere for use in downstream products like computers, smartphones, and automotive products.[1]

Overall, U.S. exports of semiconductors declined during 2006–16, whereas U.S. imports of semiconductors remained fairly flat.[2] At the same time, U.S. imports of downstream computer and communication equipment rose significantly, while exports of downstream goods fell.[3] This shift in trade coincided with a significant decline in total employment in the U.S. semiconductor industry but also with a realignment in employment toward higher-skilled occupations, particularly engineering. The average real earnings of workers employed in the U.S. semiconductor industry rose significantly over the decade, even as total industry employment dropped. The increase in earnings was very unevenly distributed across occupations within the industry.

The shift in trade and the coinciding shift in relative labor demand within the industry is broadly consistent with the model of international trade in tasks described in Grossman and Rossi-Hansberg (2008). In their model, firms are able to split their production process into a number of distinct tasks and then perform these tasks in different countries in order to minimize the costs of production and trade. The Grossman and Rossi-Hansberg model predicts how increased trade affects the wages of workers performing different production tasks in different countries. Their model explains why increased trade with countries that have lower labor costs can lead to a significant shift in labor demands to relatively skilled workers in more advanced countries, but also to increased productivity that benefits all workers in the industry involved through higher wages.[4]

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[1] According to data from the U.S. Bureau of Economic Analysis, approximately 75 percent of the production by foreign affiliates of U.S. parents in the semiconductor industry is sold outside of the United States. Bureau of Economic Analysis, U.S. Direct Investment Abroad, Activities of U.S. Multinational Enterprises, 2014 preliminary statistics (accessed May 30, 2017).
[2] While most of the data presented in this paper is updated to 2016, 2017 data is presented whenever possible.
[3] Most of the data in this paper are for the U.S. industry manufacturing semiconductors and other electronic components, classified under North American Industry Classification System (NAICS) code 3344. In this article we abbreviate this industry as the "semiconductor industry." When available, this paper provides data for NAICS code 334413, which is more specific to the semiconductor manufacturing industry. See Appendix Tables A-2, A-3, and A-4 for breakdown of 6 digit NAICS codes within NAICS 3344.
[4] Feenstra (2016) provides an excellent summary of this theoretical literature.

The rest of this paper is organized into four sections. The second section gives an overview of the semiconductor industry, while the third section documents the changes in the pattern of international trade in this sector. The fourth section documents the change in U.S. labor market outcomes and briefly discusses how they relate to the predictions of the Grossman and Rossi-Hansberg model. The fifth section offers conclusions discussing implications for theory in this area.

Overview of the Semiconductor Industry

The semiconductor industry supplies crucial electronic components to all manufactured products with computing or power management capabilities, ranging from computers and personal electronics to automotive goods and heavy machinery. Even as global consumption of semiconductors has shifted heavily towards Asia in the past two decades, the U.S. semiconductor industry has maintained its competitiveness in large part by efficiently managing global design and manufacturing supply chains. This approach has included offshoring low-value production work while keeping high-value design and production work within the United States.[5]

The Global Semiconductor Supply Chain

Semiconductor production can be divided into four general stages: (1) research and development (R&D), (2) design, (3) wafer production, and (4) assembly, testing, and packaging.[6] The third step is known as front-end production, while the fourth step is back-end production. The resulting semiconductors are then consumed by electronics manufacturers. Each part of this supply chain tends to occur in different parts of the world, with more technically sophisticated front-end production generally taking place in higher-income countries while back-end production often takes place in lower-income countries.

For U.S.-based integrated device manufacturers (e.g., Intel, Texas Instruments) and fabless firms (design-only firms like Qualcomm and Nvidia), most activities in the R&D and design stages take place within the United States. These steps are capturing an increasing portion of the value of the semiconductor industry.

Wafer production can take place near the design facilities or can be offshored or outsourced to different firms or countries.[7] Decisions about whether to outsource or offshore production must take into account the rising costs of maintaining internal production capabilities. Because of the increasing complexity of wafer manufacturing, the costs of building front-end manufacturing facilities capable of making cutting-edge semiconductors range from $5 billion to more than $10 billion, and construction takes one to two years to complete (Wong and Chanda 2015, 14).

[5] "Offshoring" refers to shifting production to facilities in external countries, while "outsourcing" refers to shifting production or services to external companies. We use the term interchangeably in this paper, as the semiconductor industry engages in both.
[6] "Wafers" are disk-shaped silicon-based products that contain etched semiconductor dies (SIA and Nathan Associates 2016).
[7] For example, while Apple has designed its own mobile microprocessors for iPhones and iPads, it has outsourced its production to third-party foundries, including Samsung and TSMC (Lovejoy 2017).

Furthermore, due to the pace of innovation, wafer production facilities require frequent retooling, adding significant costs. As these fixed costs of production have risen, only a few firms can afford to build and maintain new wafer facilities, and many semiconductor firms have outsourced front-end fabrication to specialized foundries, such as Taiwan's TSMC. This trend has increased the popularity of firms that focus solely on semiconductor design work (fabless firms), allowing many semiconductor firms to shift risks of ever-higher fixed costs of production to specialized foundries. Taiwan, South Korea, and Japan have the world's largest wafer production capacities, followed by the United States and China (table 1).

Table 1: Wafer production capacity, by country or region, in 2017 (percentage of global capacity)

Region	Taiwan	Japan	South Korea	China	United States	Europe	Other
Percent	20	19	17	15	13	10	7

Source: Authors' calculations from data provided by SEMI, December 2017.
Note: SEMI indicates that the United States accounts for more than 95 percent of wafer capacity in North America, so the authors used 95 percent in their calculations. Europe includes the Middle East region.

In the past 20 years, regional production capacity has shifted from the United States and Japan, the traditional production leaders, towards (non-Japan) Asia-Pacific countries (Taiwan, South Korea, and China), even as U.S. firms maintained a majority market share in semiconductor sales. Silicon wafer shipments data are a reliable measure of front-end semiconductor manufacturing capacity, as silicon is needed for making semiconductor wafers. Table 2 shows the shifts in wafer shipments (a proxy for production capacity shares) in the past 20 years, indicating the overall trend of outsourcing and offshoring away from the United States and towards the Asia-Pacific region.

Table 2: Wafer shipments to selected countries or regions, from 1996 to 2016 in five-year increments (percentage of global shipments)

Year	Japan	United States	Europe	Other Asia-Pacific (including China)
1996	40	25	13	22
2001	31	26	14	27
2006	25	19	12	44
2011	21	14	9	55
2016	19	12	9	60

Source: Authors' calculations from data provided by SEMI, April 2017.
Note: SEMI indicates that the United States accounts for more than 95 percent of wafer capacity in North America, so the authors used 95 percent. Europe includes the Middle East region.

The back-end activities needed to make semiconductors (assembly, testing, and packaging) are generally more labor-intensive and require more material inputs, such as specialized chemicals, than front-end work. These steps are generally outsourced to Asian countries with low labor costs and proximity to semiconductor customers, such as electronic product manufacturers in China, Malaysia, Vietnam, and the Philippines (SIA and Nathan Associates 2016, 3).

Once the assembly, testing, and packaging processes are complete, the finished semiconductors are sold to customers for use as intermediate inputs in the production of electronics. Semiconductor consumption in Asia-Pacific has risen sharply over the last 20 years (table 3), as production and assembly of electronic goods have shifted to this region in this period.[8] This may lead to increased portions of semiconductor production in the Asia-Pacific, as semiconductor producers have incentives to produce their goods close to their customers.

Table 3: Semiconductor consumption by region (as percentage of global consumption)

Year	Americas	Japan	Europe	Other Asia Pacific (including China)
1996	32	26	21	21
2008	15	20	15	50
2016	19	10	10	62

Source: World Semiconductor Trade Statistics and SIA estimates; SIA 2017, 18.

Finished semiconductor products are consumed by a variety of industries requiring computing power. In the Americas region, in which the United States is the dominant consuming country, manufacturers of communications devices and computers account for a majority of total semiconductors sales by value, while the automotive industry and industrial machinery manufacturers also purchase a significant value of semiconductors (table 4).

Table 4: Semiconductor consumption by end markets in the Americas in 2015

End market	Consumer goods	Automotive	Computers	Industry	Communications equipment	Government	Total
Billion $	7.5	6.5	22.3	9.6	21.6	1.3	68.7
Percent	10.9	9.4	32.4	14.0	31.4	1.9	100.0

Source: World Semiconductor Trade Statistics and SIA, 2016.

The Semiconductor Industry in the United States

The U.S. semiconductor industry is highly competitive.[9] Domestic and U.S.-headquartered multinational enterprises sold $164 billion worth of semiconductors in 2016. This was 48 percent of the $339 billion global semiconductor market that year (SIA 2017, 2).[10] The United States' closest competitors, by market share, were South Korea (17 percent), Japan (11 percent), the EU (10 percent), Taiwan (7 percent), and China (5 percent) (SIA 2017, 3). While U.S. firms

[8] Because semiconductor products are mostly intermediate goods, "consumption" most often involves inserting the semiconductor into an electronic product, such as mobile phones or automotive parts.
[9] Within the United States, the semiconductor industry is defined by NAICS 334413—the industry manufacturing semiconductors and related devices.
[10] The revenue figure includes revenues for fabless firms (firms that solely design semiconductors, having no production capacity), as well as integrated device manufacturers (which both design and manufacture goods) and foundries (which only manufacture goods).

accounted for about half of world sales, a majority of their wafer production took place outside of the United States (table 5), as did most of their assembly, testing, and packing work.

Table 5: Wafer production capacity of U.S.-headquartered firms, by region/country, in 2016 (percentage of world production capacity)

Region	United States	Other Americas	Europe	Japan	China	Other Asia
Percent	44	2	9	9	3	33

Source: Authors' calculations from SIA 2017, 7.
Note: SIA indicates that the United States accounts for more than 95 percent of wafer capacity in North America, so the authors used 95 percent in their calculations.

This sector includes integrated device manufacturers, like Intel, Micron, and Texas Instruments, as well as foundries like Global Foundries.[11]

A large share of trade in semiconductors is between U.S. parent companies and their majority-owned foreign affiliates (MOFAs). In 2014, $11.8 billion of U.S. exports and $15.7 billion of U.S. imports in NAICS 3344 were from U.S. parents to/from their MOFAs; 97 percent of U.S. exports to the MOFAs were intermediate products that required further processing. About one-quarter of the global sales of the MOFAs in this industry were in the U.S. market.[12]

Employment in the U.S. semiconductor industry is spread throughout the world. According to the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce, 95,930 U.S. workers were employed in the U.S. semiconductor industry in 2014.[13] More than half (56 percent) of these employees were production workers, who earned a total of $4.1 billion in annual payroll. However, U.S. multinationals in the semiconductor industry had 64 percent of their employees outside of the United States, mainly in Asia.[14] Of the 386,700 foreign employees in MOFAs of these multinationals, 132,300 worked in China, 157,600 worked in other Asian countries, 46,700 worked in Europe, 22,700 worked in Mexico, and 5,700 worked in Canada.[15]

[11] Fabless semiconductor firms with no production capacity (such as Qualcomm or Nvidia) are not classified in NAICS 334413.

[12] NAICS 3344 includes industries related to semiconductor manufacturing in addition to the semiconductor industry, including circuit board manufacturing, printed circuit assembly, and other electronic components. 334413 (semiconductors) accounts for more than a majority share of international trade associated with NAICS 3344. The data on trade between parents and affiliates within the same multinational enterprise are from the Bureau of Economic Analysis (BEA), tables II.H 2. Bureau of Economic Analysis, U.S. Direct Investment Abroad, Activities of U.S. Multinational Enterprises, 2014 preliminary statistics (accessed May 30, 2017).

[13] The semiconductor industry reports a higher number of direct jobs for the U.S. semiconductor industry. This may be partly due to the inclusion of fabless semiconductor firms.

[14] There were 386,700 employees in MOFAs in the semiconductor industry in 2014, compared to 218,300 employees in their U.S. parents. These data are from BEA MNE tables II.G 2 and I.K 1.

[15] These estimates of foreign affiliate employment in 2014 are from BEA MNE Table II.G 2. The data are publicly available at https://www.bea.gov/international/di1usdop.htm.

International Trade in Semiconductors and Associated Downstream Products

U.S. imports of downstream electronic equipment increased significantly in the decade from 2006 to 2016. At the same time, U.S. exports of these products fell, as did imports and exports of semiconductors. China and Vietnam became more important trading partners of the United States as both import and export markets.

U.S. Exports

U.S. exports of both semiconductors and the computer and communications equipment that embeds semiconductors fell significantly in the first five-year period, then fell more moderately during the second five-year period (table 6). The decline in U.S. exports of these products implies a decline in the demand for U.S. labor to produce these products.

Table 6: U.S. exports of semiconductors and downstream products (billion 2016 dollars)

Industry	**2006**	**2011**	**2016**
Semiconductors (NAICS 3344)	59.3	43.9	35.5
Computer and communications equipment (NAICS 3341 and 3342)	53.4	39.1	36.9

Source: USITC/USDOC DataWeb, defined by NAICS code, domestic exports (accessed January 16, 2018).

In addition, there were large shifts in the export shares of the countries that were the top 20 destinations for U.S. exports of semiconductors (table 7). The largest changes were the increases in the export shares of China and Vietnam and the decreases in the shares of South Korea and the Philippines.

Table 7: Export shares of semiconductors (NAICS 3344) by destination country (percentage of U.S. exports)

Destination	**2006**	**2011**	**2016**
China	10.7	10.6	15.0
Mexico	11.6	10.8	12.5
Malaysia	11.1	11.6	10.7
Taiwan	7.3	7.4	8.9
South Korea	9.7	8.7	8.0
Philippines	8.6	5.8	5.6
Hong Kong	4.0	5.3	4.9
Vietnam	0.1	0.5	4.7
Canada	6.4	7.1	4.3
Thailand	2.7	3.3	3.6
Singapore	5.2	5.1	3.4
Japan	3.7	3.1	2.8
Germany	4.2	3.1	2.4
Israel	0.8	1.8	2.3
United Kingdom	1.7	1.8	1.4
Netherlands	0.9	0.7	1.0
France	0.8	1.2	0.7
Costa Rica	2.0	1.6	0.7
Brazil	1.0	1.3	0.6
Italy	0.8	0.8	0.5

Source: USITC/USDOC DataWeb, domestic exports.

U.S. Imports

Like exports, U.S. semiconductor imports declined over the decade (table 8). However, imports fell by less than exports, widening the U.S. trade deficit in the semiconductor industry.[16] U.S. imports of downstream computer and communications equipment, on the other hand, increased significantly. These imports competed indirectly with U.S. semiconductor production by reducing the demand for U.S. semiconductor production for use in domestic downstream products.

Table 8: U.S. imports of semiconductors and downstream products (billion 2016 dollars)

Industry	**2006**	**2011**	**2016**
Semiconductors (NAICS 3344)	90.7	79.5	75.2
Computer and communications equipment (NAICS 3341 and 3342)	163.1	200.7	205.3

Source: USITC/USDOC DataWeb, imports for consumption.

Again, as there was for exports, the sourcing of U.S. imports shifted from 2011 to 2016. The shift included a significant decline in the share of imports from Japan and smaller declines in the shares of imports from China, Taiwan, and South Korea (table 9). At the same time, the shares of imports from Vietnam and Ireland increased significantly, mostly due to intra-firm trade by U.S.-based firms with investments in these countries.

[16] The figures in table 7 are based on data for NAICS 3344, which includes a few additional products closely related to semiconductors. However, this trend also holds true for a narrower semiconductor category, NAICS 334433.

Table 9: Semiconductor import shares by source country (percentage of U.S. imports)

Source Country	2006	2011	2016
China	20.2	27.3	25.6
Malaysia	14.7	10.2	21.2
Taiwan	10.4	8.3	7.7
South Korea	7.5	7.3	6.7
Japan	10.1	9.4	6.6
Mexico	8.1	5.5	5.6
Vietnam	0.0	0.2	4.4
Ireland	0.4	0.1	3.6
Thailand	2.9	1.9	2.8
Philippines	4.1	3.6	2.7
Germany	2.5	3.1	2.2
Canada	4.9	3.1	2.2
Israel	1.0	0.6	1.6
Singapore	3.6	3.2	1.4
France	1.1	0.7	0.8
United Kingdom	1.3	1.1	0.7
Italy	0.7	0.8	0.5
India	0.5	0.6	0.4
Switzerland	0.4	0.5	0.3
Indonesia	0.5	0.4	0.3

Source: USITC DataWeb/USDOC, imports for consumption (accessed January 16, 2018).

Employment and Labor Earnings in the U.S. Semiconductor Industry

The shift in the pattern of U.S. trade coincided with significant changes in employment and labor earnings in the U.S. semiconductor industry. Between both 2006–11 and 2011–16, average annual labor earnings increased even as employment fell. In 2006–11, the increase in average earnings was mostly driven by the movement of workers from lower-paying occupations to higher-paying ones. In 2011–16, the increase in average earnings was larger than 2006–11 and reflects increases in the earnings in almost all categories of occupations. These trends are broadly consistent with predictions of the international trade in tasks model in Grossman and Rossi-Hansberg (2008), as we explain below.

Changes between 2006 and 2011

According to U.S. Census data, U.S. semiconductor industry employment fell during 2006–11.[17] Total industry employment dropped by 72,660 workers, from 452,060 in 2006 to 379,400 in 2011.[18] This reflected a decline within all of the major occupation groups except for financial

[17] The Semiconductor Industries Association (SIA) estimates a slight increase of employment during this time period estimated by observing semiconductor companies' financial reports, including fabless firms, but Census data regarding semiconductor and closely related industries (such as the printed circuit industry) reports a decline in employment. SIA, 2017b, 51

[18] The discrepancies between total figures in employment derived from various sources are primarily due to calculation methodologies of the reporting agencies and associations. For the purposes of this paper, the shifts in labor over time are more important than the total employment at any given year.

occupations (table 10).[19] Among all of the occupation groups, production workers recorded the largest decline in their share of industry employment, with a 2.25 percentage point decline over the five-year period. These are relatively low-paying jobs within the semiconductor industry. Engineering occupations recorded the largest increase in share, a 1.68 percentage point increase.[20] These are some of the highest-paying jobs within the industry.

Table 10: Employment in semiconductor industry, 2006 and 2011

Occupation	**Share of industry employment in 2006 (%)**	**Share of industry employment in 2011 (%)**	**Change in number of workers**
Management	8.4	9.2	-3,260
Financial	4.7	5.8	680
Computer	6.1	6.3	-3,790
Engineering	21.6	23.3	-9,300
Scientists	1.1	0.2	-4,290
Legal	0.2	0.2	-120
Arts and design	0.3	0.4	-80
Healthcare	0.1	0.0	-190
Protective services	0.1	0.1	-90
Building maintenance	0.4	0.3	-550
Sales	2.3	2.4	-1,450
Office support	8.6	8.2	-7,640
Construction	0.1	0.1	-40
Installation and repair	2.6	2.4	-2,880
Production	42.0	39.7	-39,040
Transportation	1.41	1.52	-600

Source: U.S. Bureau of Labor Statistics, Occupational Employment Statistics (accessed January 17, 2018).

Despite the reduction in total industry employment, over the five-year period average annual earnings for workers in the semiconductor industry rose by $2,519 per year (in constant dollars). This increase is a higher than average increase across all industries ($1,604). The changes in annual earnings varied significantly across the occupation groups (table 11).

[19] The definitions of the major occupation groups are provided in appendix table A1.
[20] More disaggregated OES data indicate that most NAICS 3344 workers in the engineering occupations are electrical, electronic, or industrial engineers and technicians that support them. The jobs in the management occupation group are similarly concentrated in engineering and industrial management.

Table 11: Annual labor earnings within the industry, 2006 and 2011 (constant 2016 dollars)

Occupation	Average annual earnings within the semiconductor industry in 2006	Increase in average annual earnings within the semiconductor industry, 2006–11	Increase in average annual earnings in all industries, 2006–11
Management	144,406	5,223	5,161
Financial	80,056	4,863	1,914
Computer	98,227	1,034	1,573
Engineering	85,466	1,558	3,486
Scientists	89,691	4,153	964
Legal	157,882	4,199	3,348
Arts and design	73,046	-2,218	2,563
Healthcare	72,726	-3,443	3,755
Protective services	41,516	1,182	1,496
Building maintenance	28,542	-340	390
Sales	93,105	2,662	-861
Office support	43,128	-647	250
Construction	59,079	-5,959	844
Installation and repair	54,299	-465	-205
Production	35,488	-799	226
Transportation	30,943	-296	352

Source: U.S. Bureau of Labor Statistics, Occupational Employment Statistics (accessed January 17, 2018).

The $2,519 increase in earnings reflects the combined effect of two factors: (1) the change in earnings for each occupation in the industry and (2) the change in the share of workers in each occupation in the industry. During this five-year period, the overall earnings increase was primarily driven by the influx of workers into higher-paying occupations (mostly engineering jobs), rather than the increase in the earnings within each occupation. If the shares of industry employment in the different occupations had remained at their 2006 values, then the average annual earnings of U.S. workers in the industry would have increased by only $762 per year over the 2006–11 period (a small fraction of the actual increase of $2,519).

Changes between 2011 and 2016

During the more recent five-year period, U.S. semiconductor industry employment again declined, falling by 9,780 workers to 369,620.[21] The decline was mostly concentrated in the production, office support, and management occupations (table 12). Engineering occupations, on the other hand, saw a large increase in employment.

[21] The five-year employment decline occurred while global sales (demand) increased by about $39 billion. SIA estimates that accelerated industry consolidation between 2014 and 2016 contributed to decline in employment. SIA, Databook 2017, p. 51.

Table 12: Employment in the semiconductor industry, 2011 and 2016

Occupation	Share of industry employment in 2011 (%)	Share of industry employment in 2016 (%)	Change in number of workers
Management	9.17	8.59	-3,010
Financial	5.83	5.92	-260
Computer	6.29	6.35	-380
Engineering	23.27	25.90	7,450
Scientists	0.17	0.25	250
Legal	0.16	0.19	130
Arts and design	0.37	0.47	330
Healthcare	0.04	0.07	100
Protective services	0.12	0.08	-130
Building maintenance	0.33	0.23	-400
Sales	2.36	2.60	650
Office support	8.19	7.53	-3,230
Construction	0.08	0.05	-100
Installation and repair	2.37	2.67	880
Production	39.72	37.60	-11,720
Transportation	1.52	1.47	-330

Source: U.S. Bureau of Labor Statistics, Occupational Employment Statistics (accessed January 17, 2018).

Over this five-year period, average annual earnings for workers in the semiconductor industry grew even more than in the first five-year period, rising by $5,187 per year. This increase was nearly four times the average increase of $1,370 for the economy as a whole. Earnings for scientists and construction workers in semiconductors fell, but all other occupations in the industry saw earnings increase (table 13).

Table 13: Annual labor earnings, 2011 and 2016, by occupation, in constant 2016 dollars

Occupation	Average annual earnings within the semiconductor industry in 2011	Increase in average annual earnings within the semiconductor industry, 2011–16	Increase in average annual earnings in all industries, 2011–16
Management	144,406	13,084	3,415
Business and financial	80,056	4,444	1,725
Computer and mathematical	98,227	8,363	3,876
Engineering	85,466	5,394	2,014
Scientists	89,691	-5,394	940
Legal	157,882	15,448	1,010
Arts and design	73,046	7,524	933
Healthcare	72,726	6,704	1,558
Protective services	41,516	4,784	218
Building maintenance	28,542	2,088	738
Sales	93,105	2,325	527
Office support	43,128	1,422	854
Construction	59,079	-879	1,280
Installation and repair	54,299	1,341	393
Production	35,488	1,172	678
Transportation	30,943	1,407	646

Source: U.S. Bureau of Labor Statistics, Occupational Employment Statistics (accessed January 17, 2018).

Unlike the increase during 2006–11, the $5,187 increase in average earnings between 2011 and 2016 was primarily driven by an increase in earnings within each occupation. If the shares of industry employment in the different occupations had remained at their 2011 values, the *average* annual earnings of U.S. workers in the industry would still have increased by $3,987 (more than half of the actual increase of $5,187).

Comparison of Actual Labor Market Shifts to Predictions from the Grossman and Rossi-Hansberg Model

The “trade in tasks” model described in Grossman and Rossi-Hansberg (2008) predicts that trade depresses domestic employment of less-skilled workers within an industry, but also pushes up the wages of domestic workers at almost all other skill levels within the industry. The predictions of this model are broadly consistent with observed trends in trade and earnings in the U.S. semiconductor industry.[22] In 2006–11, increased trade coincided with a reduction in the relative demand for production workers within the United States while increasing the relative demand for engineers and others in high-skilled occupations. During 2011–16, on the other hand, all categories of semiconductor jobs that remained in the United States benefited from an increase in labor earnings that may reflect a productivity gain associated with the restructuring of industry production.

Conclusions

The semiconductor industry has changed substantially during 2006–16. While the U.S. industry remains highly competitive, the shift in semiconductor consumption towards Asia has contributed to changes in trade. U.S. exports of semiconductors fell, as U.S. imports of finished electronics increased and as China and Vietnam emerged as major importers and exporters of semiconductors.[23]

The changes in employment and labor earnings in the U.S. semiconductor industry over the last decade reflect a shift in relative labor demand toward high-skilled workers, due in part to globalization of the industry. Aggregate U.S. employment in the industry fell, but there was also a shift in the composition of employment from production workers to engineers and to the technicians that support them.[24] There was also an increase in the average annual earnings of workers in the industry due both to the movement of workers to higher-paying occupations and to an increase in earnings in most occupations in the industry. However, the increase in earnings was very unevenly distributed across occupations within the industry.

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[22] Wright (2014) is an econometric analysis of the effect of offshoring on labor in U.S. manufacturing industries during an earlier period, 2001–07. Wright finds evidence of a positive effect of offshoring from increased productivity and a negative effect from the displacement of U.S. workers, consistent with the Grossman and Ross-Hansberg model.

[23] A significant portion of semiconductor trade in China and Vietnam involves U.S. firms, which is additional evidence of the increased offshoring of various stages of semiconductor production.

[24] Including fabless semiconductor firms’ activities in the analysis would further highlight this impact.

A simple economic theory of trade and wages suggests that increases in imports of downstream products and reductions in export demand in the data would have reduced the demand for U.S. labor, reducing employment and wages in the U.S. semiconductor industry.[25] On the other hand, trade-in-tasks models like that of Grossman and Rossi-Hansberg (2008) provide richer predictions about the effects on workers in different occupations that seem to fit the data. The data documented in this paper support the theory as an apt description of the link between trade and wages in the increasingly globalized semiconductor industry.

[25] For example, this is what would be predicted by a traditional Ricardo-Viner model of trade, in which labor is a specific factor of production in the industry.

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Data Appendix

Table A-1: Definitions of occupation groups

Occupation	**OES major group name**	**OES major group code**
Management	Management occupations	11-0000
Financial	Business and financial operations occupations	13-0000
Computer	Computer and mathematical occupations	15-0000
Engineering	Architecture and engineering occupations	17-0000
Scientists	Life, physical, and social science occupations	19-0000
Legal	Legal occupations	23-0000
Arts and design	Arts, design, entertainment, sports, and media occupations	27-0000
Healthcare	Healthcare practitioners and technical occupations	29-0000
Protective services	Protective services occupations	33-0000
Building maintenance	Building and grounds cleaning and maintenance occupations	37-0000
Sales	Sales and related occupations	41-0000
Office support	Office and administrative support occupations	43-0000
Construction	Construction and extraction occupations	47-0000
Installation and repair	Installation, maintenance, and repair occupations	49-0000
Production	Production occupations	51-0000
Transportation	Transportation and material moving occupations	53-0000

Source: Bureau of Labor Statistics, Occupational Employment Statistics (accessed January 17, 2018).

Table A-2: NAICS 3344 (semiconductor and other electronic component manufacturing) subcategories

NAICS 6	Category
334412	Bare printed circuit board manufacturing
334413	Semiconductor and related device manufacturing
334416	Capacitor, resistor, coil, transformer, and other inductor manufacturing
334417	Electronic connector manufacturing
334418	Printed circuit assembly manufacturing
334419	Other electronic component manufacturing

Source: U.S. Census, 2012 definitions (accessed May 9, 2018).

Table A-3: U.S. general imports of NAICS 3344 subcategories, 2006 to 2017 (billion $)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
334413	28.4	28.1	26.9	22.2	30.5	39.2	38.8	39.3	40.4	41.7	45.5	45.5
334418	27.3	18.0	14.8	15.3	19.7	13.8	12.9	13.4	15.7	15.2	13.8	20.4
334419	10.2	9.8	9.9	8.0	10.2	11.2	5.4	5.7	6.0	6.3	6.2	6.2
334416	1.0	1.0	1.0	0.7	1.0	1.1	3.8	4.0	5.0	4.5	4.2	4.4
334417	3.2	3.4	3.5	2.8	3.8	3.9	2.1	2.2	2.3	2.4	2.4	2.4
334412	2.3	2.3	2.1	1.5	1.9	1.9	1.9	1.9	2.0	2.0	2.1	2.0

Source: USITC DataWeb/USDOC (accessed January 16, 2018).

Table A-4: U.S. Total Exports of NAICS 3344 subcategories, 2006 to 2017 ($Billion)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
334413	52.0	50.8	51.1	38.1	48.1	44.8	41.7	42.0	42.7	41.8	42.9	46.1
334416	0.6	0.6	0.6	0.5	0.7	0.7	3.5	3.5	3.7	3.5	3.4	3.9
334419	7.2	6.1	6.1	5.4	5.9	6.5	3.0	3.3	3.3	3.1	3.1	3.5
334417	3.5	3.9	4.1	3.6	4.7	4.8	1.7	1.9	2.3	2.6	2.4	2.5
334412	2.2	1.8	1.6	1.5	1.8	1.7	1.7	1.8	2.0	1.7	1.9	1.8
334418	1.4	0.6	0.6	0.5	0.5	0.6	0.7	0.7	0.9	0.9	0.7	0.6

Source: USITC DataWeb/USDOC (accessed January 16, 2018).