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# Measuring Manufacturing: How the Computer and Semiconductor Industries Affect the Numbers and Perceptions

Susan N. Houseman
*W.E. Upjohn Institute for Employment Research*, houseman@upjohn.org

Timothy J. Bartik
*W.E. Upjohn Institute for Employment Research*, bartik@upjohn.org

Timothy Sturgeon
*Industrial Performance Center, Massachusetts Institute of Technology*

Upjohn Author(s) ORCID Identifier:
https://orcid.org/0000-0003-2657-8479
https://orcid.org/0000-0002-6238-8181

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Researching the causes and consequences of unemployment

# Measuring Manufacturing: How the Computer and Semiconductor Industries Affect the Numbers and Perceptions

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Susan Houseman
*W.E. Upjohn Institute for Employment Research*
e-mail: houseman@upjohn.org

Timothy J. Bartik
*W.E. Upjohn Institute for Employment Research*

Timothy Sturgeon
*Industrial Performance Center, MIT*

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**ABSTRACT**

Growth in U.S. manufacturing's real value-added has exceeded that of aggregate GDP, except during recessions, leading many to conclude that the sector is healthy and that the 30 percent decline in manufacturing employment since 2000 is largely the consequence of automation. The robust growth in real manufacturing GDP, however, is driven by one industry segment: computers and electronic products. In most of manufacturing, real GDP growth has been weak or negative and productivity growth modest. The extraordinary real GDP growth in computer-related industries reflects prices for computers and semiconductors that, when adjusted for product quality improvements, are falling rapidly. Productivity growth in these industries, in turn, largely reflects product and process improvements from research and development, not automation. Although computer-related industries have driven growth in the manufacturing sector, production has shifted to Asia, and the U.S. trade deficit in these products has soared since the 1990s. The outsized effect computer-related industries have on manufacturing statistics also may distort economic relationships in the data and result in perverse research findings. Statistical agencies should take steps to assure that the influence that computer-related industries have on manufacturing-sector statistics is transparent to data users.

**JEL Classification Codes**: L60, F60

**Key Words**: Manufacturing, computers, semiconductors, productivity, globalization, global value chains

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## INTRODUCTION

Since 2000, the U.S. manufacturing sector has lost more than 5 million jobs, or over 30 percent of its employment base. Large-scale employment losses in manufacturing are not confined to a few rust belt states. Manufacturing employment over the period has fallen in all but one state (Alaska), and the drop has exceeded 20 percent in 40 states. In response to these employment losses, as well as to a large trade deficit in manufactured goods and concerns that U.S. manufacturing is losing its international competitiveness, President Obama created a cabinet-level Office of Manufacturing Policy, and Congress has considered a number of measures to help U.S. manufacturers.[1]

The development of special policies to promote U.S. manufacturing has many detractors, however. At the heart of the debate is a basic disagreement over the state of U.S. manufacturing. Those who oppose government intervention typically argue that there is little need, pointing to robust output growth in the sector. Over the past decade the average annual growth of real value-added in manufacturing has outpaced that in the aggregate economy, except during recessions, and in quantity terms, the output of U.S. manufacturers relative to the rest of the economy has remained steady (Figure 1).[2] These statistics, by themselves, provide compelling evidence that U.S. manufacturing remains highly competitive. Citing such figures, Robert Lawrence and Lawrence Edwards recently asserted, "The concerns about U.S. manufacturing are not about output or growth but relate to employment . . ." (Lawrence and Edwards 2013). High growth in real value-added coupled with large employment losses implies high labor productivity growth:

[1] McCormack (2013) reports on the status of congressional action on manufacturing policies.

[2] Throughout this chapter, we use the terms real value-added and real GDP interchangeably. Although nominal value-added in manufacturing has declined as a share of GDP in the United States, this decline may be attributed to the fact that prices have risen less quickly for manufactured products than for services.

many influential researchers and analysts promote the narrative that employment losses in manufacturing, as in agriculture, are largely a consequence of automation, not import competition.[3] As U.S. Chamber of Commerce Executive Vice President and Chief Operating Officer David Chavern put it, “Where did those [manufacturing] jobs go? Mostly to a country called ‘productivity’” (Chavern 2013).

Statistics, and their interpretation, play a crucial role in shaping our understanding of the economy and informing policy. Yet, the debate over the state of U.S. manufacturing, with its dueling narratives, bolstered by apparently contradictory sets of statistics, illustrates how the rapid pace of globalization and technological change greatly complicates the collection and interpretation of economic data. Building on Houseman et al. (2011), we raise concerns about the widely cited output growth statistics in Figure 1, which have served as a basic indicator of the health of American manufacturing. That article focuses on biases to manufacturing statistics resulting from the rapid shift toward imported intermediates from low-wage countries and estimates that real GDP growth in manufacturing was overstated by up to 20 percent between 1997 and 2007. In this chapter, we argue that, even in the absence of such biases, the manufacturing output statistics in Figure 1 are misleading and commonly misinterpreted.

First, it is generally unknown that the robust growth in real GDP in the manufacturing sector is largely driven by one industry: computers and electronic products. For most of manufacturing, real output growth has been relatively weak or negative.[4] When the computer and electronic products industry is excluded, real GDP growth in manufacturing falls by two-thirds between 1997 and 2007, the decade leading up to the Great Recession. In 2011, without computer-related industries, real GDP in the manufacturing sector was actually lower than in

[3] See, for example, Becker (2012), Hassett (2010), and Perry (2012). Atkinson et al. (2012, pp. 24–25) includes citations to many other prominent analysts and policymakers promoting this view.

[4] Houseman et al. (2011) originally made this point. Atkinson et al. (2012) also emphasized this fact.

2000. The computer and electronic products industry similarly drives real manufacturing output growth in most U.S. states. Real manufacturing GDP growth between 1997 and 2007 falls by more than half in a majority of states and by at least 25 percent in all but 10 states.

Furthermore, the extraordinary growth in real value-added and the accompanying productivity growth in the computer and electronic products industry results largely from prices for two sets of products: computers and semiconductors that, when adjusted for quality improvements, are falling rapidly. These quality improvements, in turn, largely reflect better design and increases in the density of electronic circuitry. While changes in manufacturing processes are necessary to produce these improved designs, the production processes in computer and semiconductors have been automated for many decades. Thus, the high growth in real value-added and productivity in the computer and semiconductor product segments, and by extension the manufacturing sector, reflects, to a large degree, product improvements from research and development rather than automation of the production process. Unlike productivity resulting from automation, which involves the substitution of capital for labor, productivity arising from improvements to product design and production processes does not, in and of itself, cause job losses.

Ironically, the extraordinary growth in real value-added and productivity in the computer and semiconductor industries does not signal the competitiveness of the United States as a manufacturing location for these products. Drawing on new market research data, we provide evidence of the shift in the location of computer and semiconductor manufacturing to Asia. Few personal computers and servers are assembled in the United States today, and consequently the United States runs a large trade deficit for these products. The United States retains a significant presence in semiconductor wafer fabrication, but over the last decade manufacturing capacity has expanded much more rapidly in Asia, and, as a result, U.S. market share has declined rapidly. Although many of the computers and semiconductors produced overseas are still designed in the United States, the shift in the location of production has important implications for the number and types of U.S. jobs.

The effect that computer-related industries have on measured growth in manufacturing real GDP has important implications not only for the interpretation of published statistics but also for research based on them. We illustrate with an empirical analysis of the relationship between employment and real output growth using state manufacturing data. The computer and electronic products industry is an outlier in manufacturing, characterized both by extraordinary real value-added growth and by above-average employment declines. An increase in a state's manufacturing output resulting from higher demand for its products should lead to an increase in employment, but we find no such employment effect in instrumental variables regression analyses. Although a naïve interpretation of this finding would suggest that policies to promote U.S. manufacturing will fail to generate jobs, the finding makes no sense, and such an interpretation would be incorrect. When the computer and electronics product industry is dropped from the manufacturing measures, the expected relationship between output and employment holds: higher demand generates roughly equal percentage increases in real manufacturing shipments and employment.

Misleading statistics have helped shape an important policy discussion concerning U.S. manufacturing. To address the problem, statistical agencies first and foremost should take steps to assure that the outsized effect that computer-related industries have on manufacturing sector statistics is transparent to data users. This could easily be accomplished by publishing real output and productivity statistics for the manufacturing sector less computer-related industries.

In the remainder of the paper, we do three things. First, we detail the influence that computer and electronic products manufacturing has on real manufacturing GDP growth nationally and in states. Second, we examine the global competitiveness of the U.S. computer and semiconductor industry segments and the sources and interpretation of the rapid real value-added and productivity growth in them. And third, we illustrate the distorting effect computer-related industries may have on research findings through an empirical examination of the relationship between output and employment growth using state manufacturing data. We conclude with recommendations for statistical agencies.

## THE EFFECT OF THE COMPUTER AND ELECTRONIC PRODUCTS INDUSTRY ON REAL GDP GROWTH IN MANUFACTURING

Manufacturing output statistics mask divergent trends within the sector. Figure 2 displays annual average growth rates for each three-digit NAICS manufacturing industry. Real value-added in the computer and electronic products industry, which includes computers, semiconductors, telecommunications equipment, and other electronic products manufacturing,[5] grew at a staggering rate of 22 percent per year from 1997 to 2007. In contrast, real value-added in petroleum and coal products manufacturing, the second-fastest growing industry, expanded less than 5 percent per year. Real value-added declined in seven industries over the decade. As shown formally below, without the computer and electronic products industry, which accounted for just 10 to 13 percent of value-added throughout the decade, manufacturing output growth in the United States was relatively weak.

[5] NAICS 334 also includes the manufacture of audio and video equipment; navigational, measuring, electromedical, and control instruments; and magnetic and optical media.

The rapid growth of real value-added in the computer and electronic products industry, NAICS 334, can be attributed to two subindustries: computer manufacturing, NAICS 334111, and semiconductor and related device manufacturing, NAICS 334413.[6] The extraordinary real GDP growth in these subindustries, in turn, is a result of the adjustment of price indexes used to deflate computers and semiconductors for improvements in quality. From 1997 to 2011, for example, the BLS producer price indexes have fallen at a compound annual rate of 52 percent for microprocessors, 36 percent for portable computers, and 28 percent for desktop personal computers and workstations.

**Contribution of the Computer and Electronic Products Industry to Aggregate Manufacturing Growth**

Growth rates for industry subsets may be approximated from published data using a Törnqvist formula. Specifically, the growth rate of real value-added for a subset of industries, expressed as a logarithmic change, is approximately equal to the weighted average of the growth rates of the component industries:

$$\ln(Q_t / Q_{t-1}) \approx \sum_i w_{i,t} \ln(q_{i,t} / q_{i,t-1}) \quad , \tag{1}$$

where $q_{i,t}$ is the published real dollar or (equivalently) quantity index for industry *i* in year *t* and $w_{it}$ is the average of industry *i's* share of nominal manufacturing value-added in adjacent time periods (*t*, *t-1*); $\sum_i w_{i,t} = 1$.[7]

[6] This information was provided to us by Erich Strassner at the Bureau of Economic Analysis. Detailed industry value-added data are not published by BEA, and consequently the analysis presented below is based on data aggregated to the three-digit NAICS level.

[7] Atkinson et al. (2012, Figure 30) presents similar calculations. In the late 1990s, the Bureau of Economic Analysis along with the other U.S. statistical agencies introduced the use of chained aggregates. Although the BEA publishes value-added in "real chained dollars" for all individual manufacturing industries, these industry-level real chained dollars cannot be summed to create a real series for subsets of industries. BEA publishes annual figures on industry contributions to aggregate real GDP growth.

Figure 3 shows average annual growth in real GDP for U.S. manufacturing as published and for manufacturing excluding the computer industry (NAICS 334) along with aggregate real GDP growth rates from 1997 to 2007 and from 2000 to 2010.[8] Although the computer and electronic products industry only accounted for between 10 and 13 percent of value-added in the U.S. manufacturing sector throughout the period, it has an outsized effect on manufacturing statistics. Without NAICS 334, U.S. manufacturing's real GDP growth was only 1.2 percent per year from 1997 to 2007, a third of the published aggregate manufacturing growth rate, and was much weaker than overall growth in the economy. The manufacturing sector is disproportionately affected by recessions, and so when computed over a more recent period, real GDP growth was somewhat lower in manufacturing than in the aggregate economy. From 2000 (a business cycle peak) to 2011, real GDP grew at an annual rate of 1.3 percent in manufacturing compared to 1.7 percent for the economy overall. Without the computer and electronic products industry, however, real value-added in manufacturing was about 5 percent lower in 2011 than in 2000. The computer and electronic products industry has a similarly large impact on manufacturing productivity statistics. For example, manufacturing's multifactor productivity growth rates between 1997 and 2007 fall by almost half when the computer industry is excluded (Houseman et al. 2011).

## Contribution of the Computer and Electronic Products Industry to State-Level Manufacturing Growth

The nationwide pattern of strong manufacturing output growth in combination with a large employment decline is also apparent in most states. In the decade leading up to the Great

[8] Because of revisions to the data, the contribution of compound annual growth rates for the 1997 to 2007 period reported in Figure 3 differs somewhat from that reported in Houseman et al. (2011). BEA issued additional revisions to the national industry accounts data in January 2014, but had not updated state data at the time of this writing. The analyses in this paper are based on national and state manufacturing data available as of December 2013. Recent updates to the national manufacturing statistics do not affect the substantive findings of this paper.

Recession, real value-added declined in only four states (Pennsylvania, New Jersey, Kentucky, and West Virginia), while the growth rate of real value-added exceeded 20 percent in 33 states and real value-added more than doubled in seven (Oregon, Idaho, Nevada, Arizona, California, South Dakota, and Texas). In spite of strong manufacturing output growth, the large majority of states experienced significant employment declines in the sector. Manufacturing employment declined by more than 10 percent in 37 states and the District of Columbia and expanded in just four states over the decade.

Paralleling our analysis of national manufacturing data, we examine the extent to which state-level manufacturing's real GDP growth is attributable to the computer and electronic products manufacturing industry (NAICS 334). Figure 4 displays state-level average annual growth rates of real GDP for all manufacturing and for manufacturing excluding NAICS 334 from 1997 to 2007. The influence of the computer industry on the sector's real value-added growth naturally is greatest in states with relatively high or significantly growing concentrations of computer manufacturing.[9] For example, when NAICS 334 is omitted, manufacturing's average annual real GDP growth rate between 1997 and 2007 falls from 8.7 to 2.4 percent in Arizona, from 7.9 to 2.5 percent in California, from 5.9 to 1.0 percent in Colorado, from 12.8 to 1.5 percent in Idaho, from 6.3 percent to −0.3 percent in Massachusetts, from 5.4 to −1.4 percent in New Mexico, and from 15.1 percent to 1.1 percent in Oregon.

The influence on manufacturing output growth rates is substantial, however, even in states in which the computer industry has a modest presence. That growth rate added falls by more than half in 28 states and the District of Columbia when NAICS 334 is excluded and by at least 25 percent in all but 10 states. And without computers, real GDP for the rest of

[9] The share of manufacturing value-added in NAICS 334 exceeded 20 percent in 1997 in 10 states: Arizona (50%), California (30%), Colorado (28%), Idaho (29%), Massachusetts (28%), New Hampshire (43%), New Mexico (81%), Oregon (44%), South Dakota (22%), and Vermont (27%).

manufacturing experienced an absolute decline in 10 states and the District of Columbia in the decade before the Great Recession.

A state's manufacturing output growth often is used to assess the sector's overall health and competitiveness vis-à-vis manufacturing in other states. Although the computer industry is an important component of manufacturing in some states, we argue below that the extraordinary growth in real value-added and productivity in this industry segment largely reflects product innovations resulting from research and development (R&D), and such innovations may not have occurred in the state, potentially giving a distorted picture of the relative competitiveness of states' manufacturing sectors.

Table 1 shows, for selected states, rankings according to manufacturing's real value-added growth from 1997 to 2007, as published, and new rankings based on real valued-added growth rates of manufacturing excluding NAICS 334. For 22 states and the District of Columbia, rankings change by at least 10 when growth rates exclude NAICS 334; rankings for five states fell by more than 20. As expected, states with large or growing shares of computer and electronic products manufacturing tend to have the highest manufacturing GDP growth rates and experience the largest decline in ranking when the growth is calculated without NAICS 334. Still, the changes are dramatic. Most notable are the drop in the rankings for New Mexico (from 11 to 49) and Massachusetts (from 9 to 43). Oregon, the state with the highest manufacturing GDP growth rate over the period in official statistics, falls to 25 in the new rankings. Correspondingly, 12 states with a relatively small presence of computer manufacturing experience significant improvements under the new ranking. In sum, states with apparently rapidly expanding manufacturing sectors are for the most part simply states with sizable computer and semiconductor industries.

## INTERPRETING THE EXTRAORDINARY REAL OUTPUT AND PRODUCTIVITY GROWTH IN THE COMPUTER AND SEMICONDUCTOR INDUSTRIES

So far, we have argued that U.S. manufacturing-sector statistics are often misinterpreted because it is not understood that computer and related industries largely drive the apparent robust growth in real manufacturing GDP and have a large effect on the manufacturing productivity measures. One might suppose, at least for this industry segment, that the strong real output growth indicates the competitiveness of the United States as a location of production and that the sharp drop in employment is a consequence of productivity growth. Both, however, would be a misinterpretation of the numbers.

### The Competitiveness of the United States as a Location for Production of Computers and Semiconductors

As noted, the influence of NAICS 334 on aggregate manufacturing's real GDP growth largely derives from electronic computer manufacturing (NAICS 334111), whose key product segments are personal computers and servers, and from the semiconductor industry (NAICS 334413), which in the United States largely comprises the production of integrated circuits. To put their influence into perspective, we plot data on the (nominal) value of shipments published by the Census Bureau in these two subindustries for the 2002-to-2011 period in Figure 5.[10] Semiconductor shipments were relatively flat until the 2008 recession, declined during the recession, and have expanded significantly since 2009.[11] In contrast, the value of shipments in electronic computer manufacturing was relatively flat until the recession in 2008 and has declined precipitously since. Although these two subindustries accounted for most of the growth in manufacturing real GDP over the period, because of rapidly declining price deflators their

[10] At the time of this writing, 2011 is the last year for which shipments data are available. Data on industry value-added are not published at the six-digit NAICS level.

[11] It is possible that the semiconductor industry includes some fabless entities, which design integrated circuits but contract out production, typically to overseas foundries.

share of the manufacturing sector's output did not increase; together, they accounted for only 2 to 3 percent of all manufacturing shipments throughout the period.

Real output and productivity statistics are commonly used as indicators of the competitiveness of U.S. industries, but the extraordinary growth of these measures for the computer and semiconductor industries may be a poor indicator of the overall competitiveness of the United States as a location for manufacturing these products. How competitive is the United States in computer and semiconductor manufacturing? To address this question, we present market research data and analysis on trends in the global location of production of personal computers, computer servers, and semiconductors. We supplement these data with import and export data in these product groups from the UN Comtrade database.

**Personal computers and servers**

Personal computers (termed single-user computers in U.S. statistics) include desktop and portable computer devices, while servers (termed multiuser computers) provide shared data services. Figure 6 displays estimates by the market research firm International Data Corporation (IDC) of the share (in units) of worldwide production of PCs and servers assembled in the United States since the early 2000s. In both product segments, the share assembled in the United States is small and has fallen dramatically over the last decade. In 2001, an estimated 12 percent of personal computers were manufactured in the United States; by 2012 that share had fallen by more than half, to about 5 percent. U.S. assembly is most common with desktop computers; portable computers are almost exclusively manufactured in Asia. The shift in demand away from desktops in favor of portable computers partly explains the decline in U.S. market share. As with PCs, a growing share of servers are manufactured in Asia and Mexico and a declining share in the United States. Large Internet content providers (e.g., Google), retailers (e.g., Amazon), and social media companies (e.g., Facebook) did some assembly in the United States for their own server farms in the early 2000s—explaining the increase in U.S. market share around 2003 in Figure 6—but have since discontinued that practice, according to the IDC.

What PC product segments are still assembled in the United States? According to IDC analysts, U.S. assembly is primarily done for government and education sector orders that require domestic content. In addition, for PCs, last-minute customized configuration is sometimes carried out domestically for desktop PC units, though several such plants have recently closed (Ladendorf 2012). PC configuration generally entails inserting specific processors, memory, and hard disk drives into mostly built-up machines to meet the requirements of specific orders. Because the manufacturing process requirements are minimal, PC configuration facilities are sometimes referred to as "screwdriver plants" in the industry.

The shift of PC production away from the United States is reflected in trade statistics. The nominal value of U.S. PC exports rose only 3.6 percent on an average annual basis from 2002 to 2012 (from $1.8 to $2.6 billion), while world exports rose 18.4 percent (from $28.3 to $153.1 billion), causing the U.S. share of world PC exports to fall from 6.5 percent in 2002 to 1.7 percent in 2012. Most of this growth in world exports has come from China. China's exports rose 42 percent on an average annual basis from 2002 to 2012 (from $3.5 to $117.4 billion), and its share of world exports soared from 12.4 to 76.6 percent. During the same period, PC imports to the United States rose at an average annual rate of 14.7 percent, and as a result, by 2012 the United States ran a trade deficit of $38.3 billion in PCs.

The center of PC production clearly has shifted to China, where PCs (increasingly in notebook format, since that format is cost-effective to ship by air) are assembled in huge numbers, largely by Taiwan-headquartered contract manufacturers such as Quanta and Foxconn for major global brands such as Lenovo, Hewlett-Packard, and Apple. Although U.S.-based PC companies remain important as brand leaders and orchestrators of the global PC value chain, little production occurs within the borders of the United States.[12]

World trade in computer servers displays a similar pattern. In 2005, China surpassed the United States as the world's largest exporter of computer servers. The nominal value of U.S. server exports rose only 4.4 percent on an average annual basis from 2002 to 2012 (from $2.8 to $4.2 billion), while world exports have risen 5.8 percent (from $18.3 to $32.1 billion). During the same period, China's exports rose 25 percent per year (from $1.1 to $10.2 billion), and the number-two server exporter, Mexico, increased exports at a rate of 12.4 percent per year (from $1.3 to $4.3 billion). At same time, huge server farms were being erected in the United States to support the expansion of the Internet, driving import growth at an annual average rate of 16.3 percent per year, from $2.9 billion in 2002 to $13.1 billion in 2012. By 2012, server imports to the United States accounted for 34.9 percent of the world total, far higher than server imports to Japan, the second largest importer, which accounted for only 7.8 percent of total world imports. These figures reflect the continued dominance of the United States as a hub of the global Internet, with imports to the United States rising much faster than worldwide imports (16.3 percent per year for the United States compared to 5.8 percent worldwide). As with PCs, the shift of server manufacturing to outside the United States does not mean that American-branded server companies are losing global market share, only that the United States is losing ground as a

[12] According to Gartner, U.S. PC brands Hewlett-Packard and Dell ranked number two and number three in unit sales worldwide in the third quarter of 2013, with market shares of 17.1 percent and 11.6 percent, behind China's Lenovo, which held a 17.6 percent market share. See: http://www.gartner.com/newsroom/id/2604616. Although little computer assembly takes place in the United States, the United States remains an important location for PC design. Even Lenovo, the Chinese company that purchased IBM's PC division in 2005, maintains a large design center in North Carolina.

location for server manufacturing. As a result, the U.S. trade balance has declined dramatically in the past 10 years in both PCs and servers (see Figure 7).

**Semiconductors**

To gauge the relative position of the United States as a location for semiconductor manufacturing, we acquired annual data on all major semiconductor fabrication plants (called "fabs") worldwide from the market research firm IHS Global Inc. for the period 2000 to 2013. Semiconductor fabs fall into two general categories: integrated device manufacturing (IDM) plants (e.g., Intel and Samsung), which mainly produce semiconductors that are designed and sold by the fab's owner, and "foundries," which produce semiconductors designed by others on a contract basis (e.g., the largest are Taiwan Semiconductor Manufacturing Company and United Manufacturing Corporation, both based in Taiwan). Foundries are analogous to the PC contract manufacturers (e.g., Foxconn) mentioned earlier.

For IDMs, the data include, among other things, information on plant capacity (normalized to eight-inch wafer size), product type (logic, memory, analog, microcontroller, and discrete), plant location, and the average cost of producing wafers (also normalized to eight-inch equivalence) by product type and level of technology. For foundries, which almost exclusively produce logic chips (programmable, often application-specific [ASIC] microprocessors), the data include the same information, except product type.

Figure 8 shows the growth of total semiconductor production capacity by country or region between 2000 and 2013. Strikingly, total capacity has grown at a considerably slower pace in the United States and Europe than in key semiconductor-producing countries in East Asia. Specifically, the compound annual growth rate of total capacity was 4.2 percent in the United States and 2.3 percent in Europe, compared to 8.0 percent in South Korea, 8.7 percent in

Singapore and Malaysia, 11.3 percent in Taiwan, and 23.8 percent in China. While China's growth is measured from a low base, its global share of semiconductor capacity nonetheless grew by 7 percentage points, from less than 1 percent in 2000 to 8 percent in 2013. At the same time, the U.S. share of global semiconductor capacity shrank from 19 to 13 percent, and Europe's share fell from 14 to 7 percent. Most strikingly, Taiwan's share of world semiconductor fabrication capacity increased from 12 to 20 percent over the same period, driven mainly by the popularity of the fabless/foundry model, as we will discuss below.

The trends displayed in Figure 8 may be misleading because capacity is aggregated across all types of semiconductors, combining products with quite different design parameters, prices, and manufacturing requirements. As Table 2 shows, the most expensive and design-intensive semiconductors are digitally programmable devices called "logic semiconductors." They include central processing units (CPUs) such as Intel processors, but also a wide range of application-specific devices that provide functionality for nearly all electronic-based products that can be programmed by users (from mobile-phone handsets to automated factory equipment). While design requirements for logic semiconductors are extremely high, because they include millions of microcomponents and multiple technologies in a single chip of silicon, manufacturing requirements, while also high, are not extreme. Computer memory chips, by contrast, contain even greater numbers of microcomponents per area of silicon, and are thus extremely demanding to produce, but the circuitry is relatively simple, with information storage grids dominating the design. Other major semiconductors vary in regard to design intensity, but are generally less demanding to produce and are produced in lower volumes.

Figure 9 displays global capacity by product type from 2000 to 2013, along with the U.S. market share by product type in the beginning and at the end of the period. The greatest increase in capacity has occurred in memory chips, which are predominantly produced by IDMs such as Samsung (from Korea). Only one company, Micron Semiconductor, produces memory in the United States. While U.S. memory capacity expanded at a compound annual growth rate of 6 percent, the share fabricated in the United States has declined as production has shifted to Asian countries, notably Taiwan, Japan, South Korea, and China. A large share of analog, microcomponent, and discrete semiconductor products are fabricated in the United States, but these are relatively small segments of the semiconductor market.

Changing patterns in the location of production of logic semiconductors is linked to the rise of the foundry model. So-called fabless semiconductor design companies design and sell logic semiconductors, which are associated with high manufacturing and design requirements as well as high profit margins and contract out production to foundries. Many dominant fabless design companies, such as Qualcom and Broadcom, are located in the United States, while foundries are concentrated in Taiwan and Singapore. In 2000, 41 percent of the capacity to produce logic semiconductors was in foundries, but by 2013 foundries accounted for 65 percent of logic capacity.

The United States accounted for only 3.1 percent of world foundry capacity in 2013, down from 4.6 percent in 2000. Manufacturing of logic semiconductors in the United States is concentrated in the domestic plants of highly successful IDMs, such as Intel and Texas Instruments.[13] While the share of IDM logic semiconductor capacity in the United States has expanded since 2000, the U.S. share of total world logic semiconductor capacity has fallen from 12.8 percent in 2000 to 9.9 percent in 2013, again, mainly because of the rise of the

[13] According to IHS Global Inc., five of Intel's nine logic fabs are located in the United States, with two in Ireland, one in Israel, and one in China. Four of Texas Instruments' five logic fabs are in the United States, with the additional fab in Japan. Besides these logic fabs, Intel has seven fabs producing microcomponents, all in the United States, and Texas Instruments has 14 smaller fabs producing analog semiconductors, half of which are in the United States.

fabless/foundry model. In sum, a more detailed analysis does not alter the general picture of decline in the importance of the United States as a location for semiconductor manufacturing, depicted in Figure 8.

As with computers, this decline is reflected in trade statistics. Semiconductor exports from the United States (of all types) fell at an average annual rate of 2.5 percent per year from 2002 to 2012 (from $26.3 to $20.5 billion), while worldwide exports increased at a rate of 8.7 percent per year (from $161.9 to $371.1 billion). As a result, the U.S. share of world semiconductor exports fell from 16.3 percent in 2002 to just 5.5 percent in 2012. This pattern is similar to export trends in PC and computer servers.

However, changes in world semiconductor imports show a different pattern. Instead of rising imports, as shown for the United States in PC and servers, semiconductor imports were stagnant, increasing at an average annual rate of less than 1 percent from 2002 to 2012. Since semiconductors are only of use as components in larger systems, imports have mainly risen for the major producers of PCs, servers, and other electronics-based products. China's semiconductor imports, not surprisingly, grew the most rapidly from 2002 to 2012, at an average annual rate of 21.3 percent, and China's share of total world imports grew from 15.3 to 41.6 percent. During this same period, the U.S. share of world semiconductor imports shrank from 8.4 to 3.6 percent, reflecting the general decline of the United States as a location for electronics final goods manufacturing.

The location of production of computer and semiconductor manufacturing has clearly shifted away from the United States toward Asian countries, both overall and within the most important and technologically demanding product types (from a manufacturing perspective). Again, this does not necessarily imply that the U.S.-based computer and semiconductor industries, broadly defined to include research and design functions, have lost global competitiveness. U.S. companies continue to drive innovation and growth in the ITC industry, pioneering and dominating new industry segments such as Internet search and retailing, social media, and cloud computing. However, these software-based systems now run, in large part, on hardware manufactured outside the United States. In semiconductors, the addition of new and acquired U.S. IDM fabs outside the country and the rise of the foundry/fabless design business model have enabled U.S. semiconductor companies to continue to design chips in the United States while shifting production overseas (Brown and Linden 2011). The shift of manufacturing to Asia, however, has important implications for the number and types of jobs located in the United States.

In sum, despite the extraordinary real output growth in the U.S. computer and semiconductor manufacturing industries, as measured in official statistics, the competitiveness of the United States as a manufacturing location for these products has substantially eroded. Exactly how, over the longer term, the shift in the locus of production to Asia will impact research and development activities in the United States remains to be seen.

**Interpreting Productivity Growth**

The rapid growth in real output, coupled with a sharp drop in employment—39 percent since 1997 compared to 30 percent for all manufacturing—has led to surging labor productivity in the computer and electronic products industry. Analysts often interpret productivity growth to mean that workers are working faster or that automation (the substitution of capital for labor) is driving the growth, as illustrated in a recent White House report on manufacturing, which stated, "Manufacturing workers have paradoxically often been the victims of their sector's own success, as rapid productivity growth has meant that goods can be produced with fewer workers" (Executive Office of the President of the United States 2009).

Productivity growth in computer-related industries, however, is largely attributable to rapidly falling price deflators that aim to capture consumer valuation of improvements in product quality. These improvements, we argue, primarily reflect innovations from research and development and innovations in the production processes. While, for example, the typical computer produced in the United States today may in some statistical sense be the equivalent of several computers produced a decade ago, that does not, in and of itself, mean that fewer workers are needed to manufacture a computer today than in the past. For an industry where full automation has reigned for many decades, the notion of capital substituting for labor appears quaint. Indeed, a recent report by the McKinsey Global Institute concluded that all of the large-scale net job losses in U.S. computer and electronic products manufacturing are attributable to the offshoring of production (Roxburgh et al. 2012).

## IMPLICATIONS FOR RESEARCH

The outsized effect that the computer and electronic products industry has on real output and productivity measures holds important implications for empirical research. While computer-related industries show extraordinary real GDP growth, owing to price deflators that account for improvements in product quality, they registered above-average employment declines and import penetration. Such an outlier may distort relationships between economic variables, result in anomalous findings, and lead researchers to draw incorrect inferences, for example, about the causes of the sharp decline in manufacturing employment or the effects of imports on domestic industry.

In addition to the large effect that computer-related industries have on measured aggregate and state-level manufacturing's real value-added growth, the sizable growth of imported intermediates used in manufacturing has likely imparted a significant bias to real value-added in the published statistics for all manufacturing industries. BEA estimates that the import share of materials intermediates used in manufacturing rose from 18 percent to 25 percent between 1997 and 2007. Moreover, most of the growth in imported intermediates came from developing countries, most notably China, whose market share increased largely because suppliers from these countries offered lower (quality-adjusted) prices for these intermediate inputs. So-called offshoring bias arises because the price declines associated with the shift in sourcing to low-cost countries are unlikely to be captured in the import and producer price indexes constructed by the Bureau of Labor Statistics and used by the Bureau of Economic Analysis to deflate intermediate inputs in the industry accounts data. As a result, official statistics may substantially understate the quantity of inputs used by U.S. manufacturers and overstate the growth in manufacturing's real valued-added (Houseman et al. 2011).

Although growth in a state's real manufacturing GDP should be a good predictor of a state's manufacturing employment growth, computer-related industries and offshoring bias may substantially weaken the relationship between measured output and employment in manufacturing.[14] Consequently, we expect that a state's real value-added growth in manufacturing, adjusted for the contribution from computer-related industries and for offshoring bias, will be a better predictor of the state's employment growth than published real value-added growth measures.

[14] This is particularly true if a state's real output growth results from increased demand for a state's products, rather than from state-level productivity shocks, as we would expect demand would have only modest effects on productivity.

Here we test that proposition by regressing a state's manufacturing employment growth over the 1997-to-2007 period on real value-added growth over the same period, measured three ways: first as the published aggregate manufacturing measure; next as the published measure, excluding NAICS 334; and finally as a measure that both excludes NAICS 334 and adjusts for offshoring bias.[15]

$$\ln(E_{s,07} / E_{s,97}) = \alpha + \beta \ln(Q_{s,07} / Q_{s,97}) + \varepsilon_s \tag{2}$$

Ordinary least squares estimates of Equation (2) may be subject to simultaneity bias because employment and output growth in a state's manufacturing industry are determined by both demand- and supply-side forces: while overall national demand conditions for an industry's product affect state-level industry demand for labor, a state's supply of workers may affect industry growth in that particular state. For example, industries may expand relatively more in states with higher population growth, and hence growth in their supply of labor. In addition, state-level labor productivity shocks may expand output while reducing employment to output ratios. In other words, the ordinary least squares estimates of Equation (2) do not correspond to any well-defined structural relationship.

To address possible simultaneity bias and to focus on how demand forces at the national level affect state labor markets, we instrument state-level manufacturing's real GDP growth rates using national industry-level growth rates: the instrument is a weighted average of the national industry-level growth rates, where the weights are the state's nominal shares of value-added in

[15] In the second and third measures, we exclude employment in NAICS 334 from the manufacturing employment measure, but doing so has little effect on our estimates. The appendix to this paper provides details on our adjustment of state manufacturing's real GDP growth for offshoring bias, which is based on estimates in Houseman et al. (2011).

the component industries.[16] This instrument proxies for what would happen to state-level demand for manufacturing output if each of a state's manufacturing industries maintains its current competitiveness and hence its market share of national demand. With this instrument, Equation (2) estimates a structural relationship showing the effects of national demand shocks to products produced in a state's manufacturing sector on that state's manufacturing employment.

Table 3 presents ordinary least squares and two-stage least squares estimates of Equation (2). The first two columns of Table 3 are based on observations from all 50 states and the District of Columbia. Strikingly, the coefficient estimate on the output growth term more than doubles, from 0.23 to 0.56, in the OLS model when NAICS 334 is omitted from the growth measure. State-level employment growth is much more strongly related to output growth when we omit the information from this industry.

In the 2SLS models reported in column 2, the coefficient on the aggregate manufacturing growth term is 0.06, whereas the coefficient on the manufacturing growth measure that excludes computer-related industries is 1.07. A coefficient estimate of approximately 1 implies that a 1 percent increase in a state's output results in a 1 percent increase in employment, which is a reasonable estimate of the effect of a demand shock. In contrast, the coefficient close to zero on aggregate manufacturing growth implies that demand shocks to a state's industries have little effect on state employment growth, a finding that makes little sense and suggests problems in using the aggregate manufacturing data.

The output measure in the bottom panel of Table 3 excludes NAICS 334 and adjusts for offshoring bias. This last output measure is subject to important caveats. As discussed in the

[16] Specifically, we generate a new annual quantity index series for each state so that the rate of real value-added change between years for the state s is $ln(q_{s,t} / q_{s,t-1}) = \sum_t w_{i,s,t} \ln(q_{i,US,t} / q_{i,US,t-1})$, where the weight for industry *i* is the average of industry *i's* nominal share of value-added in years *t* and *t*−1. See Bartik (1991) for further discussion of the instrument.

appendix, estimates of offshoring bias in state manufacturing real GDP measures likely significantly understate true variation across states in offshoring bias. Given this fact, it is perhaps not surprising that also adjusting for offshoring bias has little effect on the point estimates. Nevertheless, it does substantially reduce the standard error of the estimate in the 2SLS model: the coefficient estimate of 0.99 in the third panel of column 2 has a *p*-value of 0.12.

In the models reported in columns 3 and 4 of Table 3, we omit observations from the District of Columbia, Hawaii, and Alaska, which have the smallest manufacturing sectors and which differ from other states in geographic proximity or size. The patterns of the coefficient estimates are similar to those reported in columns 1 and 2, but excluding these very small states substantially improves the precision of the estimates, particularly in the 2SLS models. In the models that instrument for state output growth, the coefficient on manufacturing real value-added growth is 0.08 and insignificant. The coefficients on the growth measures that either exclude NAICS 334 or exclude NAICS 334 and correct for offshoring bias are 0.69 and 0.70, respectively, and both are significant at conventional levels (*p*-values 0.05 and 0.02).[17]

Although, using state-level data, the results from these regressions show that the computer and electronic products industry breaks the empirical link between real output and employment growth in the manufacturing sector, this analysis does not provide insights into the reasons underlying the sharp trend decline in U.S. manufacturing employment since 2000. It does, however, underscore the point that the strong output and productivity growth in the

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[17] These coefficient estimates of about 0.7—though not significantly different from one—imply that long-run demand shocks to a state's industries may boost labor productivity somewhat. Such a boost to labor productivity could occur if healthy demand conditions could allow greater investment and hence increased use of newer technologies and vintage capital. Healthy demand conditions also may permit greater exploitation of scale economies. However, because technology innovations can be shared nationwide, these productivity effects should be limited, and indeed point estimates of 0.7 indicate that output demand shocks do considerably boost state labor demand. In contrast, the point estimate of 0.08 on the aggregate manufacturing growth term reported in column 4, panel 1, implies that almost all of a demand shock to state output growth is manifested in productivity growth rather than in employment growth, which is hard to believe.

aggregate manufacturing statistics is not evidence, in and of itself, that automation caused the decline, as many researchers and analysts have concluded.[18]

The dominance of the computer industry on measured real output growth in manufacturing may lead to other perverse research findings, as illustrated in Acemoglu et al. (2013). In an analysis of the effect of import penetration on domestic shipments in manufacturing industries, the study's authors find that an increase in import penetration significantly lowers nominal shipments but has no effect on real shipments in the affected industry. The naïve researcher would conclude, therefore, that imports have had no adverse impact on the quantity of goods manufactured in the United States. This finding, however, is driven by computer-related industries, which are outliers—simultaneously experiencing extraordinary real output growth and high growth in import penetration. Acemoglu et al. show that the coefficient on the import penetration term becomes negative and significant when computer-related industries are excluded from the regression.

## RECOMMENDATIONS FOR STATISTICAL AGENCIES

Statistics play a critical role in informing policymakers and shaping their responses to economic issues. The recent debate over manufacturing policy in the United States, however, illustrates how the numbers can obfuscate as much as enlighten. More transparency in the publication of the data—in particular, making clear to data users the influence the computer and semiconductor industries have on the aggregate manufacturing numbers—could have avoided

[18] Autor, Dorn, and Hanson (2013) and Acemoglu et al. (2013) provide the most rigorous analysis to date of the causes of the recent decline in manufacturing employment and its associated impacts on regional employment and labor force participation. They find strong evidence that the growth of imports from China caused a substantial share—potentially most—of the large decline in manufacturing employment in the years leading up to the Great Recession.

much of the confusion. The extraordinary growth of real value-added and productivity in the computer and semiconductor industries also naturally raises the question: Are these numbers right? The outsized effect that this small industry has on aggregate statistics is reason for further scrutiny of the data. In addition, the growth of globalization, accompanied by rapid shifts in the location of production, underscores the inadequacy of current price indexes to capture price changes associated with changes in sourcing. In this closing section, we recommend steps the statistical agencies can take to improve communication with data users and highlight several areas for further research.

**Improve Transparency and Communication with Data Users**

Many influential economists and policy analysts have cited the robust growth in U.S. manufacturing's real value-added and productivity as evidence of the sector's strength (Atkinson et al. 2012). It is unlikely that most citing those statistics understand that one small industry segment largely accounts for the sector's growth, that the output and productivity growth in the computer industry primarily derives from product innovation, or that the manufacturing presence of these industries in the United States appears to be declining. Making these facts more transparent to data users is important. The statistical agencies could accomplish the first relatively easily and with little cost by publishing separate tabulations for real value-added in manufacturing excluding computer-related industries. The statistical agencies also should disseminate information to users clarifying how price deflators affect the industry's measured output growth and what the output growth measures mean. Ideally, the statistical agencies would develop better measures of the global competitiveness of domestic industries by generating and publishing systematic comparisons of U.S. manufacturing industries with industries elsewhere in the world.

State policymakers are among the many users who would benefit from more transparent manufacturing data. In seeking to understand how national manufacturing trends might be affecting their state labor markets, state policymakers will not learn much from a naïve use of the official statistics. Adjusting statistics to exclude computer-related industries and to correct for import price biases will result in data that are more sensible and useful for understanding trends in state labor markets.

Beginning in 2017, the U.S. statistical agencies are planning to classify so-called factoryless goods producers (FGPs)—organizations that design and sell products, but contract out their production—in the manufacturing sector (Doherty 2013). Currently, such organizations usually are classified in wholesale trade or research. This change is expected to significantly increase measured manufacturing output in a number of industries, including computers and semiconductors. While their classification in manufacturing has merit, the activities in FGPs (such as fabless semiconductor design firms and computer firms that use contract manufacturers in China) are a far cry from the factories of old. At the very least, extensive education of data users about this change and the publication of separate tabulations on FGPs within manufacturing will be critical to avoid even further misinterpretation of the manufacturing statistics.

**Research on Price Deflators**

The price deflators for a small number of products within the computer and electronic products industry fundamentally drive growth in the manufacturing sector and have a large influence on aggregate GDP growth as well. Those price deflators, however, are potentially sensitive to methods used to adjust for quality improvements. Existing price indices for computers and related electronic products, for example, implicitly assume that consumers and businesses derive value solely from the hardware embedded in these products. In practice, however, consumers benefit from the interaction of the hardware with software and from networking with other computer users via the Internet. In the presence of network externalities, the welfare implications for an individual consumer of some change in computer-related hardware characteristics and prices depend upon the hardware and software used by others. When some users upgrade their computers, it may force others to upgrade theirs in order to maintain the same level of interaction. These negative externalities must be taken into account in order to capture real output measures that correspond to changes in consumer well-being. Current price index procedures do not take these externalities into account. A version of this problem was explored in Ellison and Fudenberg's (2000) article on excessive upgrades in the software industry.[19]

Future research should address this and other critiques that current methodology may significantly overstate the true benefits to consumers and businesses from technological advances in computer and related hardware.

**Crediting Gains from R&D**

Rapid advances in research and product development in the computer and electronic products industry have resulted in rapid declines in measured quality-adjusted product prices, which in turn have driven rapid measured output and productivity growth in manufacturing. Conversely, recent plant closures and associated downward revisions to shipments in the computer industry contributed to a substantial downward revision in real GDP growth in

[19] Feenstra and Knittel (2004) consider a related problem: that individuals purchase computer hardware beyond its current usefulness because they anticipate future changes in software that will make it necessary to have better computer hardware. As a result, short-run changes in consumer well-being are overstated by the measured decline in computer hardware prices for constant-quality models.

manufacturing.[20] And if offshoring of the computer and semiconductor production continues, it likely will significantly dampen measured value-added and productivity growth in manufacturing in the future.

But one might ask whether the true economic impact of increased or decreased production in this industry is commensurate with its impact on the manufacturing statistics? Should, for example, the effect on real output and productivity growth in U.S. manufacturing from the closure of a computer assembly plant be an order of magnitude greater than the closure of a similarly sized auto assembly plant, particularly if research and development for the former still takes place in the United States?

Crediting the output and productivity growth from product improvements to production would matter little if firms were vertically integrated—performing tasks from product design to the manufacturing of the products—and if these tasks were all performed in one firm in one country. As the computer and electronic products industry illustrates, however, the United States increasingly is moving away from making things and instead specializing in services and product design (Corrado and Hulten 2010). Research should address distortions to statistics arising from the fact that gains from technical advances are being credited solely to the manufacture of physical products.

**Research on Price Index Construction**

Finally, research indicates that the rapid shift in sourcing of products to low-cost foreign suppliers is imparting a significant bias to real value-added and productivity statistics in the computer and electronic products industry and in manufacturing overall. The bias is part of a more general problem in the construction of price indexes: the way they are constructed

[20] For a discussion of the revision, see Mandel (2012).

implicitly assumes that the "law of one price" holds, and thus that observed price differences across suppliers reflect differences in the quality of their goods. The entry and market expansion of low-cost suppliers, however, is an important part of the ongoing dynamics in prices facing consumers and businesses. The input price index proposed by Alterman (2013), which would be based on a survey of input purchasers, represents a first step toward addressing this important gap in price measurement. Research is needed to pilot the index and determine its feasibility.

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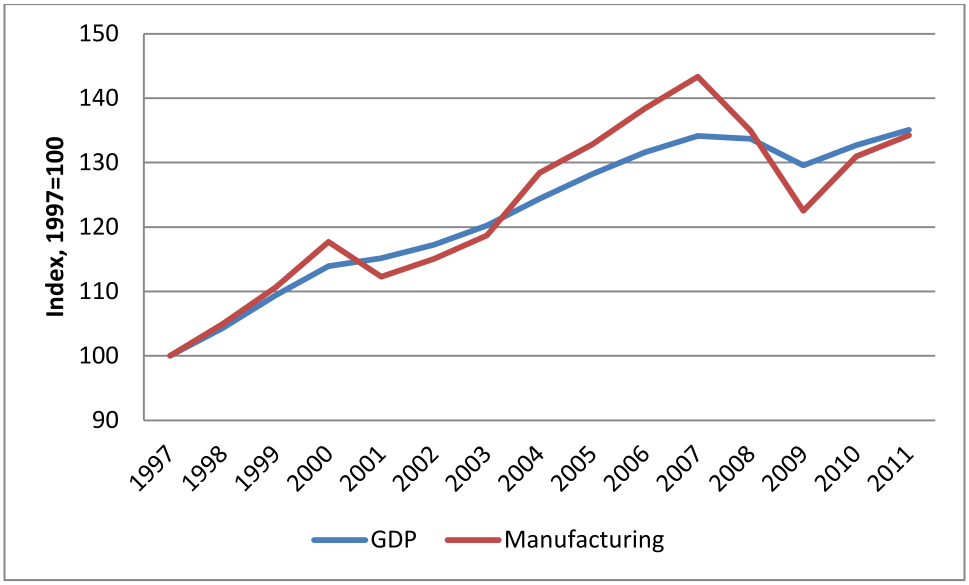



**Figure 1  Growth in Real GDP and Manufacturing Value-Added, 1997–2011**
SOURCE: BEA

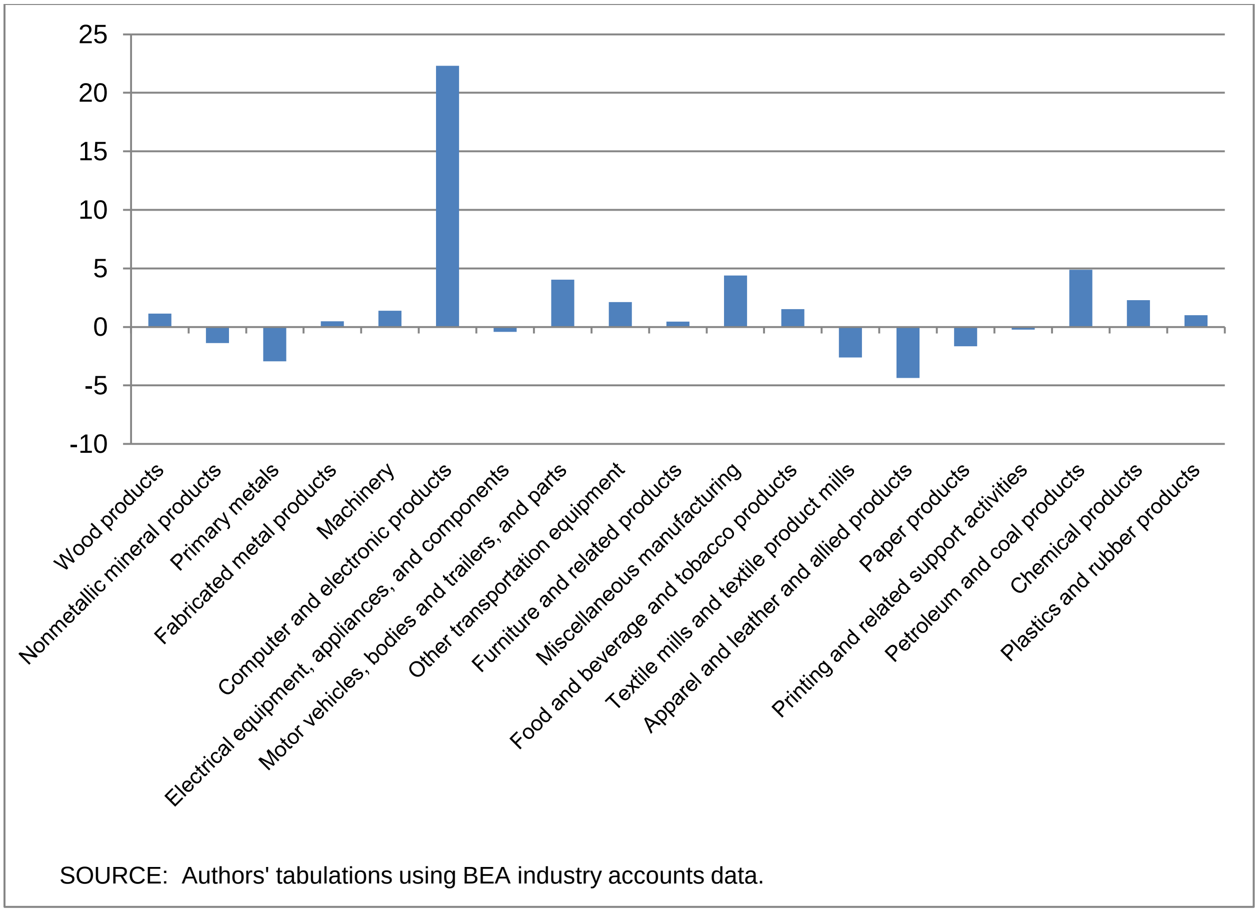



**Figure 2 Average Annual Growth Rate, 1997–2007**

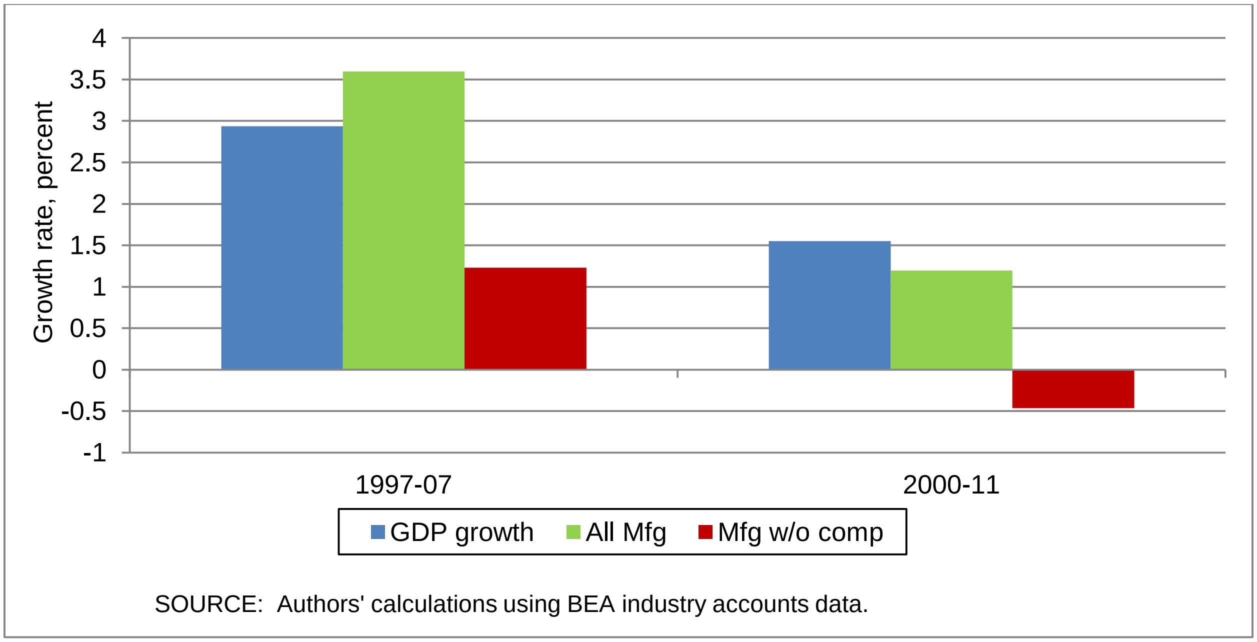



**Figure 3 Average Annual Growth Rates, Real GDP, Manufacturing Value-Added**

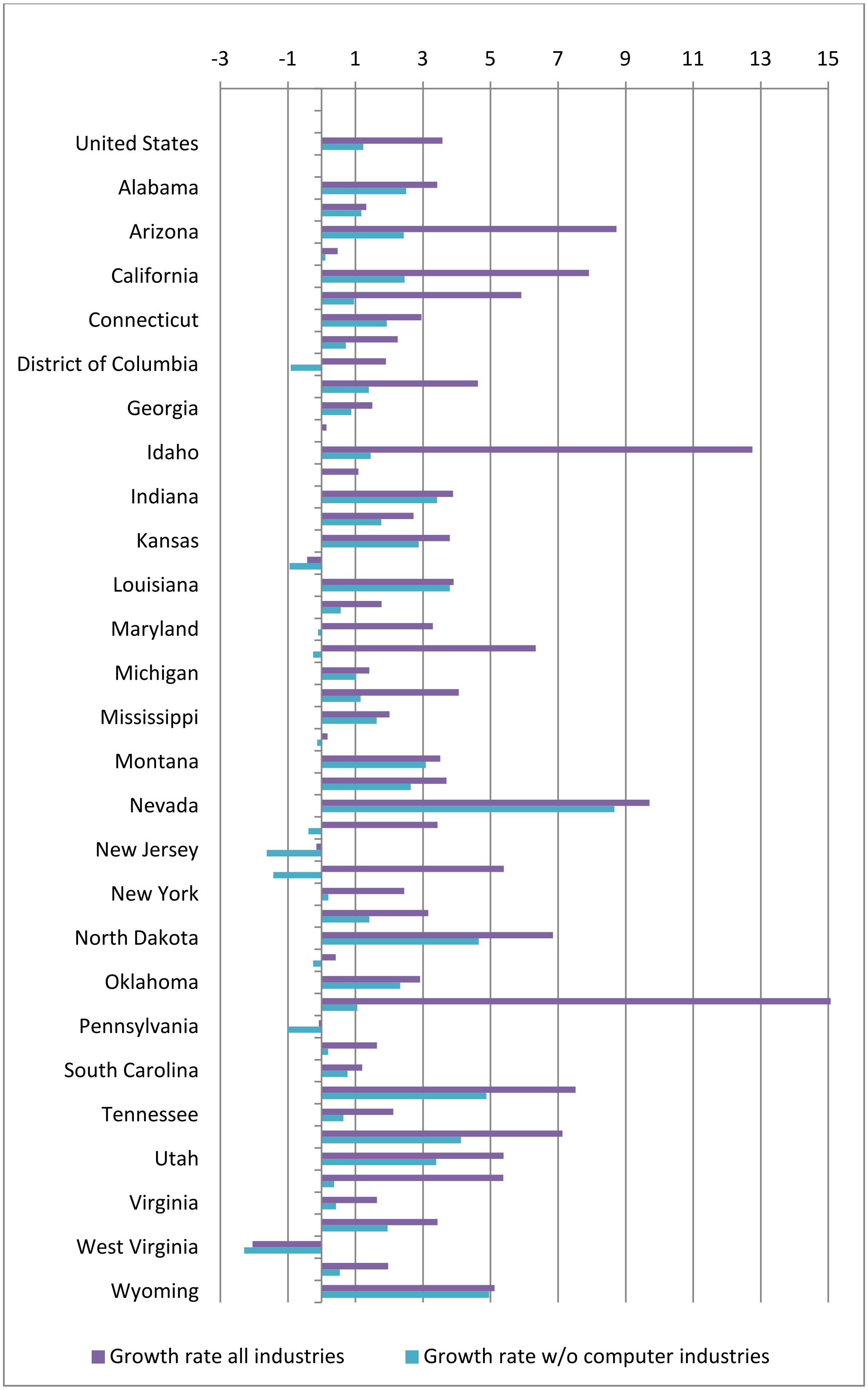



**Figure 4 Manufacturing Real Value-Added Growth Rates, 1997–2007 (% annual growth).**
SOURCE: Authors' calculations using BEA data.

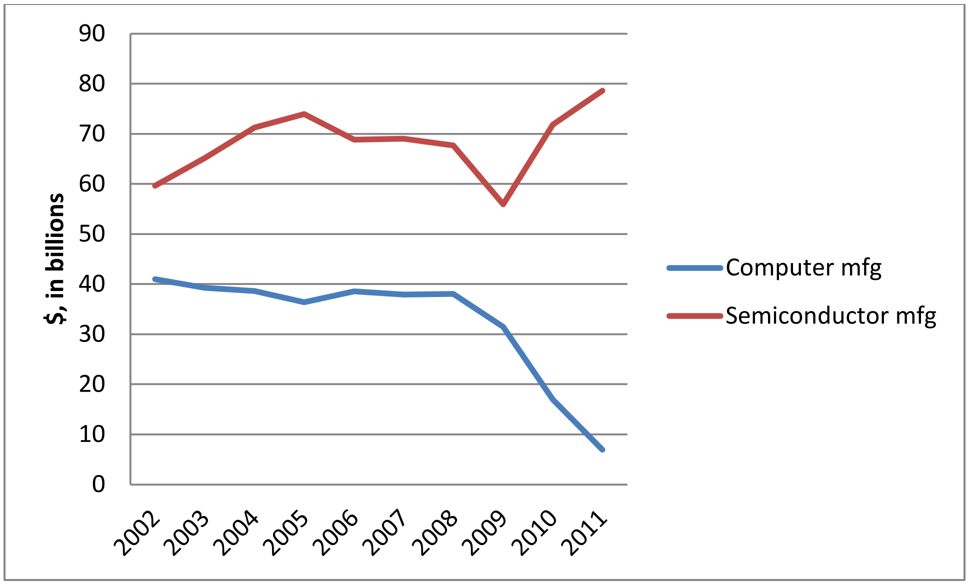



**Figure 5  Computer (NAICS 334111) and Semiconductor (NAICS 334413) Shipments, 2002–2011 ($ billions)**
SOURCE: U.S. Census Bureau, Annual Survey of Manufactures.

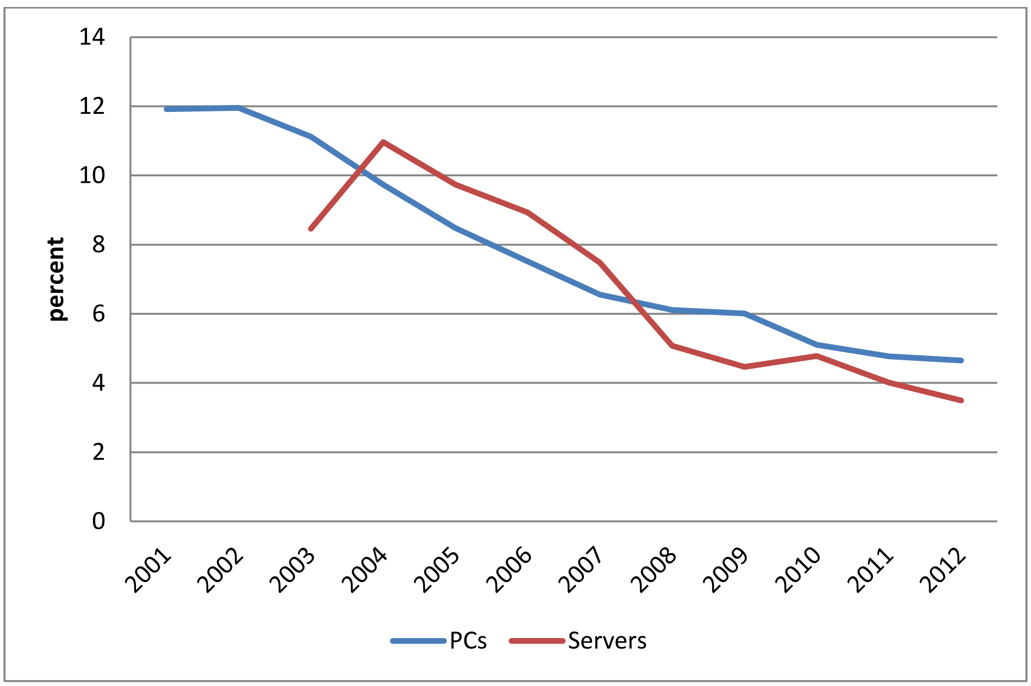



**Figure 6  U.S. Share of Personal Computers and Computer Servers Production (in units)**
SOURCE: IDC.

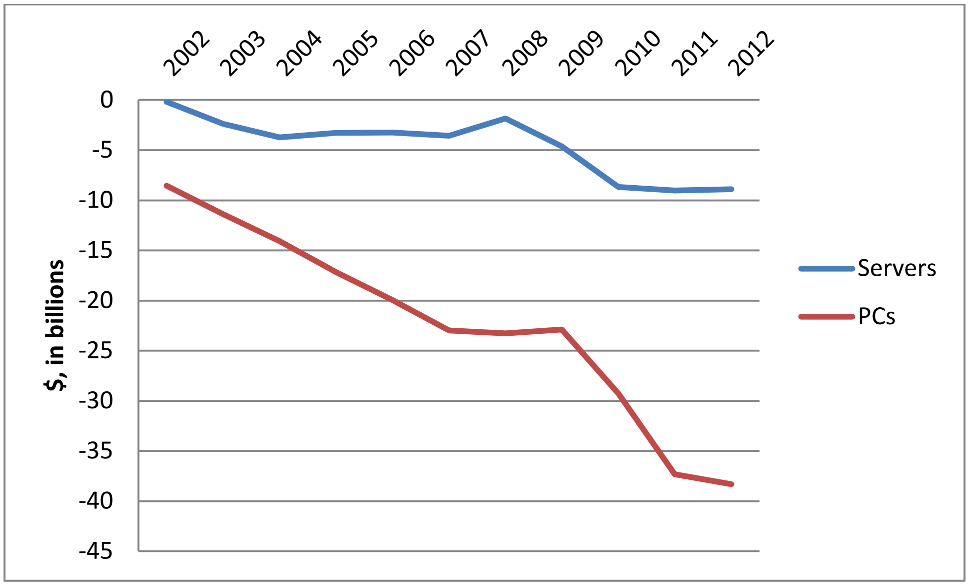
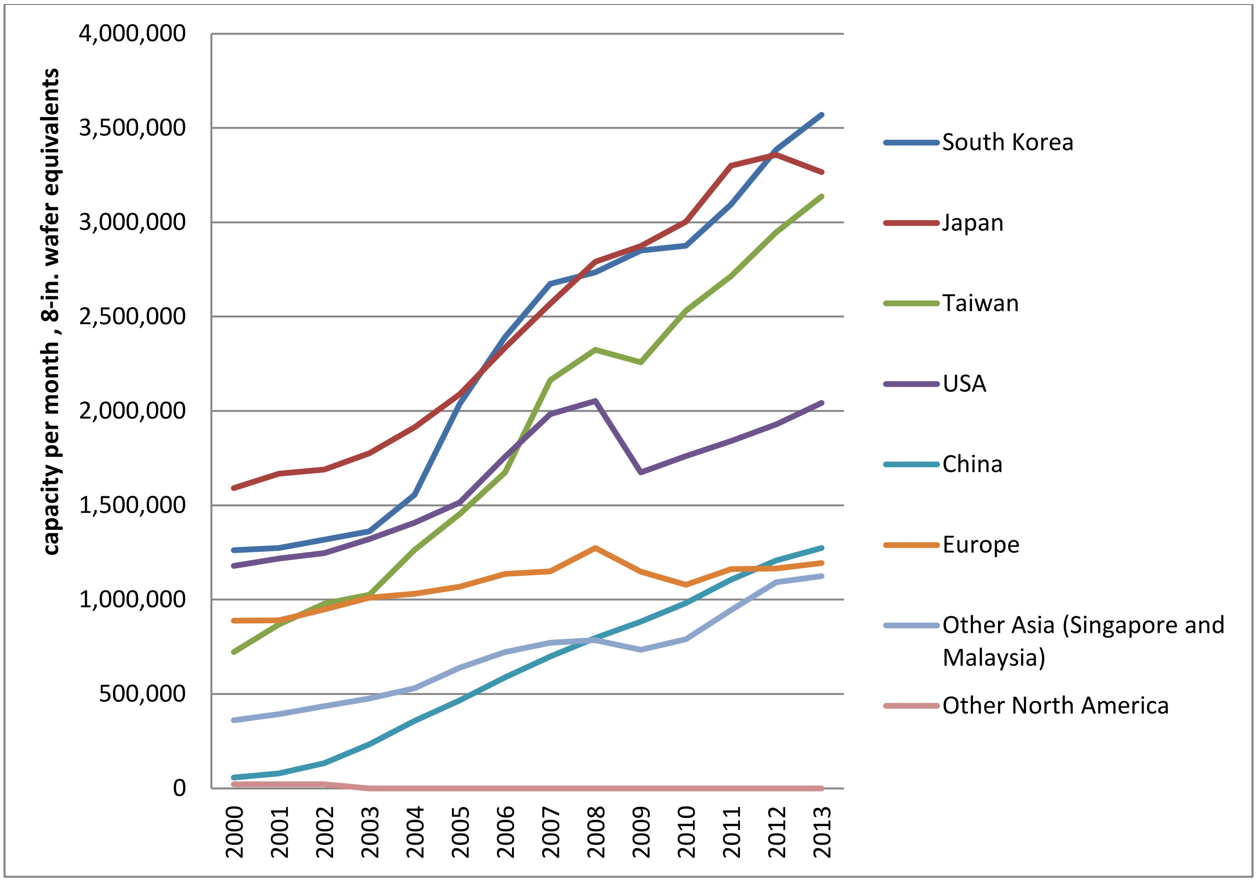
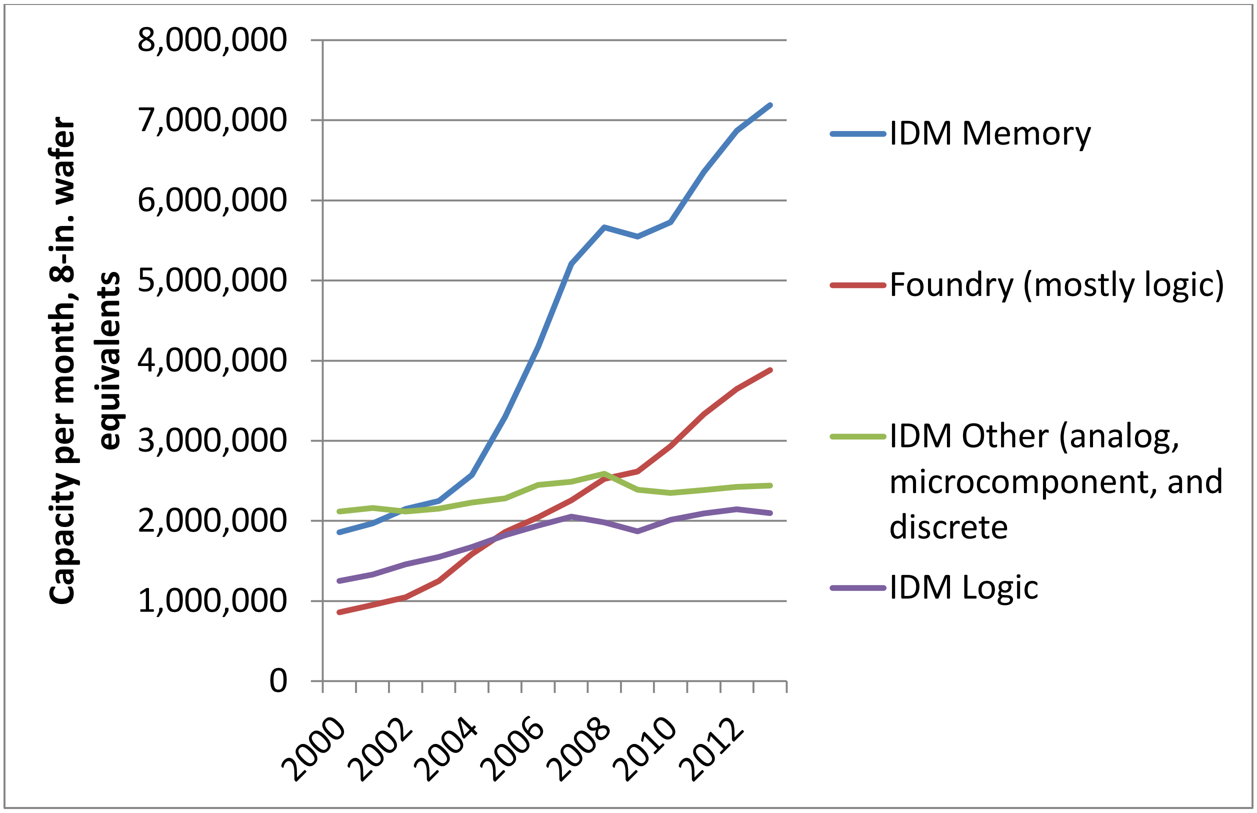



**Figure 7 U.S. Trade Deficit in PCs and Servers, 2002–2012**
SOURCE: UN Comtrade data.




| 2000 | | | 2013 | | | Annual Growth |
|---|---|---|---|---|---|---|
| 1 | Japan | 1,590,549 | 1 | South Korea | 3,570,447 | 8.0% |
| 2 | South Korea | 1,262,014 | 2 | Japan | 3,265,501 | 5.5% |
| 3 | USA | 1,178,370 | 3 | Taiwan | 3,136,841 | 11.3% |
| 4 | Europe | 889,309 | 4 | USA | 2,042,534 | 4.2% |
| 5 | Taiwan | 722,255 | 5 | China | 1,274,393 | 23.8% |
| 6 | Other Asia | 360,645 | 6 | Europe | 1,194,959 | 2.3% |
| 7 | China | 57,687 | 7 | Other Asia | 1,124,601 | 8.7% |
| 8 | Mexico | 21,250 | 8 | Mexico | 0 | |

**Figure 8 World Semiconductor Wafer Production Capacity by Country or Region, 2000–2013**
SOURCE: IHS Global Inc.




| US Global Capacity Share by Product Type and Business Model | 2000 | 2013 | Annual Growth |
|---|---|---|---|
| IDM Logic | 18.40% | 22.50% | 1.50% |
| IDM Memory | 15.50% | 8.90% | -4.20% |
| IDM Other (analog, microcomponent, and discrete) | 29.30% | 33.20% | 1.00% |
| Foundry (mostly logic) | 4.60% | 3.10% | -2.80% |
| | | | |
| IDM Logic & Foundry, combined | 12.79% | 9.93% | -1.95% |

**Figure 9 Global Semiconductor Capacity and U.S. Global Capacity Share and Compound Annual Growth Rates, by Product Type, 2000–2013**
SOURCE: IHS Global Inc.

**Table 1 Rankings by Growth in Manufacturing Real Value-Added and Real Value-Added Excluding NAICS 334, 1997–2007, Selected States**

| | Rank, all mfg. | Rank, mfg. less NAICS 334 | Change in rank |
|---|---|---|---|
| New Mexico | 11 | 49 | −38 |
| Massachusetts | 9 | 43 | −34 |
| Oregon | 1 | 25 | −24 |
| New Hampshire | 22 | 45 | −23 |
| Vermont | 13 | 35 | −22 |
| Idaho | 2 | 20 | −18 |
| Colorado | 10 | 27 | −17 |
| Maryland | 25 | 41 | −16 |
| District of Columbia | 35 | 46 | −11 |
| Arizona | 4 | 14 | −10 |
| | | | |
| Connecticut | 27 | 17 | 10 |
| Georgia | 39 | 28 | 11 |
| Indiana | 18 | 7 | 11 |
| Iowa | 29 | 18 | 11 |
| Louisiana | 17 | 6 | 11 |
| Alabama | 24 | 12 | 12 |
| Montana | 21 | 9 | 12 |
| Wyoming | 14 | 2 | 12 |
| Oklahoma | 28 | 15 | 13 |
| South Carolina | 42 | 29 | 13 |
| Michigan | 40 | 26 | 14 |
| Mississippi | 33 | 19 | 14 |
| Alaska | 41 | 23 | 18 |

SOURCE: Authors' calculations using BEA regional data.

**Table 2 Semiconductor Manufacturing Requirements, Design Requirements, and Typical Selling, by Product Type**

| Product Type | Manufacturing requirements | Design Requirements | Typical selling prices | Typical use |
|---|---|---|---|---|
| **Logic** | High | High | High | Digital processing (programmable devices, such as CPUs and ASICs) |
| **Memory** | Very high | Low | Medium to low | Information storage and retrieval |
| **Other:** | | | | |
| • **Analog** | Low | High | Medium | Analog signal processing (e.g., radio and other "real world" signals) |
| • **Micro-controllers** | Low | Medium to low | Low | Single-function systems (non-programmable, such as engine controls) |
| • **Discrete** | Very low | Very low | Very low | Single function (transistors, resistors, capacitors, etc.) |

SOURCE: Authors' compilation.

**Table 3 The Effect of Manufacturing Output Growth on Employment Growth, 1997–2007**

| | (1) OLS | (2) 2SLS | (3) OLS | (4) 2SLS |
|---|---|---|---|---|
| Growth in mfg. real value-added | 0.227 | 0.057 | 0.228 | 0.084 |
| | (0.066) | (0.106) | (0.050) | (0.080) |
| Constant | −28.041 | −21.907 | −27.588 | −22.146 |
| | (3.231) | (4.473) | (2.478) | (3.512) |
| Growth in mfg. real value-added w/o computers | 0.560 | 1.067 | 0.504 | 0.692 |
| | (0.095) | (0.741) | (0.069) | (0.338) |
| Constant | −26.493 | −33.353 | −25.196 | −27.900 |
| | (2.271) | (10.312) | (1.692) | (5.061) |
| Growth in mfg. real value-added w/o computers, adjusting for offshoring bias | 0.559 | 0.990 | 0.502 | 0.700 |
| | (0.095) | (0.621) | (0.068) | (0.299) |
| Constant | −24.518 | −28.839 | −23.372 | −25.499 |
| | (2.093) | (6.619) | (1.548) | (3.534) |
| *N* | 51 | 51 | 48 | 48 |

NOTE: Each panel represents the regression of state employment growth on output growth for the period 1997−2007. Standard errors of the coefficient estimates are reported in parentheses. A weighted average of national-level industry real value-added growth is used as an instrument for state growth measures in the two-stage least squares models. See text for further discussion.

## Appendix A: Biases to Real Growth from Offshoring

### *Background on Offshoring Bias*

The potential bias from the shift in sourcing to a low-cost foreign supplier occurs because of the methodologies the BLS uses in constructing its price indexes. The BLS samples the prices paid by importers for the import price index and the prices received by producers for the producer price index. Each observation used in the construction of a particular price index represents the period-to-period price change of an item as defined by very specific attributes and reported by a specific importer or domestic producer. These price changes will not necessarily capture price changes purchasers experience when they shift from one supplier to another.

Consider the case where a low-cost foreign supplier enters the U.S. market and captures market share from high-cost domestic suppliers of intermediates used by U.S. manufacturers. Hypothetically, the price drops that U.S. manufacturers realize when they shift to the foreign supplier could be fully captured in the import and input price indexes if the foreign supplier initially offers the same (quality-adjusted) price as the domestic suppliers: Markets instantaneously clear, and thus any expansion of the foreign supplier's market share reflects contemporaneous price declines relative to the domestic supplier that occur *after* entry; also, the new foreign supplier is picked up in the import price sample prior to any decline in its relative price. In practice, however, these conditions are likely to be violated: The lag between the time when a new supplier enters the market and its products are integrated into the BLS prices sample can be considerable; new suppliers often enter the market with a lower price than incumbent suppliers; and because of information and other adjustment costs that decline over time, businesses may not immediately switch to the low-cost supplier, and thus price differentials between low- and high-cost suppliers may persist (see, for example, Griliches and Cockburn

1994; Foster, Haltiwanger, and Syverson 2008; Byrne, Kovak, and Michaels 2013; Kovak and Michaels 2013). Diewert and Nakamura (2009) formally show that the bias to the input price index from shifts in sourcing, which is analogous to outlet substitution bias in the Consumer Price Index, is proportional to the growth in the low-cost supplier's market share and to the percentage discount offered by the low-cost supplier.[1]

In the case of shifts in sourcing from high-cost domestic to low-cost foreign suppliers, import and intermediate input price deflators—which are weighted averages of the domestic and import price indexes—are upwardly biased. This, in turn, results in an underestimation of the real growth in imports and an overestimation of the growth in real value-added produced domestically (Diewert and Nakamura 2009; Houseman, Kurz, Lengermann, and Mandel 2011; Houseman et al. 2010; Mandel 2007; Reinsdorf and Yuskavage 2009). Alterman (2013) proposes a survey of purchasers to address the bias to the input price index and examines the feasibility of implementing the survey. In theory, buyers could accurately report any change in price of a specific input when they change suppliers.

Biases to the input price index may occur whenever a producer shifts from a high-cost to a low-cost supplier, irrespective of whether the low-cost supplier is domestic or foreign. However, the rapid growth of imported intermediates from emerging economies raised concerns that biases in the data from offshoring have been empirically important. Houseman et al. (2010, 2011) estimate the size of the potential bias to the growth of real value-added and multifactor productivity in U.S. manufacturing from the growth in imported materials intermediates over the 1997-to-2007 time period. Because the size of the price decline associated with the offshoring of

[1] Outlet substitution bias is an example of a shift in sourcing from high- to low-cost domestic suppliers. Diewert and Nakamura (2009) show that the characterization of the bias to the input price index that results when producers shift sourcing of intermediates is identical to the characterization of the bias to the CPI from outlet substitution.

an intermediate good to a low-cost foreign supplier is not observed, it is necessary to make some assumptions about the size of the discount. Houseman et al. (2010, 2011) compute offshoring bias at the three-digit NAICS level under a variety of assumptions about the size of the price differentials, drawing on information from case studies and micro import price data collected by the BLS.

In addition, U.S. statistical agencies do not track the destination of imports and consequently do not know which industries use imported intermediates. In generating the industry-level data used in Houseman et al., the BEA assumes that all industries use imported inputs in proportion to their overall use of the input in the economy. For example, if an industry accounts for 20 percent of the use of an intermediate product economy-wide, then, under the so-called import proportionality assumption, it is assumed the industry uses 20 percent of the imports of this intermediate product. While certain inputs are specific to an industry, often products are inputs to a wide variety of industries. If manufacturers more intensively (less intensively) engage in offshoring than businesses in other sectors, the estimates in Houseman et al. will understate (overstate) the degree of offshoring bias in manufacturing. Similarly, within manufacturing there may be considerable variation in the intensity with which industries offshore specific intermediate inputs; the import comparability assumption will dampen any differences in estimates of offshoring bias among manufacturing industries.

Houseman et al. estimate that the substitution of imported for domestic materials inputs used by U.S. manufacturers resulted in an overstatement of the annual growth in real value-added by between 0.2 and 0.5 percentage points per year from 1997 to 2007. Estimates of the bias to real value-added growth from the offshoring of materials intermediates were the largest in the computer and electronics products industry—ranging from 0.5 to 1.4 percentage points per year—although because the average annual growth rate in the computer industry exceeded 20 percent, adjusting for the bias lowers that growth by only 4 to 7 percent. For manufacturing excluding computers, Houseman et al. estimate that the growth in real value-added was upwardly biased by 0.2 to 0.4 percentage points per year, implying that real value-added growth was upwardly biased by as much as 50 percent over the period in the rest of manufacturing. Estimates of the bias from materials offshoring to multifactor productivity ranged from about 0.1 to 0.2 percentage points per year for all manufacturing and from about 0.2 to 0.4 percentage points per year for the computer and electronic products industry.

***Offshoring Bias in State Manufacturing Real GDP***

The adjustments to state manufacturing real GDP growth for offshoring bias, which are used in the regressions reported in Table 3, are based on estimates generated in Houseman et al. (2010). A couple of caveats should be made about these state-level adjustments. First, and perhaps most importantly, as noted above, imports are imputed to industries using the import proportionality assumption, and thus differences across states in their industry mix generate cross-state differences in our estimates of biases to real value-added growth from offshoring. Because the import proportionality assumption minimizes measured variation in import use across industries, it also minimizes measured cross-state variation in offshoring bias.

In addition, BEA has revised the manufacturing GDP numbers since the estimates in Houseman et al. (2010) were generated. We use the revised manufacturing real GDP figures and assume that the bias from offshoring affects measured growth rate in the same proportion as estimated in that paper:

(3) $$\frac{AdjQ_{i,s.t}}{Q_{i,s.t}} = \left[\frac{1+r_{a,i}}{1+r_{m,i}}\right]^{t} .$$

The left-hand expression is the ratio of adjusted to unadjusted manufacturing real value-added in industry *i*, state *s*, and year *t*; $r_{a,i}$ is the growth rate in industry *i* adjusted for offshoring bias; $r_{mi}$ is the measured or baseline growth rate of real value-added in industry *i* as estimated in Houseman et al. (2010); and *t* is an index for year, 1997 = 0.[2]

We estimate the effect of offshoring bias on state manufacturing growth rates under two assumptions about the quality-adjusted price differences of products between developing countries (e.g., China) and the United States and the quality-adjusted price differences between countries with an intermediate level of development (e.g., Mexico) and the United States: 1) the developing country discount is 30 percent and the intermediate country discount is 15 percent, and 2) the developing country discount is 50 percent and the intermediate country discount is 30 percent. These two assumptions yield estimates of offshoring bias on the low and high end of those presented in Houseman et al. (See Table A.1.)

Compared to real value-added growth measures that exclude NAICS 334, measures that also adjust for biases to the input price index from the growth of imported materials intermediates result in an additional downward adjustment of 0.1 to 0.7 percentage points. The largest adjustments occur in Michigan (a 0.3 to 0.7 percentage-point reduction), followed by Kentucky (a 0.3 to 0.5 percentage-point reduction) and Ohio and Indiana (a 0.2 to 0.5 percentage-point reduction). Our estimates of the bias for another 20 states fall in the 0.2 to 0.4 percentage-point range. As previously noted, however, the import comparability assumption used to allocate imports to user industries tends to minimize cross-state differences in offshoring bias and consequently may introduce considerable error into these estimates.

[2] We do not have access to the detailed data on imported and domestic intermediate inputs needed to generate entirely new estimates. The growth rate $r_m$ for industry *i* corresponds to column 2 and the rate $r_a$ for industry *i* corresponds to those in columns 10 or 11 of Table 9 of Houseman et al. (2010). Houseman et al. detail the classification of countries as developing, intermediate, or advanced and the evidence on price discounts.

The state manufacturing real GDP figures utilized in the regressions reported in Table 3 assume a price discount of 50 percent with developing countries and 30 percent with intermediate countries.  Corrections based on these assumptions performed somewhat better in regressions than those based on smaller discount assumptions.

**Table A.1 Average Annual Growth of Real Value-Added in Manufacturing, Adjusted for Computer Industry and Offshoring Bias, by State, 1997–2007**

| | All manufacturing | Mfg. less NAICS 334 | Mfg. less NAICS 334, adj. offshoring bias, 15−30 | Mfg. less NAICS 334, adj. offshoring bias, 30−50 |
|---|---|---|---|---|
| Alabama | 3.4 | 2.5 | 2.3 | 2.1 |
| Alaska | 1.3 | 1.2 | 1.1 | 1.0 |
| Arizona | 8.7 | 2.4 | 2.2 | 2.0 |
| Arkansas | 0.5 | 0.1 | −0.1 | −0.3 |
| California | 7.9 | 2.5 | 2.3 | 2.1 |
| Colorado | 5.9 | 1.0 | 0.8 | 0.7 |
| Connecticut | 2.9 | 1.9 | 1.8 | 1.6 |
| Delaware | 2.2 | 0.7 | 0.6 | 0.4 |
| District of Columbia | 1.9 | −0.9 | −1.0 | −1.2 |
| Florida | 4.6 | 1.4 | 1.2 | 1.1 |
| Georgia | 1.5 | 0.9 | 0.7 | 0.5 |
| Hawaii | 0.1 | 0.0 | −0.1 | −0.2 |
| Idaho | 12.8 | 1.5 | 1.3 | 1.2 |
| Illinois | 1.1 | 0.0 | −0.2 | −0.3 |
| Indiana | 3.9 | 3.4 | 3.2 | 2.9 |
| Iowa | 2.7 | 1.8 | 1.6 | 1.4 |
| Kansas | 3.8 | 2.9 | 2.7 | 2.5 |
| Kentucky | −0.4 | −0.9 | −1.2 | −1.5 |
| Louisiana | 3.9 | 3.8 | 3.7 | 3.5 |
| Maine | 1.8 | 0.6 | 0.4 | 0.2 |
| Maryland | 3.3 | −0.1 | −0.3 | −0.4 |
| Massachusetts | 6.3 | −0.3 | −0.4 | −0.6 |
| Michigan | 1.4 | 1.0 | 0.7 | 0.3 |
| Minnesota | 4.1 | 1.2 | 1.0 | 0.8 |
| Mississippi | 2.0 | 1.6 | 1.5 | 1.3 |
| Missouri | 0.2 | −0.1 | −0.3 | −0.6 |
| Montana | 3.5 | 3.1 | 3.0 | 2.8 |
| Nebraska | 3.7 | 2.6 | 2.5 | 2.3 |
| Nevada | 9.7 | 8.7 | 8.5 | 8.4 |
| New Hampshire | 3.4 | −0.4 | −0.6 | −0.7 |
| New Jersey | −0.2 | −1.6 | −1.8 | −1.9 |
| New Mexico | 5.4 | −1.4 | −1.6 | −1.7 |
| New York | 2.4 | 0.2 | 0.0 | −0.2 |
| North Carolina | 3.2 | 1.4 | 1.3 | 1.1 |
| North Dakota | 6.8 | 4.6 | 4.4 | 4.2 |
| Ohio | 0.4 | −0.3 | −0.5 | −0.8 |
| Oklahoma | 2.9 | 2.3 | 2.1 | 1.9 |
| Oregon | 15.1 | 1.1 | 0.9 | 0.7 |
| Pennsylvania | −0.1 | −1.0 | −1.2 | −1.3 |
| Rhode Island | 1.6 | 0.2 | 0.0 | −0.2 |
| South Carolina | 1.2 | 0.8 | 0.6 | 0.3 |
| South Dakota | 7.5 | 4.9 | 4.7 | 4.5 |
| Tennessee | 2.1 | 0.6 | 0.4 | 0.2 |
| Texas | 7.1 | 4.1 | 4.0 | 3.8 |
| Utah | 5.4 | 3.4 | 3.2 | 3.0 |
| Vermont | 5.4 | 0.4 | 0.2 | 0.0 |
| Virginia | 1.6 | 0.4 | 0.3 | 0.1 |
| Washington | 3.4 | 2.0 | 1.8 | 1.6 |
| West Virginia | −2.1 | −2.3 | −2.5 | −2.7 |
| Wisconsin | 2.0 | 0.5 | 0.4 | 0.2 |
| Wyoming | 5.1 | 5.0 | 4.8 | 4.7 |

SOURCE: Authors' calculations using BEA data. Adjustments for offshoring bias use estimates from columns 10 and 11 of Table 9 in Houseman et al. (2010). See text for further details.