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ABSTRACT

U.S. manufacturing experienced a precipitous and historically unprecedented decline in employment in the 2000s. Many economists and other analysts—pointing to decades of statistics showing that manufacturing real (inflation-adjusted) output growth has largely kept pace with private sector real output growth, that productivity growth has been much higher, and that the sector's share of aggregate employment has been declining—argue that manufacturing's job losses are largely the result of productivity growth (assumed to reflect automation) and are part of a long-term trend. Since the 1980s, however, the apparently robust growth in manufacturing real output and productivity have been driven by a relatively small industry—computer and electronic products, whose extraordinary performance reflects the way statistical agencies account for rapid product improvements in the industry. Without the computer industry, there is no prima facie evidence that productivity caused manufacturing's relative and absolute employment decline. This paper discusses interpreting labor productivity statistics, which capture many factors besides automation, and cautions against using descriptive evidence to draw causal inferences. It also reviews the research literature to date, which finds that trade significantly contributed to the collapse of manufacturing employment in the 2000s, but finds little evidence of a causal link to automation.

JEL Classification Codes: J21, F66, J24

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The manufacturing sector experienced a precipitous and historically unprecedented decline in employment in the 2000s, which coincided with a surge in imports, weak growth in exports, and a yawning trade deficit. The plight of U.S. manufacturing featured prominently in the 2016 presidential election, with candidates Donald Trump and Bernie Sanders arguing that globalization had severely damaged U.S. factories. This argument resonated in many American communities and may have played a role in the election of President Trump. Making good on campaign promises, the president pulled out of the Trans-Pacific Partnership agreement, proposed renegotiating the North American Free Trade Agreement, and has begun levying tariffs on imports, raising concerns about a trade war.

Countering this view, many economists, policymakers, and pundits cite manufacturing output and productivity statistics to assert that American manufacturing has never been stronger. They point out that although manufacturing employment had been relatively stable before 2000, its share of U.S. employment had been in decline for decades. Often making analogies to the agricultural sector, they contend that automation, not globalization, largely explains manufacturing's relative employment declines and steep job losses in recent years.[1]

This perspective often is presented as the consensus view among economists and taken as fact in media reports. Typical is a *New York Times* article published in late 2016 in which reporter Binyamin Appelbaum asserts, "From an economic perspective . . . there can be no revival of American manufacturing, because there has been no collapse. Because of automation, there are far fewer jobs in factories. But the value of stuff made in America reached a record high in the first quarter of 2016, even after adjusting for inflation."

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[1] See, for example, Lawrence and Edwards (2013), Muro (2016), and DeLong (2017). Atkinson et al. (2012, pp. 27–28) includes a long list of notable economists and policymakers who subscribe to this view.

Regardless of whether the view represents a consensus, it reflects a misreading of the data and research evidence. The apparently robust growth in manufacturing inflation-adjusted (real) output and productivity are driven by a relatively small sector—computers and electronic products, which account for only about 13 percent of value-added in manufacturing. Without the computer and electronic products industry (hereafter referred to simply as "the computer industry"), real value-added or GDP growth in manufacturing was less than half that of the private sector average from 1979 to 2000, and only 12 percent in the 2000s. And without the computer industry, manufacturing labor productivity generally has been no higher or only somewhat higher than that of the private sector.

The computer industry, in turn, is an outlier and statistical anomaly. Its extraordinary output and productivity growth reflect the way statistical agencies account for improvements in selected products produced in this industry, particularly computers and semiconductors. Rapid productivity growth in this industry—and by extension the above-average productivity growth in the manufacturing sector—has little to do with automation of the production process. Nor is extraordinary real output and productivity growth an indicator of the competitiveness of domestic manufacturing in the computer industry; rather, the locus of production of the industry's core products has shifted to Asia.

Manufacturing's declining employment share has mirrored its declining share of output (nominal GDP) and to a large degree reflects the fact that, in most manufacturing industries, there has been relatively little growth in the amount of goods made in American factories for the past 40 years. The recent precipitous decline in manufacturing employment is a distinct phenomenon, and a growing body of research examines whether—and the extent to which—international trade can explain it. Although none of the studies comprehensively examine the various mechanisms by which trade and the broader forces of globalization may impact employment, collectively they find that trade has played a significant role in the collapse of U.S. manufacturing employment in the 2000s. In contrast, research to date finds little support for the hypothesis that automation was responsible for the sudden decline.

In the remainder of the paper, I elaborate on these points. I close with a brief discussion of the consequences of the large job losses in manufacturing for workers and regional economies and consider lessons for policy.

THE COLLAPSE OF MANUFACTURING EMPLOYMENT IN THE 2000s

Figure 1 depicts employment in the manufacturing sector from 1947 to 2016 and the number of manufacturing establishments from 1977 to 2014.[2] Manufacturing employment trended upward in the years following World War II, peaking at over 19 million in 1979. From 1979 to 1989, the year of the next business cycle peak, manufacturing shed 1.4 million jobs, or 7.4 percent of its base. The job losses were concentrated in the primary metals and textile and apparel industries. The oil price hikes of the 1970s and early 1980s dampened demand for steel at a time when developing countries were expanding capacity. The resulting excess global capacity led to downsizing in the United States and other advanced economies. The declines in apparel and textiles reflected the shift in production in these labor-intensive industries to developing countries.

[2] Changes in industry classification systems, particularly the shift from the Standard Industrial Classification (SIC) system to the North American Classification System (NAICS) implemented in the late 1990s or early 2000s (depending on the data series), have made historical analysis of trends in manufacturing and other sectors difficult. The Bureau of Economic Analysis recently constructed a consistent time series for industries or sectors from 1947 to the present for data on employment (breakdowns for manufacturing industries since 1977), nominal and real GDP, and GDP price deflators. Most of the analyses in this paper make use of this consistent time series. The number of manufacturing establishments plotted in Figure 1 comes from the Census Bureau's Business Dynamics Statistics.

Employment in manufacturing was relatively stable in the 1990s. Although measured employment declined by about 700,000, or 4 percent, from 1989 to 2000, the net decline in jobs can be entirely explained by the outsourcing of tasks previously done in-house. For example, the number of temporary help workers assigned to manufacturers increased by an estimated one million over the period. Although these workers are the legal employees of temporary help agencies and so are counted in the services sector, they work in the factories side-by-side with manufacturing employees. Had these workers been counted in manufacturing, manufacturing employment would have risen by an estimated 1.3 percent rather than declining (Dey, Houseman, and Polivka 2012).

Evidence suggests that other types of domestic outsourcing, although not well measured, partly explain the decline in manufacturing employment since World War II. Berlingieri (2014) estimates that domestic outsourcing accounted for 25 percent of manufacturing's employment decline from 1948 to 2002. Although manufacturers have continued to outsource in the 2000s, this factor likely has played a relatively small role in the recent declines in manufacturing employment (Dey, Houseman, and Polivka 2012, 2017).

The precipitous decline in manufacturing employment in the 2000s is historically unprecedented. Between the business cycle peaks of 2000 and 2007, manufacturing employment declined by 3.4 million, or 20 percent. Although employment in manufacturing, a cyclically sensitive sector, often drops sharply during recessions, the early 2000s marked the first period in which employment in the sector did not entirely or largely recover during the subsequent expansion. Manufacturing employment was hard-hit again during the Great Recession of 2008–2009, rebounding only slightly during the ensuing recovery. From 2007 to 2016, manufacturing employment declined on net by 1.5 million. In total, since 2000, manufacturing employment has fallen by nearly 5 million, or by over 28 percent. Unlike the declines experienced in the 1980s, the job losses have been broad-based, affecting all industries. Widespread plant closures accompanied the employment declines. As shown in Figure 1, from 2000 to 2014, the number of manufacturing establishments dropped by more than 78,000, a 22 percent decline.

Not only was the sharp decline in manufacturing employment historically unprecedented in the United States, the magnitude of the decline was unique among the world's leading manufacturing economies, according to an analysis by the U.S. International Trade Commission (Benedetto 2018). Over the 1998 to 2014 period, manufacturing employment significantly expanded in China and in South Korea. Although manufacturing employment shrank by almost 9 percent in Germany during this period, the drop was far less than in the United States and, Benedetto notes, was accompanied by a 4.8 percent decrease in the German working age population. Among the five leading manufacturing economies, only Japan experienced a similar percentage decline in manufacturing employment as the United States, but its working age population declined by over 9 percent over the period—in contrast to the United States, where the working age population grew by more than 16 percent.

THE PUZZLE

Reflecting stable or declining employment in the manufacturing sector, the share of U.S. private sector employment in manufacturing has dropped steadily, and relative declines have been particularly prominent since the 1980s. Manufacturing employment as a share of private sector employment peaked at 35 percent in 1953; by 2016, that share had fallen to just under 10 percent. Manufacturing's share of private sector GDP has experienced a parallel decline: manufacturing's contribution to private sector GDP peaked at 33 percent in 1953, and by 2016 its share was just 13 percent. The trends in these shares are depicted in the right scale of Figure 2. Together, they suggest that performance in the manufacturing sector has been weak relative to the rest of the economy.

Figure 2 also depicts indices of real GDP for the private sector and for manufacturing (left scale). Although manufacturing output is more cyclically sensitive than the average for the private sector, real GDP growth in manufacturing has largely kept pace with that of the private sector overall. This fact is somewhat paradoxical in view of manufacturing's declining employment and GDP shares. Only since the Great Recession has real GDP growth been considerably slower in manufacturing than in the aggregate economy.

If real GDP growth for manufacturing has kept pace with real GDP growth in the aggregate economy yet manufacturing's share of private sector GDP is falling, then it must be the case that the average price growth of manufactured goods has been slower than the average price growth for the goods and services produced in the economy. Figure 3, which displays an index of GDP price deflators for manufacturing and for the private sector, confirms this pattern. The slower growth in price deflators for manufacturing is evident since about 1980. In addition, if real GDP growth has kept pace with real GDP growth in the aggregate private sector yet manufacturing's share of private sector employment is falling, it follows that labor productivity growth is higher in manufacturing than the average for the private sector.

RECONCILING MANUFACTURING'S DECLINING SHARES WITH ROBUST OUTPUT GROWTH: THE PREVAILING NARRATIVE

Manufacturing's declining share of private sector employment results because manufacturing employment is growing more slowly than the aggregate private sector employment. Using the fact that labor productivity is defined as output per unit labor, these differential growth rates can be expressed by the following identity:

$$(1)\ \Delta ln(L_T) - \Delta ln(L_M) = \left(\Delta ln(GDP_T) - \Delta ln(GDP_M)\right) - \left(\Delta ln(Prd_T) - \Delta ln(Prd_M)\right)$$

In an accounting sense, the difference in the growth rates of labor employed in the aggregate private sector and in manufacturing (L_T and L_M) is equal to the difference in the growth rates of real GDP less the difference in the growth rates of labor productivity. If manufacturing's real GDP growth rate is approximately the same as the average for the private sector, as indicated in Figure 2, then all, or virtually all, of manufacturing's declining employment share is accounted for by higher labor productivity growth.

Although research economists widely recognize that such accounting identities and other descriptive evidence cannot be used to infer causality, many have taken it as strong prima facie evidence that higher productivity growth in manufacturing—implicitly or explicitly assumed to reflect automation—has largely caused the relative and absolute declines of manufacturing employment. Even when some role for trade is recognized, it is deemed small, and the decline is taken as inevitable (e.g., DeLong 2017).

Yet productivity growth, which is necessary for improvements in living standards, does not by itself cause employment declines. Productivity growth should lead to higher inflation-adjusted wages, and higher productivity growth in manufacturing should lead to declining prices for manufactured goods relative to other goods and services. This, in turn, stimulates demand for manufactured products. To meet higher demand for their products, manufacturers produce more—potentially fully (or more than fully) offsetting the adverse effects of higher labor productivity on employment. To reconcile higher manufacturing productivity growth with declining relative and absolute employment, therefore, it must also be the case that consumer demand for manufactured goods is limited and so not very responsive to the declining prices. Analogies are often made to agriculture, where people's food consumption is limited and where mechanization has displaced most farm workers.

AN ALTERNATE RECONCILIATION: MEASUREMENT ISSUES

The arguably anomalous patterns depicted in Figure 2—sharply declining manufacturing share of GDP coupled with robust growth in real GDP in manufacturing—imply that price inflation is much lower in manufacturing than in the aggregate economy. One might suppose that there is something unusual about price deflators in manufacturing. Indeed, the apparently strong growth in real manufacturing output is driven by the computer and electronic products industry and reflects the fact that price deflators for certain key products in the industry, namely computers and semiconductors, are adjusted to reflect rapidly improving product quality. For much of the recent past, these price deflators have been sharply declining. Although the computer industry has accounted for less than 15 percent of value-added in manufacturing throughout the period, it has an outsized effect on measured real output and productivity growth in the sector, skewing these statistics and giving a misleading impression of the health of American manufacturing.[3]

Figure 3 depicts price indices used to deflate private industry and manufacturing GDP. Figure 4 shows price indices for private industry and manufacturing, omitting the computer industry, and for the computer industry by itself.[4] The price index for the computer industry rises

[3] The discussion on the computer industry here and below follows analysis in Houseman, Bartik, and Sturgeon (2015).

[4] In the late 1990s, the BEA began using chained indexes for its real output and price indices in lieu of fixed-weight, constant dollar indices. The chained indices effectively allow the composition of the basket of goods

until 1968 and falls thereafter, with particularly steep declines in the 1990s.[5] Without the computer industry, the price indices for the private sector and manufacturing display similar trends. Although price inflation for manufacturing without computers has been somewhat lower than the average for the private sector in some years—most notably in the early 1980s and early 2000s—overall the differences are small.

Figure 5 displays indices of real GDP in the private sector and manufacturing, as published and omitting the computer industry. Unsurprisingly, omitting the computer industry has little effect on measured real GDP growth in manufacturing initially. From 1947 to 1979, the average real growth of manufacturing was 99 percent of that of real GDP growth in the private sector; omitting the computer industry from each, the rate of real output growth in manufacturing falls to 94 percent of the private sector average growth. The computer industry, however, has had large effects on measured real GDP in manufacturing since the 1980s, reflecting the rapid development of semiconductor and computer technology. From 1979 to 2000, measured real GDP growth in manufacturing was 97 percent of the average for the private sector; when the computer industry is dropped from both series, manufacturing's real GDP growth rate is just 45 percent that of the private sector average.

Output growth substantially slowed in both manufacturing and the private sector in the 2000s. In the published series displayed in Figure 2, real output growth in manufacturing was somewhat higher in manufacturing than in the private sector between the business cycle peaks of

and services to change smoothly over time. Although they avoid biases associated with the old fixed-weight indices, they are computationally more difficult to work with. To back out the computer industry from aggregate price indices and real GDP measures using published data, I employ a Törnqvist index, as described in Houseman, Bartik, and Sturgeon (2015, p. 157).

[5] Whelan (2000) notes that in the mid-1980s the Bureau of Economic Analysis began to apply hedonic methods developed by economist Zvi Griliches to construct price deflators for computers. The application of this method, which endeavors to account for the value buyers attach to product quality changes, led to more rapid declines in their price deflators.

2000 and 2007; netting out the computer industry from both series, real output growth in manufacturing was about 60 percent that in the private sector. Interestingly, without the computer industry, the average rate of real GDP growth in manufacturing was approximately the same over the 2000–2007 period, 1.4 percent per year, as it had been over the 1979–2000 period. While most manufacturing industries experienced lower and in some cases negative real GDP growth in the early 2000s, this was counterbalanced by especially large increases in real GDP growth in the transportation and, to a lesser degree, chemicals industries. I discuss the special case of the motor vehicles industry during this period further below.

Since the Great Recession, real output growth in manufacturing has been noticeably lower than average private-sector real output growth. Just as, in prior years, rapidly declining computer industry price deflators were responsible for the fact that manufacturing's output growth largely kept pace with that in the aggregate economy, a dramatic slowing of the decline in these price deflators and, correspondingly, of real output growth in the computer industry, significantly contributed to the differential growth rates between manufacturing and the aggregate private sector since the last recession.[6] In published statistics, whereas private sector output was about 11 percent higher in 2016 compared to 2007, manufacturing output was approximately the same. Netting out the computer industry, manufacturing output was more than 6 percent lower in 2016 than in 2007.

Over the entire 2000–2016 period, real GDP growth in manufacturing was 63 percent of the average private sector growth. Omitting the computer industry from each series,

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[6] Byrne, Oliner, and Sichel (2015) detail the slowdown in the decline of the semiconductor industry's price deflators, and Schmalensee (2018) shows the contribution the computer industry to manufacturing's lower labor productivity growth during the period.

manufacturing's measured real output growth is near zero (about 0.2 percent per year) and just 12 percent of the average for the private sector in the 2000s.

Figure 6 repeats the series displayed in Figure 5 that omit the computer industry and adds real output growth for the computer industry. The figure illustrates why this industry has such an outsized effect on measured real output growth in manufacturing. Real GDP growth in the computer industry is a different order of magnitude than that for either the private sector or the manufacturing industry series, which omit the computer industries and appear as near horizontal lines along the x-axis because of the different scale needed on the y-axis to accommodate the extraordinary growth in the computer industry. From 1977, the base year in this graph, to 2016 real output in the private sector less computers grew by 169 percent, real output in manufacturing less computers grew by 45 percent, while real output in the computer industry increased by 19,257 percent.

WHAT EXPLAINS THE EXTRAORDINARY OUTPUT GROWTH IN THE COMPUTER AND SEMICONDUCTOR INDUSTRY?

As indicated earlier, the answer to the question of what explains the large and sustained growth in computers and semiconductors lies in the way that the statistical agencies, through the construction of price indices, account for the rapid technological advances in the products produced in this industry. The semiconductors embedded in our electronics are much more powerful today than they were a decade or even a year ago. Likewise, the computers and related devices that consumers and businesses buy today have much greater functionality than in the past. If, for example, buyers are willing to pay 15 percent more for a new computer model that boasts greater speed and more memory than last year's model, then 100 of the new computers would be the equivalent of 115 of the previous year's model. The rapid output growth in this industry does not necessarily imply that American factories are producing many more computers, semiconductors, and related products—they may be producing less. Instead, it reflects the fact that the quality of the products produced is better than in the past. The statistical agencies adjust price deflators for other products, such as autos, for changes in quality. However, the effects of quality adjustment in other industries on aggregate statistics, to date, have generally been small compared to those of the computer industry.

It follows that the rapid productivity growth accompanying output growth in the computer industry has little if anything to do with automation: production of computers and semiconductors has been automated for many years. Rather, rapid productivity growth in the industry—and, by extension, the above-average productivity growth in manufacturing—largely reflects improvements in high-tech products.

Nor is the rapid growth in measured computer and semiconductor output a good indicator of the international competitiveness of domestic manufacturing of these products. As detailed in Houseman, Bartik, and Sturgeon (2015), the locus of production of these products has been shifting to Asia, and the large employment losses in this industry reflect offshoring and foreign competition.

It should be emphasized that the statistical agencies are correct to adjust prices for improvements in product quality. The adjustments, however, can be highly sensitive to methodology and idiosyncratic factors. A change in Intel's pricing strategy for older-generation semiconductors is partly responsible for the slowdown, as explained in Byrne, Oliner, and Sichel (2015). The slowdown in the rate at which price deflators are falling has sparked a debate over whether the size of the quality adjustments for the computer and semiconductor industry has been too great or too little. Because these adjustments potentially have large effects at both industry and aggregate levels on measured real output and productivity growth, it is an important area for future research.

Such quality adjustment, however, can make the numbers difficult to interpret. Because the computer industry, though small in dollar terms, skews the aggregate manufacturing statistics and has led to much confusion, figures that exclude this industry, as shown in Figure 5, provide a clearer picture of trends in manufacturing output.

PRODUCTIVITY GROWTH AND INTERPRETING DECOMPOSITIONS THAT SHOW PRODUCTIVITY'S CONTRIBUTION TO EMPLOYMENT GROWTH

The computer industry also has a large influence on measured productivity in the manufacturing sector. For various time horizons from 1987 to 2011, Baily and Bosworth (2014) estimate labor and multifactor productivity growth for the private sector, for aggregate manufacturing and for manufacturing excluding the computer industry. They find that while labor and multifactor productivity growth are considerably higher in manufacturing, when the computer industry is dropped from the calculations, these productivity measures are virtually identical to average productivity growth for the private sector over all time periods examined. As noted from Equation (1), if real GDP growth equals the average growth for the private sector, then productivity growth accounts for all of the relative decline in manufacturing employment. Conversely, if, excluding the computer industry, real GDP growth is lower in manufacturing than in the private sector and labor productivity growth is the same, labor productivity growth can account for *none* of the relative decline in employment in most of manufacturing.

Since 1977, the Bureau of Economic Analysis has published an industry employment series that is consistent with its industry real and nominal output series. Although employment is a crude measure of labor input because it does not control for differences in hours worked, it allows me to construct the decompositions using Equation (1) for a relatively long-time horizon and show the sensitivity of these decompositions to inclusion of the computer industry. The top panel of Table 1 decomposes the difference in the average employment growth rate for private industry and manufacturing into the part accounted for by differences in growth rates and the part accounted for by differences in labor productivity. The bottom panel shows this decomposition when the computer industry is omitted from the private sector and manufacturing numbers. From the top panel, over the entire period from 1977 to 2016, average annual employment growth in manufacturing was about 0.025 log points (approximately 2.5 percent) lower than average employment growth in the private sector. Only 15 percent of the differential is accounted for by lower output growth in manufacturing, while higher manufacturing labor productivity accounts for 85 percent of its higher employment growth. When the computer industry is omitted from both series, 61 percent of the lower manufacturing employment growth is accounted for by manufacturing's lower output growth, and just 39 percent by its higher labor productivity growth.[7] The decompositions are highly sensitive to the inclusion of the computer industry in all subperiods, whose starting and ending years (except for 2016) are business cycle peaks.

The point of this exercise is to show that there is no prima facie evidence that productivity growth is entirely or primarily responsible for the relative and absolute decline in manufacturing employment. Although such decompositions underlie the narrative that productivity growth, in the form of automation, has caused the relative decline in manufacturing employment, they are fraught with measurement problems, and the direction of causality is

[7] Unlike Baily and Bosworth (2014), I find somewhat higher labor productivity growth in manufacturing compared to the private sector when the computer industry is omitted from both series. Some of the difference likely reflects the fact that BEA made significant revisions to the industry accounts data, which particularly affected growth in the computer industry, following the publication of the Baily and Bosworth paper.

unclear. If output growth in manufacturing is low relative to the private sector, for instance, it could be because of slower demand growth (domestic or global) or the loss of international competitiveness, as evidenced by the growth in the share of imported products or by slow export growth. Some decompositions are embellished to try to capture changes in output owing to trade, measured as changes in imports and exports. Yet imports and exports must be separately deflated, and existing price indices, particularly import price indices, suffer from well-known biases that lead researchers to understate the growth of real imports.[8] In addition, industries are connected by supply chains; imports in one industry will affect demand for inputs in upstream industries, but such effects are not captured in decompositions. Decompositions based on disaggregated industries exacerbate this problem. Job losses owing to trade may depress domestic demand, but such general equilibrium effects are not captured in these reduced-form accounting identities.

Moreover, labor productivity growth is not synonymous with automation, and measured productivity growth may be simply picking up the effects of international trade and other forces associated with globalization. Given its importance, I elaborate on this last point in the following section.

What Labor Productivity Measures Capture

Labor productivity in an industry or sector is typically defined as value-added (the returns to capital and labor) divided by a measure of labor input (hours worked or employment). Labor

[8] The methodology used to construct price indices does not capture price drops when a purchaser shifts to a less expensive supplier of a good or service. Therefore, lower prices that have driven the growth in imported products from low-wage countries are not captured in import price indices. Houseman et al. (2011) discuss import price bias and estimate the bias in manufacturing statistics from the growth in imported material intermediates. Mandel and Carew (2012) estimate the bias to all GDP from the growth in imports.

productivity will increase if processes are automated—i.e., if businesses invest in capital equipment and that equipment substitutes for workers in the production process. Measured growth in labor productivity, however, captures many factors besides automation. As already discussed, the strong productivity growth in the manufacturing sector has been driven by productivity growth in the computer industry, which largely stems from product improvements owing to research and development, not from automation of the production process. Although the computer industry has had by far the largest influence on real output and productivity growth in aggregate manufacturing, output and productivity measures in other industries, such as motor vehicles, are significantly affected by quality adjustment of price deflators.

In addition, as noted, manufacturers have outsourced many activities previously done in-house, either to domestic or foreign suppliers. If the outsourced activities are primarily done by relatively low-paid, low-value-added workers, or if the outsourced labor is cheaper than the in-house labor, measured labor productivity will mechanically increase. International competition may directly impact measured manufacturing productivity by affecting the composition of products produced and processes used in the United States. The industries and plants within industries most affected by increased competition from low-wage countries will likely be the most labor-intensive. Similarly, the growth of global supply chains and the slicing up of the value chain may impact the stages of production done in the United States, affecting labor productivity measures. Exposure to trade can accelerate the adoption of automated processes (Bloom, Draca, and Van Reenen 2016; Pierce and Schott 2016). In these cases, there is no simple parsing out of the effects of trade and automation on employment.

A study of plant closures in the early 2000s with a focus on the home furniture industry illustrates these forces (Holmes 2011). The making of high-quality wood furniture such as bedroom and dining room furniture, known as casegoods, requires human craftsmanship, is labor intensive, and does not lend itself to automation. The surge of imports from China and other Asian countries beginning in the late 1990s hit the casegoods industry particularly hard; between 1997 and 2007, a majority of the large casegoods plants shut down, most of the rest downsized, and employment in the industry dropped by half. The upholstery industry was also hard-hit by imports but fared better because of the custom nature of the product and the expense associated with shipping bulky sofas. The U.S. upholstery industry, however, offshored the labor-intensive "cut-and-sew" of upholstery fabric to China in kits, which could be inexpensively shipped. These kits were then stuffed with U.S.-built frames and foam. Holmes investigated two very large plants classified in casegoods that survived the surge of Asian imports. One made ready-to-assemble furniture, thus effectively "outsourcing" the labor-intensive assembly process to the customer, [9] and had mechanized the stage where finish is applied to the furniture. The other, he discovered, actually imported all of its casegoods from China. The facility, which served as the corporate headquarters, engaged in some manufacturing of upholstered furniture, but it imported the wood furniture from China and offshored the labor-intensive cut-and-sew work to China.

The furniture case study illustrates how trade may affect the composition of products produced and the stages of production done in U.S. manufacturing and shift production toward more mechanized plants. These forces will all raise measured labor productivity.

A widely cited Ball State University report illustrates the problem with using accounting identities to draw conclusions about automation's contribution to manufacturing's job losses (Hicks and Devaraj 2017). The report's authors apply a variant of Equation (1) to manufacturing industries, concluding that productivity growth accounts for most of the job losses. For example,

[9] Basker, Foster, and Klimek (2017) argue that such shifting of tasks to consumers results in an overstatement of an industry's productivity growth.

Hicks and Devaraj claim that from 2000 to 2010 a staggering 3.9 million jobs in the computer and electronics products industry were "not filled due to productivity," more than five times the number of jobs lost (Table 3). Such a claim is absurd. As noted, the productivity gains in the computer industry largely reflect dramatic improvements in the speed and functionality of computers and related products, not automation of the production process. While computers sold in 2010 are better than those sold in 2000 (and in a statistical sense a 2010 model counts as more than one 2000 computer model), this does not mean that the production of a 2010 model requires fewer workers than the production of a 2000 model.

For the auto industry, Hicks and Devaraj (2017) conclude that nearly 600,000 jobs were not filled because of productivity, representing 93 percent of the industry's job losses over the period. Yet, much of the productivity growth in autos, like computers, reflects product improvements. Since the 1960s, the Bureau of Labor Statistics has adjusted new vehicle price indices for the cost of quality improvements between model years, using estimates of the cost of improvements provided by manufacturers (Williams and Sager 2018). In addition, the development of global supply chains and offshoring of some production assembly and auto parts production during this period, particularly within the NAFTA countries, means that some of the productivity growth likely reflects cost savings and changes in the composition of products produced in the United States. Between the business cycle peaks of 2000 and 2007, the number of vehicles produced in the United States declined at a rate of nearly 5 percent per year, according to data from the Federal Reserve Board, while real GDP in the motor vehicles industry grew at a rate of about 3.5 percent per year, according to data from the BEA. The divergent trends in the two quantity measures suggest that adjustment of price deflators for product quality had sizable effects on measured real output growth in the BEA series. The divergent trends are also consistent with offshoring and substantial restructuring of the domestic industry. Automation may well have contributed to job losses in the auto and other industries, but the decompositions in the Hicks and Devaraj report can shed no light on the importance of this factor.

In short, productivity growth does not, per se, cause employment declines. Accounting identities and other descriptive evidence cannot be used to draw inferences about the causes of these declines, but once the anomalous effects of computer industry are excluded, even descriptive statistics provide no prima facie evidence that higher rates of automation were primarily responsible for the long-term decline in manufacturing's share of employment. Rather, they suggest that understanding the reasons for the slow output growth in manufacturing output—whether from weak growth in domestic demand, strong growth in imports, or weak growth in exports—is critical.[10]

RESEARCH ON THE CAUSES OF MANUFACTURING'S EMPLOYMENT DECLINE IN THE 2000s

Accounting identities such as those in Equation (1) are appealing because they appear to provide a simple decomposition of the effects of trade and technology on manufacturing's relative or absolute employment decline. But, understanding the causes of the decline in manufacturing employment requires rigorous research. Although such studies are never comprehensive in nature and cannot provide a decomposition of the effects of trade and

[10] According to BEA data, real growth in domestic consumption of manufactured goods was slower than that for services prior to 2000, consistent with common assertions that faster growth in consumption of services partially contributed to the decline in manufacturing's employment share. Interestingly, real consumption of manufactured goods has outpaced that of services since 2000, which is consistent with consumers' responding to a surge of low-cost imports.

technology—indeed to some degree developments of the two are interrelated—they can provide insights into the relative importance of the two forces.[11]

Motivated by the dramatic decline in manufacturing employment in the 2000s, recent studies have focused on the effects of trade and automation on employment in the sector. I provide a brief review of the existing literature on these topics in this section.[12]

The Causal Effect of Trade

The international competitiveness of manufacturing in the United States is influenced by exchange rates, differential subsidies provided to manufacturing firms in the United States versus other countries, tariffs, and various nontariff barriers, among other factors. The forces of globalization may reduce domestic manufacturing output growth by increasing the growth of real imports or by slowing the growth of exports. U.S. plants may close or downsize because of import competition. U.S. producers also may close plants and shift production overseas or simply expand production in other countries to take advantage of lower wages, higher subsidies, or lower tax rates. In these cases, some of the products produced overseas may show up as U.S. imports, but much may be exported to other countries; thus, the effects on U.S. output growth through this channel, though potentially important for manufacturing employment, will not show up directly in U.S. trade statistics.[13] Additionally, manufacturing job losses owing to trade will have spillover effects in the economy, potentially depressing domestic demand for manufactured goods. And international competition may reduce investment in the United States, undermining the sector's competitiveness and depressing demand for manufacturing workers in the future.

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[11] Fort, Pierce, and Schott (2018) also note that research cannot provide such decompositions.

[12] I do not review earlier research that focused on the effects of international trade on the declines in manufacturing employment during the 1980s. To my knowledge, no rigorous studies have examined the causes of manufacturing's declining share of aggregate employment during periods when the sector's employment levels were rising or relatively stable.

[13] Setser (2017), for example, discusses the slow growth of U.S. exports outside of NAFTA.

No study captures all aspects of globalization and its effects on manufacturing employment, and the limitations of any single study need to be recognized. Collectively, however, a growing body of research points to sizable adverse effects, operating through various mechanisms.

The precipitous decline in manufacturing employment in the early 2000s coincided with a dramatic widening of the merchandise trade deficit, led by a rise in imports from China. This suggested that trade, and Chinese imports in particular, were behind the collapse. Several studies focus on the effects of Chinese imports on U.S. manufacturing employment. Autor, Dorn, and Hanson (2013) use regional data at the commuting-zone level to examine how exposure to growth in Chinese imports affects manufacturing employment. They estimate that a quarter of the decline in manufacturing employment from 1990 to 2007 is related to the growth of Chinese imports.

Pierce and Schott (2016) also examine the effects of Chinese imports on U.S. manufacturing employment in the 2000s, but they focus specifically on the effects of granting permanent normal trade relations (PNTR) to China. Congress passed PNTR in late 2000, and it became effective at the end of 2001 with China's accession to the WTO. The authors argue that, although China had been subject to the relatively low WTO tariff rates since 1980, China's accession to the WTO eliminated the possibility of a sudden tariff spike on Chinese imports and thus removed uncertainty for investors. Pierce and Schott outline three channels by which granting China PNTR may have affected U.S. employment: 1) it increased the incentive for U.S. firms to incur sunk costs of shifting operations to China or of partnering with a Chinese manufacturer, 2) it provided Chinese producers with incentives to enter or further invest in exporting to the U.S. market, and 3) it provided an incentive for U.S. firms to invest in laborsaving technology or to shift the mix of products they produced to less labor-intensive ones. Pierce and Schott find that manufacturing industries in the United States that were more affected by the change in trade policy experienced larger employment losses and that all three channels contributed to the losses. In addition, using input-output linkages, they find that U.S. suppliers to the industries impacted by the change in trade policy also experienced employment losses and were more likely to close, which could reflect reduced demand or a decision by these firms to also offshore production to China.

In addition, studies have found sizable adverse effects of Chinese imports on U.S. firm sales, investment, patents, and research and development (Autor et al. 2017; Pierce and Schott 2017). These adverse effects raise larger concerns about the loss of competitiveness of domestic manufacturers, with implications for future employment in the sector.

Studies have also examined the effects on manufacturing employment from activities by multinational companies, which have accounted for a disproportionate share of the employment decline. Using firm-level data from the Bureau of Economic Analysis, Harrison and McMillan (2011) find that offshoring to low-wage countries substitutes for domestic employment, but that some offshoring is complementary and increases a company's domestic employment. On net, they find a small negative impact of offshoring on parent employment. Using establishment-level data on multinational firms from the Census Bureau, Boehm, Flaaen, and Pandalai-Nayar (2015) estimate that the offshoring of intermediate inputs, which they find is primarily done by multinational companies, substitutes for U.S. employment. Structural model estimates indicate that offshoring of intermediate inputs by multinational companies accounts for 13 percent of the decline in U.S. manufacturing employment between 1993 and 2011.

While the studies cited above focus on the effects of Chinese imports or multinational company offshoring on manufacturing employment, Campbell (2017) examines the effect of a temporary appreciation of the dollar on manufacturing employment in the early 2000s. Campbell's study potentially captures effects of an exchange-rate appreciation on manufacturing employment that operates through higher imports (not just imports from China) and lower exports. An important innovation of Campbell's work is to adjust the real exchange rate index for compositional changes in trading partners toward developing countries with lower price levels, such as China. This adjustment shows that the real appreciation of the dollar was substantially greater than an index that does not take into account these compositional changes.

Campbell estimates that the exchange rate appreciation can explain 1.5 million of the job losses in manufacturing from 1995 to 2008. He also presents for this and other exchange rate shocks evidence of hysteresis: job losses from a temporary exchange rate appreciation are not reversed when a currency subsequently depreciates. Economic theory suggests that hysteresis may be important when there are sunk costs and learning by doing. An appreciation of the dollar could stimulate sunk-cost investments in production and supply chains in developing countries with lower production costs. Campbell points out that even if the currency returns to its original value vis-à-vis its trading partners, production costs may still be lower in the developing countries where firms invested, and the currency depreciation would not induce firms to write off these sunk-cost investments. Additionally, firms operating in foreign countries may become more efficient over time (learning by doing) and thus develop a comparative advantage. The appreciation of the dollar, therefore, may induce investments in low-cost countries that still enjoy a cost advantage even after the dollar depreciates to its prior level.

The Causal Effect of Automation

While studies have generally found that factors related to trade have played an important role in the decline of manufacturing employment in the 2000s, studies have failed to uncover a strong relationship between automation and manufacturing job loss during the period.

Using data on manufacturing industries, Acemoglu et al. (2014) examine the argument, popularized in the book *Race Against the Machine* (Brynjolfsson and McAfee 2011), that IT capital and associated automation are transforming U.S. workplaces. The authors study the relationship between investment in IT equipment, labor productivity growth, and employment from 1980 to 2009. They find that while there is a strong relationship between IT investment and productivity growth, the relationship largely disappears once the anomalous computer and electronic products industry is dropped from the sample. IT-intensive industries do experience somewhat higher labor productivity growth in the 1990s, but the effect dissipates in the 2000s, precisely when the sector experiences a precipitous employment decline. Moreover, they find that when IT-intensive industries do experience rapid labor productivity growth, it is associated with declining output and even more rapid employment declines. If automation caused the employment decline, the higher productivity growth associated with it should be reducing costs and therefore be accompanied by higher output growth. The pattern instead is consistent with displacement from trade, whereby the remaining downsized industry is concentrated in segments that are less labor intensive.

Autor, Dorn, and Hanson (2015) use data on regional labor markets in the United States over the period 1980 to 2007 to examine the effects of both trade and automation on employment in manufacturing and nonmanufacturing industries. As reported in their earlier work, Autor, Dorn, and Hanson find that regions exposed to imports from China experienced significant reductions in employment, particularly in manufacturing industries. This affected all manufacturing occupations, including high-skilled professional and technical jobs. In contrast, labor markets that had a concentration of occupations in routine manual tasks, which are susceptible to automation, did not experience a net decline in employment in either manufacturing or nonmanufacturing, although the occupational structure of employment in these industries did shift. Most notable for the question examined in this paper, the effects of automation in manufacturing were most prominent in the 1980s and had greatly diminished by the 2000s, while the effects of automation in nonmanufacturing industries accelerated over time.

In a much-publicized paper, Acemoglu and Restrepo (2017) estimate that the adoption of robots could have large, adverse effects on employment and wages in the future. However, because the adoption of industrial robots has been limited thus far, it can explain little of the sharp decline in employment that has occurred.

Recent studies also have found that the rise of markups since the 1980s and the offshoring of labor intensive processes (not capital investment) account for the rise of capital share (De Loecker and Eeckhout 2017; Elsby, Hobijn, and Sahin 2013). Such evidence is inconsistent with the hypothesis that a large technology shock caused employment declines and a concomitant rise in capital share in manufacturing.

THE CONSEQUENCES OF MANUFACTURING JOB LOSSES

Among the most robust findings in labor economics is that plant closures and other mass layoffs have large, adverse, and lasting effects on workers and communities.[14] In a seminal article on workers laid off from distressed firms in Pennsylvania, Jacobson, Lalonde, and

[14] von Wachter (2010) and Carrington and Fallick (2017) provide recent reviews of the literature on the consequences of job displacement.

Sullivan (1993) find that dislocated workers with high job-tenure experience average long-term earnings losses of 25 percent of their predisplacement income. Using Social Security earnings data, von Wachter, Song, and Manchester (2009) find similarly large, persistent earnings losses among those affected by a mass layoff—with immediate earnings losses of 30 percent and losses of 20 percent 15–20 years following the layoff event, compared to similar workers who did not experience a mass layoff.

With just under 10 percent of U.S. employment located in the manufacturing sector, some may believe that manufacturing job losses matter little anymore. Yet through supply chain linkages, the manufacturing sector has an outsized effect on the economy. Approximately half of the labor needed in the production of manufactured goods in the United States and other advanced countries is employed outside the manufacturing sector. In addition to job creation effects through these input-output relationships, an increase in employment in the manufacturing sector increases local and national employment by increasing demand: the additional employed manufacturing workers spend more in the economy, creating new jobs. Using a local general equilibrium model, Moretti (2010) estimates that each additional manufacturing job in a city generates 1.6 nonmanufacturing jobs. Multiplier effects are higher for skilled jobs: an additional skilled manufacturing job in a city generates an estimated 2.5 jobs in local goods and services. Reflecting manufacturing's large spillover effects, research finds that the sudden and large job losses in manufacturing in the 2000s are to a large degree responsible for the weak job growth and poor labor market outcomes among less-educated workers during that decade, although the housing boom in the early 2000s initially masked some of the effects of manufacturing job losses (Acemoglu et al. 2016; Charles, Hurst, and Notowidigdo 2016).

An important lesson from the research literature is that the size of the adverse shock matters for workers' reemployment and earnings and for regional economic outcomes. Workers' long-term earnings losses depend to a large extent on the prevailing local labor market conditions at the time of the loss; those losing jobs in weak labor markets suffer larger earnings losses (Jacobson, Lalonde, and Sullivan 1993), and the effects of job loss are worse for workers during a recession (von Wachter, Song, and Manchester 2009). Correspondingly, the effects of trade and other adverse economic shocks on regional economies depend critically on the size of the shocks. While local economies can recover from modest setbacks relatively quickly, large adverse shocks can overwhelm a local economy, causing a downward spiral and depressing its economy for decades.[15]

CONCLUSION

Two stylized facts underlie the prevailing view that automation largely caused the relative decline and, in the 2000s, the large absolute decline in U.S. manufacturing employment: first, manufacturing real output growth has largely kept pace with that of the aggregate economy for decades, and second, manufacturing labor productivity growth has been considerably higher. These statistics appear to provide a compelling case that domestic manufacturing is strong, and that, as in agriculture, productivity growth, assumed to reflect automation, is largely responsible for the relative and absolute decline in manufacturing employment. Although the size and scope

[15] This dynamic is illustrated in Dix-Carneiro and Kovak (2017). In a study of trade liberalization in Brazil in the early 1990s, the authors find that regions that initially specialized in industries facing larger tariff cuts experienced prolonged declines in formal sector employment and earnings, compared to other regions. Moreover, they find that the impact of tariff changes on the regional economy is persistent and grows over time. The mechanisms, the authors argue, include low labor mobility, slow capital adjustment, and agglomeration economies, which amplify the initial labor demand shock from liberalization.

of the decline in employment manufacturing industries in the 2000s was unprecedented, many see it as part of a long-term trend and deem the role of trade small.

That view, I have argued, reflects a misinterpretation of the numbers. First, aggregate manufacturing output and productivity statistics are dominated by the computer industry and mask considerable weakness in most manufacturing industries, where real output growth has been much slower than average private sector growth since the 1980s and has been anemic or declining since 2000. Second, labor productivity growth is not synonymous with, and is often a poor indicator of, automation. Measures of labor productivity growth may capture many forces besides automation—including improvements in product quality, outsourcing and offshoring, and a changing industry composition owing to international competition. Indeed, the rapid productivity growth in the computer and electronics products industry, and by extension in the manufacturing sector, largely reflects improvements in product quality, not automation. In short, the stylized facts, when properly interpreted, do not provide prima facie evidence that automation drove the relative and absolute decline in manufacturing employment.

It is difficult to parse out the effects of various factors on manufacturing employment, and research does not provide simple decompositions of the total contribution that trade and the broader forces of globalization make to manufacturing's recent employment decline. Nevertheless, the research evidence points to trade and globalization as the major factor behind the large and swift decline of manufacturing employment in the 2000s. Although manufacturing processes continue to be automated, there is no evidence that the pace of automation in the sector accelerated in the 2000s; if anything, research comes to the opposite conclusion.

Manufacturing still matters, and its decline has serious economic consequences. Reflecting the sector's deep supply chains, manufacturing's plight contributed to the weak employment growth and poor labor market outcomes prevailing during much of the 2000s. Research shows that such large-scale shocks have persistent adverse effects on affected communities and their residents, though these costs rarely are fully considered in policy making (Klein, Schuh, and Triest 2003). In addition, because manufacturing accounts for a disproportionate share of R&D, the health of manufacturing industries has important implications for innovation in the economy. The widespread denial of domestic manufacturing's weakness and globalization's role in its employment collapse has inhibited much-needed, informed debate over trade policies.

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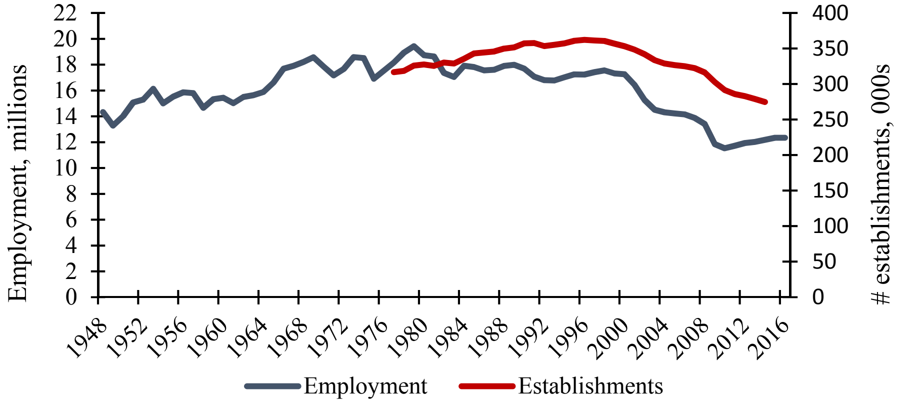
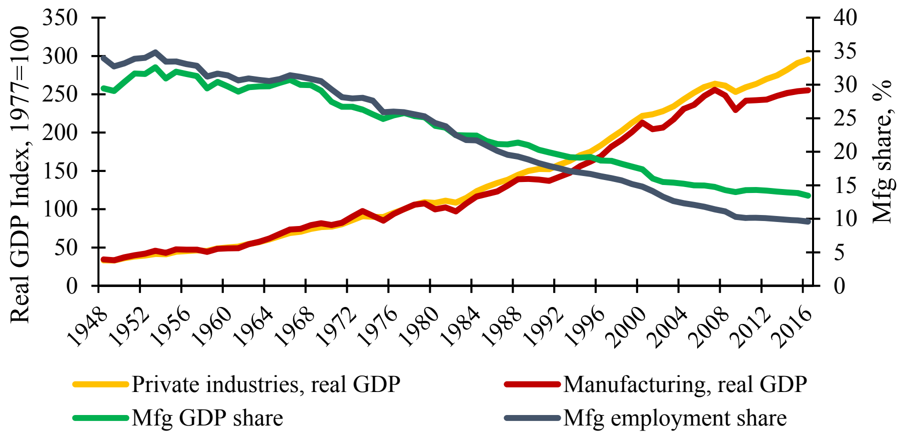
Figure 1: Manufacturing Employmemnt and Number of Establishments



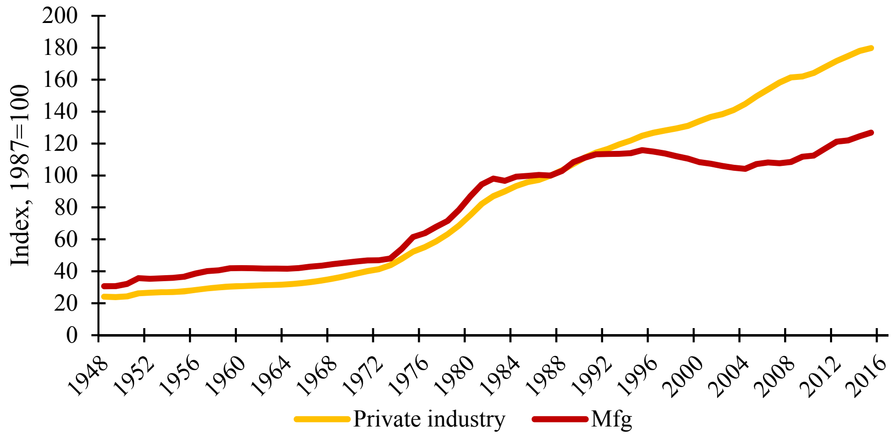
NOTE: Data on employment are from the Bureau of Economic Analysis. Data on number of establishments are from the Census Bureau's Business Dynamics Statistics.

Figure 2: Manufacturing and Private Industry Real GDP; Manufacturing GDP and Employment Shares



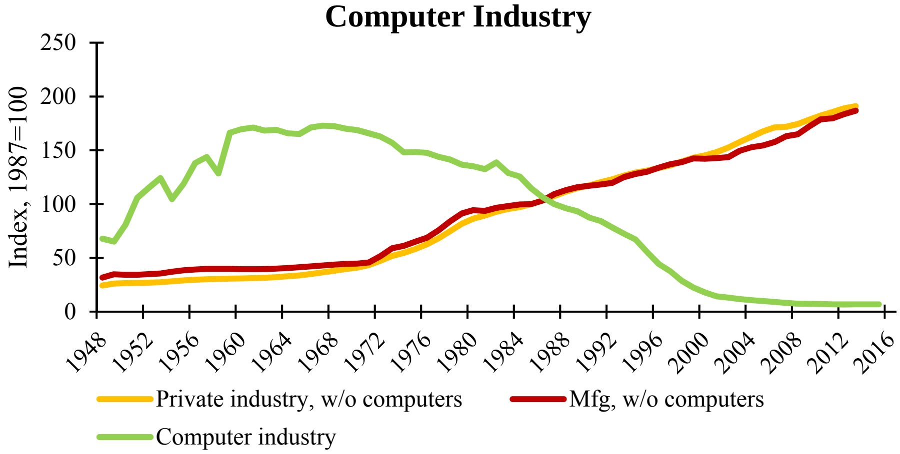
NOTE: Author calculations using data from the Bureau of Economic Analysis.

Figure 3: GDP Price Deflators, Private Industry and Manufacturing



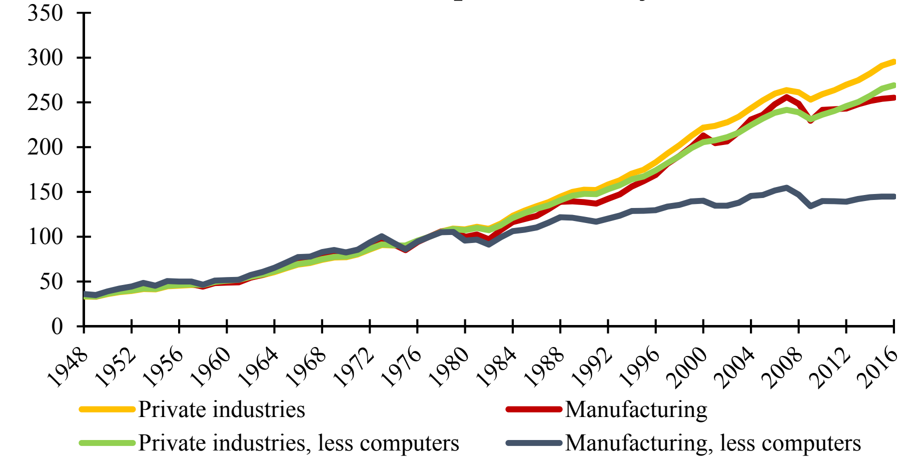
NOTE: Data are from the Bureau of Economic Analysis.

Figure 4: GDP Price Deflators, Private Industry and Manufacturing Omitting Computer Industry, Computer Industry



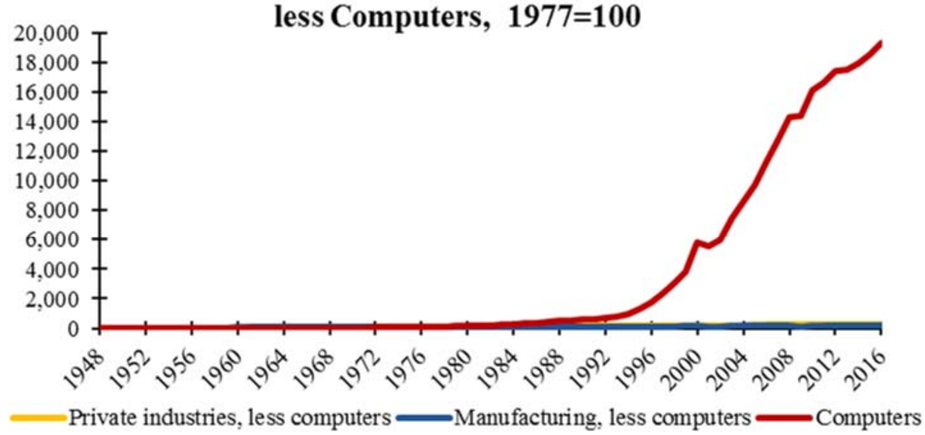
NOTE: Author calculations using data from the Bureau of Economic Analysis.

Figure 5: Real GDP, Private Industry and Manufacturing, with and without Computer Industry, 1977=100



NOTE: Author calculations using data from the Bureau of Economic Analysis.

Figure 6: Real GDP: Private Industry and Manufacturing less Computers, 1977=100



NOTE: This figure repeats the series displayed in Figure 5 that omit the computer industry and adds real output growth for the computer industry. The scale is different from that in Figure 5, however, to accommodate the extraordinary growth of the computer industry. See discussion in text.

Table 1 Decomposition of Differences in Private Sector v. Manufacturing Employment Growth Rates, With and Without Computer and Electronic Products Industry, Selected Time Periods

	1977–2016	1979–1989	1989–2000	2000–2007	2007–2016
Including Computer Industry:					
Difference in employment growth rate: private business − manufacturing	***0.025***	***0.029***	***0.022***	***0.037***	***0.019***
Share due to GDP Growth	0.147	0.195	−0.135	−0.037	0.666
Share due to Labor Productivity Growth	0.853	0.805	1.135	1.037	0.334
Excluding Computer Industry:					
Difference in employment growth rate: private business − manufacturing	***0.026***	***0.032***	***0.022***	***0.036***	***0.019***
Share due to GDP Growth	0.609	0.478	0.815	0.255	1.020
Share due to Labor Productivity Growth	0.391	0.522	0.185	0.745	−0.020

NOTE: The table shows, for various periods, decompositions of the difference in the employment growth rate in the private and manufacturing sectors—with and omitting the computer industry—into the part due to the difference in their real GDP growth and the part due to the difference in their labor productivity growth. Calculations are based on Equation (1) in the text and use data from the Bureau of Economic Analysis.