# Puzzles and Surprises in Employment and Productivity in U.S. Manufacturing After the Great Recession

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Abstract

Though U.S. manufacturing output recovered more slowly from the Great Recession than historical experience would have predicted, manufacturing employment, which peaked in 1979, *grew* between 2010 and 2017. This was the second-longest period of manufacturing employment growth in the entire post-war period. Linking these developments was an historically unprecedented, protracted absolute decline in labour productivity. This article provides an overview of these puzzling aggregate developments and of the diverse industry-level changes they summarize. The roles of foreign competition, mis-measurement of real output, and the computer industry are explored, and the value of looking within multi-industry aggregates like manufacturing is illustrated.

Using data from before the Great Recession, Houseman *et al.* (2011) provided a familiar description of U.S. manufacturing: steep declines in employment after 1979, robust growth in real value-added, and strong growth in labour productivity. They argued that growth in output and labour productivity after 1980 was attributable to a disproportionate extent to one three-digit industry, NAICS 334 (computer and electronic products).[2]

Between 2000 and 2010, manufacturing employment fell by almost a third, more rapidly than in any 10-year post-war period.[3] Just over half this fall occurred between 2000 and 2007, before the Great Recession. A number of influential studies, including Autor *et al.* (2013) and Pierce and Schott (2012),

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2 This argument is elaborated in Houseman *et al.* (2015) and Houseman (2018).

3 Until 1993-2003, no ten-year post-war period had experienced a fall of more than 10 per cent.

have concluded that increased Chinese competition after 2000 played an important role in the 2000-2007 fall in employment.

After U.S. manufacturing's emergence from the traumatic 2000-2010 decade,[4] all three elements of the Houseman *et al.* (2011) description were inverted: growth in real value-added was weak, employment grew, and labour productivity (measured as real value-added per employee) declined absolutely.[5] These inversions represent puzzling departures from pre-2000 patterns.

In 2010, observers might have predicted that manufacturing output would grow more slowly than that of the rest of the private economy for several years, despite manufacturing's greater decline in the Great Recession, because of increased foreign competition. On the other hand, if told that manufacturing output would grow more slowly between 2010 and 2017 than between 1979 and 2000, when 98 thousand manufacturing jobs were lost every year on average, it is hard to believe that anyone would have predicted the ensuing seven years of job *gains*, averaging 131 thousand jobs per year. And nobody who read popular accounts of the impact of computers, automation, and robotics on manufacturing would have predicted the dramatic collapse in labour productivity growth that occurred after 2010. NAICS 334 continued to play a disproportionate role after 2010, but it had a disproportionate impact on *declines* in the growth rates of output and productivity.

While a number of earlier studies have presented one or more elements of these shifts, as I note in what follows, this article provides a systematic overview of these dramatic, linked changes and sheds new light on the industry-level developments that underlie them. The roles of foreign competition, mis-measurement of real output, and NAICS 334 are explored.

This article highlights the value of recognizing that data on manufacturing as a whole are aggregates of the experiences of the constituent industries, and these experiences differed widely in the periods covered here. While NAICS 334 had a disproportionate impact on overall manufacturing productivity after 2010, for instance, its employment declined, and it was only one of many industries experiencing a slowdown in productivity growth. The analysis here seems to rule out some simple explanations of the changes in U.S. manufacturing after 2010, but a full solution of the associated aggregate and industry-specific puzzles discussed awaits further research.

This article contains three main sections. Section 1 focuses on manufacturing production, measured as real value-added. Before 1990, manufacturing pro-

4 Because of an interest in employment, I treat 2011, when manufacturing employment began to increase, as the start of the post-Great-Recession period rather than 2010, when real GDP began to recover.

5 This productivity measure excludes the labour input of the self-employed and is thus biased upward. The share of self-employed in total employed workers in manufacturing was 2.6 per cent in 2010 and declined to 2.3 per cent in 2017. Thus the bias in the measured level of productivity was very small and declining over this period, so that the measured rate of growth of productivity has a tiny downward bias.

duction grew only slightly more slowly than production in the rest of the private economy.[6] After 2010, that gap increased substantially. The analysis here suggests that increased foreign competition played a notable but not dominant role in slowing growth in manufacturing relative to the rest of the private economy, which is less vulnerable to foreign competition. Classifying three-digit industries by the ratio of real value-added in 2016 to 2000 reveals that those that did least well at recovering from after 2010 on that measure had on average the sharpest output declines in 2000-2010 and the greatest impact from foreign competition.[7]

Section 2 deals with employment and labour productivity in manufacturing. The pre-2010 history of robust productivity growth in manufacturing coupled with declining employment would have led most observers to predict that the unusually slow growth in manufacturing output after 2010 would have led to unusually rapid declines in employment. Instead, manufacturing employment rose from 2010 to 2016 in aggregate and in 12 of the 18 constituent three-digit industries. At the same time, productivity growth fell in 15 of those industries, and labour productivity fell absolutely in five industries and in manufacturing as a whole. The decline in manufacturing's productivity growth accounted for over half of the overall decline in productivity growth in the private economy between 1990-2000 and 2010-2016, even though manufacturing generally accounted for less than 20 per cent of private economy GDP in those periods.

Many have argued that the real output of innovative industries has been under-stated in official statistics (Feldstein, 2017). However, the analysis here does not support the notion that increasing under-statement of output was the main cause of the collapse of manufacturing productivity growth. In general, industries that did better over the 2000-2016 period in terms of value-added also performed better in terms of labour productivity.

Because NAICS 334 experienced the most dramatic productivity growth decline and because it has been at the center of many discussions of adjustment for quality changes, Section 3 examines productivity growth in that industry in more detail. Between 1990 and 2000, the decline in the NAICS 334 deflator accounted for 40 per cent of aggregate manufacturing productivity growth. Between 1990-2000 and 2010-2016 the fall in the rate of decline of the deflator accounted for 38 per cent of the drop in aggregate manufacturing productivity growth. Within NAICS 334, about 85 per cent of the fall in the rate of decline of the deflator between 1995-1997 and 2009-2011 was accounted for by falls

6 Throughout this article, data on value-added in the private economy are from the BEA series "Private Industries," and the corresponding employment data are from the BLS series "Total Private Employment."

7 Table 1 lists the 18 three-digit manufacturing industries and gives their NAICS codes.

in the rates of deflation of two of the 30 constituent six-digit industries: computers and, especially, semiconductors. While the changes in the official statistics for semiconductors may be the result of increasing mis-measurement, impacts on real GDP and, thus, aggregate productivity are likely to be small.

This analysis of NAICS 334 illustrates the fact that just as manufacturing is an aggregate of diverse industries, three-digit industries are also collections of markets that may differ substantially. It is always tempting simply to treat changes in economic aggregates as if they mirror similar changes in all their constituent parts, but it is often worthwhile to look behind the aggregation curtain.

## Manufacturing Production

Between 1947 and 1990, the average annual growth rate of real value-added in manufacturing was only 0.30 percentage points below that in the rest of the private economy.[8] Table 1 provides information on real value-added growth after 1990.

The first three columns in Table 1 show average annual growth rates of real value-added for 1990-2000, 2000-2010, and 2010-2016 for each of the 18 three-digit NAICS manufacturing industries, as well as for the private economy excluding manufacturing and for aggregates of interest within manufacturing. During 1990-2000, growth in manufacturing was more rapid than in the rest of the private sector (4.29 per cent versus 3.62 per cent per year), due to an important extent to the extremely rapid growth in NAICS 334 (22.12 per cent).

Because manufacturing output has historically been more cyclically variable than that of the rest of the private sector, and because manufacturing is more vulnerable to foreign competition, which apparently intensified after 2000, it is not surprising that growth slowed more in manufacturing than in the rest of the private sector during 2000-2010 relative to 1990-2000 (3.03 versus 2.00 percentage points). Because of manufacturing's historic cyclical variability, one might have expected growth to rebound more strongly in manufacturing in the post-2010 recovery than in the rest of the private sector, but, as Table 1 shows, the growth rate of manufacturing output in fact fell further.

Experiences within manufacturing were diverse in all three periods. Four three-digit NAICS industries had production declines during the generally prosperous 1990-2000 decade, while six had production increases during the difficult 2000-2010 decade. In the 2010-2016 recovery, six of the 18 industries had average growth rates of more than 2 per cent, while eight had declines in production. NAICS 334 is a clear outlier in the first two periods, but, because its

8 All rates of change reported in this article were calculated from changes in natural logarithms and, unless otherwise noted, all data were downloaded from the Bureau of Labour Statistics (BLS) and Bureau of Economic Analysis (BEA) websites. The Appendix describes the construction of the 1990-2016 three-digit NAICS manufacturing industry dataset employed in this article, as well as the calculation of real value-added for the private economy outside manufacturing and for a number of other aggregates that appear in various tables.

**Table 1: Real Value-added and Change in Nominal Net Import Penetration at the Three-digit NAICS Level in U.S. Manufacturing (average annual per cent change)**

| | Sector/Sub-Sector/Industry | Real Value-added 1990-2000 | Real Value-added 2000-2010 | Real Value-added 2010-2016 | ΔNIP Impacts 2000-2010 | ΔNIP Impacts 2010-2016 |
|---|---|---|---|---|---|---|
| opvt | Other (Non-Manufacturing) Private Economy | 3.62 | 1.62 | 2.39 | -0.01 | 0.15 |
| mfg | All Manufacturing | 4.29 | 1.26 | 0.90 | -0.17 | -0.46 |
| mlc | All Manufacturing less 334 | 1.70 | -0.02 | 0.52 | 0.02 | -0.43 |
| dur | Durable goods | 6.05 | 1.91 | 2.14 | -0.42 | -0.50 |
| dlc | Durable goods less 334 | 1.64 | -0.52 | 1.96 | 0.00 | -0.54 |
| 321 | Wood products | -2.53 | -1.61 | 2.19 | 0.21 | -0.52 |
| 327 | Nonmetallic mineral products | 1.98 | -3.17 | 1.99 | -0.01 | -0.29 |
| 331 | Primary metals | 2.06 | -2.00 | 7.58 | 0.21 | 0.07 |
| 332 | Fabricated metal products | 2.65 | -2.26 | 0.97 | -0.28 | -0.37 |
| 333 | Machinery | 0.24 | -0.19 | -0.28 | 0.56 | -2.19 |
| **334** | **Computer and electronic products** | **22.12** | **10.25** | **2.77** | **-2.64** | **-1.21** |
| 335 | Electrical equip., appliances, & components | 0.77 | -0.44 | -0.03 | -1.78 | -1.73 |
| 336 | Transportation Equipment | 1.76 | 0.84 | 3.94 | 0.32 | -0.26 |
| 337 | Furniture and related products | 2.97 | -5.58 | 2.41 | -1.82 | -0.52 |
| 339 | Miscellaneous manufacturing | 3.43 | 2.74 | -1.26 | 0.16 | -0.11 |
| ndr | Nondurable goods | 1.75 | 0.45 | -0.66 | -0.02 | -0.25 |
| 311FT | Food and beverage and tobacco products | 0.83 | 1.06 | -1.68 | -0.08 | -0.25 |
| 313TT | Textile mills and textile product mills | 1.37 | -6.46 | 0.01 | -2.13 | -0.81 |
| 315AL | Apparel and leather and allied products | -1.87 | -5.97 | -2.48 | -10.35 | 11.11 |
| 322 | Paper products | -0.09 | -3.06 | -0.82 | 0.29 | -0.12 |
| 323 | Printing and related supports activities | -0.39 | -0.25 | -0.38 | -0.03 | 0.04 |
| 324 | Petroleum and coal products | 5.38 | 2.61 | 2.41 | 0.73 | 0.93 |
| 325 | Chemical products | 2.37 | 2.27 | -1.47 | -0.22 | -0.57 |
| 326 | Plastics and rubber products | 4.70 | -1.84 | -0.26 | -0.60 | -0.36 |

Source: BLS and BEA data, author's calculations.

growth slowed dramatically after 2010, it was closer to the pack during this most recent period.

Because increased foreign competition has been discussed as a contributor to the slowdown in manufacturing growth, the last two columns in Table 1 show a measure of the impact of foreign competition on growth in 2000-2010 and 2010-2016 based on net import penetration (NIP): net imports (i.e., imports minus exports) as a percentage of domestic sales. It was computed from BEA input-output tables, for which data are only available beginning in 1997, and all quantities are in current dollars. This measure of the impact of foreign competition takes into account both competition from imports into the United States and competition for U.S. exports in foreign markets.

The NIP growth impact measure in Table 1 was calculated as follows. For some industry, let $Q$ be nominal gross domestic output, $M$ be nominal net imports, $S$ be nominal domestic sales in an early year, with $NIP = \frac{M}{S}$, and let $Q'$, $M'$, $S'$, and $NIP'$ be the same quantities in a later year. Since $Q = S - M = S(1 - NIP)$, the percentage growth in total output between the two years can decomposed as follows:

**Table 2: Growth Rates of Real Value-added and Change in Net Import Penetration for Three-digit U.S. Manufacturing Industries Impacts by Recovery Ratio Cluster (average annual rate of change)**

| | Real Value-added | | | ΔNIP Impacts | |
|---|---|---|---|---|---|
| Recovery Ratio Cluster* | 2010-2016 | 2000-2010 | 1990-2000 | 2010-2016 | 2000-2010 |
| (1) R = 3.29 | 2.77 | 10.25 | 22.12 | -1.21 | -2.64 |
| (2) 1.15 $\leq$ R $\geq$ 1.50 | 2.24 | 1.29 | 3.00 | 0.01 | 0.24 |
| (3) 0.95 $\leq$ R $\geq$ 1.01 | -0.04 | -0.28 | -0.22 | -0.93 | -0.22 |
| (4) 0.47 $\leq$ R $\geq$ 0.84 | 0.26 | -4.05 | 1.67 | 1.24 | -2.13 |

Source: Data from Table 1. The recovery ratio, R, is the ratio of an industry's real value-added in 2016 to its real value-added in 2000.
*The industries in each cluster are as follows, ordered by declining recovery ratio: (1) 334, (2) 324, 336, 331, 339, 325, (3) 311FT, 321, 333, 335, 323, (4) 332, 327, 326, 322, 337, 313TT, 315AL.

$$\ln(\frac{Q'}{Q}) = \ln(\frac{(1-NIP')}{(1-NIP)}) + \ln(\frac{S'}{S}) \quad (1)$$

The first term on the right of (1), converted to an average annual growth rate, is shown in the last two columns of Table 1 for the periods indicated. This is only a very rough estimate, however, because in the BEA data, growth rates of total nominal output and of real value-added are not highly correlated across industries. Moreover, it should be clear that this measure is endogenous, reflecting developments in both domestic and foreign markets; use of the term "impact" in what follows is not intended to imply causation.

For manufacturing as a whole, with and without NAICS 334, for durable goods, for non-durable goods, and for half the 18 three-digit industries, the estimated per-annum negative effect of increased foreign competition was greater in 2010-2016 than in 2000-2010. In contrast, for the private economy excluding manufacturing, changes in foreign competition had only a tiny negative impact on growth in 2000-2010 and had a positive impact after 2010. Holding the growth of domestic sales constant, equation (1) implies that growth in manufacturing in 2010-2016 would have been 0.46 percentage points per year higher but for the increase in NIP, while growth in the rest of the private economy would have been 0.15 percentage points lower but for the corresponding fall in NIP. The sum of these effects, 0.61 percentage points, is 41 per cent of the difference between the 2010-2016 growth rates in manufacturing and in the rest of the private economy. This rough estimate suggests that changes in the pattern of foreign competition may have played a significant – but far from dominant – role in the weakness of post-2010 growth in manufacturing output relative to that in the rest of the private economy.

It is instructive to cluster industries based on the extent to which their production had recovered from the 2000-2010 decade by 2016. As Table 2 indicates, there are four distinct clusters in the data:

1. NAICS 334, for which real-value-added more than tripled over the 2000-2016 period, despite a 42 per cent fall in employment;
2. five industries that experienced increases of real value-added between

15 per cent and 50 per cent;

3. six industries that had roughly returned to their 2000 output levels; and
4. seven industries for which 2016 real value-added was at least 15 per cent below the 2000 level.

Industries in clusters (1) and (2) on average experienced positive growth in all of the periods shown; industries in cluster three averaged close to zero growth in all periods; while industries in cluster (4) were hit much the hardest during 2000-2010. Apart from NAICS 334, industries in cluster (4) also seem to have suffered most from increased foreign competition during 2000-2010. The small number of three-digit industries, of course, precludes claiming statistical significance, let alone causal relationships, for these patterns.

## Employment and Productivity

From 1979 to 2000, real manufacturing value-added grew at an average annual rate of 3.26 per cent, and employment declined from its 1979 peak at an average annual rate of 1.17 per cent. Because real manufacturing value-added grew considerably more slowly from 2010 to 2017, the historical record of robust productivity growth would have led one to predict more rapid declines in employment in that period, perhaps after a brief cyclical rebound. Instead, the 2010-2017 period was much the longest and most substantial period of manufacturing job growth since the 1979 employment peak.[9] In fact, in the entire post-war period, only the 1961-1969 period of manufacturing job growth was longer. Between 2010 and 2017 manufacturing employment grew by 7.6 per cent, and about 915,800 jobs were added.[10]

As Chart 1 suggests, this expansion represented a departure from the post-1979 relationship between employment growth in manufacturing and in the rest of the private economy. From 1979 to 2000, the rate of growth of employment in the private economy apart from manufacturing averaged 3.16 percentage points above the rate of growth in manufacturing. Between 2010 and 2017, that difference fell to 1.04 percentage points.[11]

As Chart 2 shows, both manufacturing and the rest of the private economy saw drops in labour productivity growth around the mid-2000s, attributed by

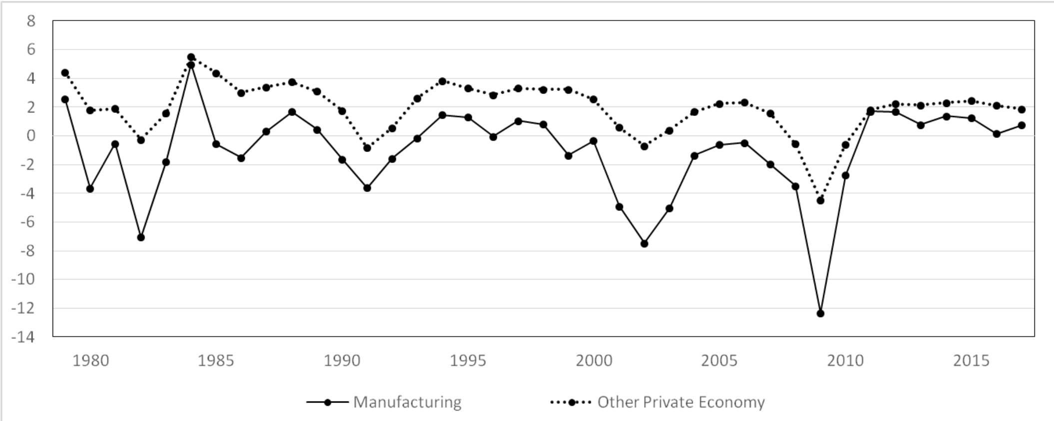
9 Fort *et al.* (2018), Levinson (2017) and Lawrence (2017) are among the few who have taken note of the historically exceptional manufacturing job growth after 2010. Lawrence (2017) is the only study I have seen that notes the apparent link to the collapse in manufacturing productivity growth at the same time, though he considers only aggregate manufacturing data.

10 In the next-longest post-1979 expansion, 1986-89, employment grew by only 2.5 per cent.

11 The p-value for a two-tailed t-test of the null hypothesis that the mean difference was the same in both periods was $9.9 \times 10^{-6}$. Between 1947 and 2000, this difference averaged 2.21 percentage points, and the p-level of the corresponding t-test was .0075.

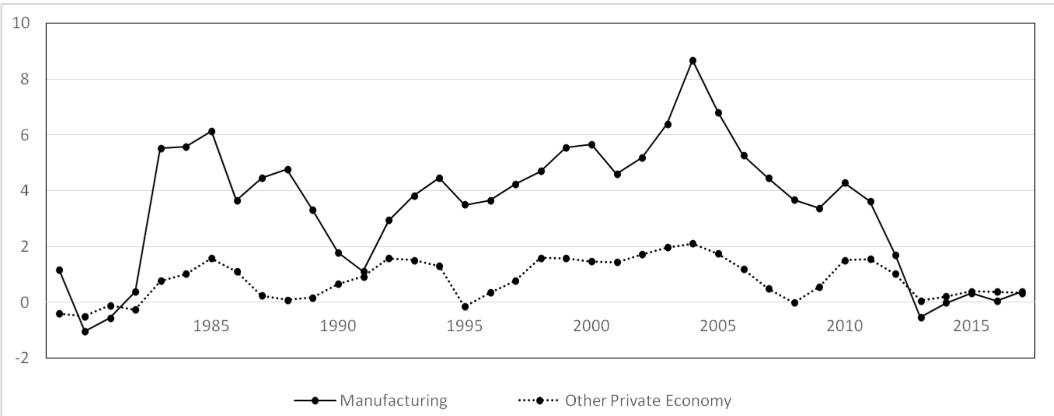
12 Dey *et al.* (2012) and others find that manufacturing employment growth prior to 2000 was substantially understated, and thus labour productivity was substantially over-stated, by increased outsourcing.

**Chart 1: Employment Growth Rates in U.S. Manufacturing and Other Private Economy Industries, 1980-2016 (per cent change)**




Source: BLS.

**Chart 2: 3-Year Moving Average Labour Productivity Growth in U.S. Manufacturing and Other Private Economy, 1980-2016 (per cent change)**




Source: BEA and BLS data, author's calculations.

many authors (e.g., Fernald (2015) and Gordon (2018)) to the end of a short IT-fueled productivity boom.[12] As Chart 2 also shows, the drop in productivity growth was much sharper in manufacturing than in the rest of the private economy. The absolute fall in manufacturing labour productivity from 2010 to 2017 is without precedent in the postwar period.

For several reasons, the sharp fall in manufacturing productivity growth after 2010 is the most puzzling post-Great-Recession change in U.S. manufacturing. First, plant closures between 2000 and 2010 were significant (Fort *et al.* 2018), and one might have expected the surviving plants to have been the most productive and the most able to increase productivity. Second, overall manufacturing capacity utilization remained low through 2017 (Pierce and Wisniewski, 2018), so capacity constraints are unlikely to have reduced productivity. (Excess capacity may have discouraged productivity-enhancing investment, though.) Third, this productivity growth collapse occurred during a period

**Table 3: Average Contributions of Manufacturing to U.S. Private Economy Labour Productivity Growth**

| | Avg. Productivity Growth (%) | | | Avg. Annual Contribution of Manufacturing | | Avg. Mfg Share (%) of Private Economy Nominal Value-added |
|---|---|---|---|---|---|---|
| Period | Private Economy | Manufacturing | Other Private | Absolute percentage points | Per cent of Private Economy | |
| 1947-1980 | 1.72 | 2.64 | 1.26 | 0.75 | 43.8 | 29.0 |
| 1980-1990 | 1.37 | 3.85 | 0.66 | 0.86 | 62.4 | 22.1 |
| 1990-2000 | 1.75 | 4.54 | 1.15 | 0.85 | 48.6 | 19.1 |
| 1980-2000 | 1.56 | 4.20 | 0.91 | 0.85 | 54.7 | 20.6 |
| 2000-2010 | 1.86 | 5.30 | 1.37 | 0.71 | 37.9 | 15.2 |
| 2010-2017 | 0.18 | -0.05 | 0.26 | 0.03 | 16.8 | 14.0 |

Source: BEA and BLS data, author's calculations.

of concern about robots substituting for humans (Acemoglu and Restrepo, 2017), which would have increased the measured productivity of those workers who remained employed. Finally, if anything, growth in the number of manufacturing employees understates the growth of quality-adjusted labour input. Average weekly hours of manufacturing employees grew slightly during 2010-2017; the ratio of self-employed workers to employees in manufacturing was tiny (footnote 5); and, at least through 2016, the average education level of manufacturing workers increased (Levinson, 2017).

From 1980 to 2000, as manufacturing employment was declining, labour productivity in U.S. manufacturing grew at an average annual rate of 4.20 per cent (Table 3) and declined in only one of those 20 years. Then from 2010 through 2017, manufacturing productivity fell at an average annual rate of 0.05 per cent and fell in three of those seven years. From 1980 to 2000, annual productivity growth in manufacturing averaged 3.29 percentage points above that in the rest of the private economy, and it exceeded growth in the rest of the private economy in all but one of those 20 years.[13]Then from 2010 to 2017, productivity growth in manufacturing averaged 0.31 percentage points below that in the rest of the private sector,[14] and it was below that in the rest of the private sector in four of those seven years.[15]

13 The difference is less dramatic in the earlier post-war years. Productivity in the rest of the private economy grew more rapidly than in manufacturing in 12 of the 33 years between 1947 and 1980, and manufacturing productivity grew more rapidly by only 1.37 percentage points per annum on average over that period. Houseman (2018) has argued that the acceleration of manufacturing productivity in the 1980-2000 period was due in large part to a surge of measured productivity in NAICS 334. In any case, the p-level for a two-tailed t-test of the null hypothesis that the mean difference between the growth rate of productivity in manufacturing and that in the rest of the private economy was equal in 1947-2000 and 2010-2017 was .0015.

14 The p-level for a two-tailed t-test of the null hypothesis that the mean difference between the two growth rates was the same in both periods was $6.5 \times 10^{-5}$. Syverson (2016) has shown that labour productivity growth fell more in manufacturing between 1995-2004 and 2005-2015 than in the nonfarm private economy generally and that the fall in manufacturing productivity growth between these periods had a disproportionate impact on the broader economy. Lawrence (2017) compared aggregate manufacturing labour productivity growth in 2010-2016 and in prior years, and Baily and Montalbano (2016) showed that growth of total factor productivity (TFP) in manufacturing in 2004-2014 was lower than in prior years.

15 The decomposition used to construct Table 3 is presented in the Appendix.

Table 3 shows that changes in manufacturing labour productivity were disproportionately important for the private economy as a whole. The first three columns show average rates of growth of labour productivity in the entire private economy, manufacturing, and the private economy excluding manufacturing. The fourth column shows that the average absolute contribution of manufacturing to private economy labour productivity growth did not vary dramatically in the sub-periods before 2010. The fifth and sixth columns show that manufacturing's per cent contribution to private economy productivity growth was substantially above its share of private economy (nominal) value-added in those sub-periods.[16]The third line of Table 3 shows that labour productivity in the entire private economy grew at an average annual rate of 1.75 per cent during 1990-2000, and almost half of that growth (0.486 = 0.85/1.75) reflected productivity growth in manufacturing, even though manufacturing accounted for only 19.1 per cent of nominal private-economy value-added on average.

This pattern changed dramatically after 2010. Comparing lines 3 and 6 in Table 3 shows that the decline in manufacturing's average contribution to private-economy productivity growth (0.82=0.85-0.03) accounted for 52 per cent of the total decline in the average growth rate of private-economy productivity (1.57=1.75-0.18) from 1990-2000 to 2010-2016 even though manufacturing generally accounted for less than 20 per cent of private-economy GDP during both those periods.[17] The decline in the growth rate of productivity in manufacturing was not the whole private-economy story, but the importance of manufacturing's role in that story greatly exceeded its share of real value-added.

Table 4 shows annual rates of change of employment and productivity for three-digit industries and aggregates of interest for the periods considered in Table 1. All industries suffered employment declines during 2000-2010, and the seven industries with rates of decline above 5.2 per cent lost at least 40 per cent of their jobs over that period. During the 2010-2016 expansion in aggregate manufacturing employment, six of the 18 industries, including NAICS 334, experienced employment declines. Durable goods industries accounted for about 60 per cent of manufacturing employment in 2010 and about 80 per cent of 2010-2016 employment growth, consistent with their suffering greater cyclical losses in the preceding decade. Two industries, NAICS 332 and 336, accounted for about two-

16 Baily and Montalbano (2016) show that this is also true for total factor productivity over the 1987-2014 period

17 Syverson (2016) compared labour productivity growth before and after 2004 and obtained quantitatively similar results. It may seem odd that Table 3 shows that manufacturing made a (tiny) positive contribution to overall private economy productivity growth in 2010-2017 even though manufacturing productivity declined. This reflects the higher absolute level of productivity in manufacturing than in the rest of the private economy, coupled with employment growth in manufacturing. (I am indebted to an anonymous referee for demonstrating this.)

Table 4: **Productivity (Real Value-added per Employee) and Employment for U.S. Three-digit NAICS Manufacturing Industries**

| | | Average Annual Growth Rate | | | | |
|---|---|---|---|---|---|---|
| | | Productivity | | | Employment | |
| | Sector/Sub-Sector/Industry | 1990-2000 | 2000-2010 | 2010-2016 | 2000-2010 | 2010-2016 |
| mfg | *All Manufacturing** | 4.53 | 5.30 | -0.33 | -4.04 | 1.14 |
| mlc | *All Manufacturing less 334** | 1.93 | 3.90 | -0.81 | -3.92 | 1.33 |
| dur | *Durable goods** | 5.92 | 6.23 | 0.67 | -4.32 | 1.48 |
| dlc | Durable goods less 334 | 1.39 | 3.65 | 0.11 | -4.17 | 1.85 |
| 321 | Wood products | -3.78 | 4.27 | -0.09 | -5.88 | 2.28 |
| 327 | Nonmetallic mineral products | 1.50 | 0.85 | 0.43 | -4.02 | 1.56 |
| 331 | Primary metals | 3.07 | 3.41 | 6.87 | -5.41 | 0.71 |
| 332 | *Fabricated metal products** | 1.80 | 0.86 | -0.79 | -3.13 | 1.76 |
| 333 | Machinery | -0.09 | 3.62 | -1.62 | -3.80 | 1.35 |
| **334** | ***Computer and electronic products**** | **22.56** | **15.33** | **3.50** | **-5.09** | **-0.73** |
| 335 | Electrical equip., appliances, & components | 1.45 | 4.53 | -1.10 | -4.98 | 1.07 |
| 336 | Transportation Equipment | 2.14 | 5.17 | 0.64 | -4.34 | 3.30 |
| 337 | Furniture and related products | 1.74 | 0.87 | 0.96 | -6.45 | 1.45 |
| 339 | *Miscellaneous manufacturing** | 2.83 | 5.24 | -1.95 | -2.51 | 0.70 |
| ndr | Nondurable goods* | 2.60 | 4.03 | -1.26 | -3.58 | 0.60 |
| 311FT | Food and beverage and tobacco products | 0.81 | 1.89 | -3.29 | -0.82 | 1.61 |
| 313TT | Textile mills and textile product mills | 3.16 | 2.91 | 0.67 | -9.37 | -0.67 |
| 315AL | *Apparel and leather and allied products** | 4.22 | 4.74 | -0.27 | -10.72 | -2.21 |
| 322 | Paper products | 0.59 | 1.21 | 0.22 | -4.27 | -1.04 |
| 323 | Printing and related support activities | -0.37 | 4.78 | 1.09 | -5.03 | -1.47 |
| 324 | Petroleum and coal products | 7.54 | 3.39 | 2.75 | -0.79 | -0.34 |
| 325 | *Chemical products** | 2.92 | 4.47 | -1.98 | -2.21 | 0.51 |
| 326 | *Plastics and rubber products** | 3.28 | 2.36 | -2.12 | -4.20 | 1.86 |

Source: BLS and BEA data, author's calculations.
*Average productivity growth in 1990-2000 was significantly different from average productivity growth in 2010-2016 at the 10% level on a two-tailed t-test, allowing for unequal variances.

thirds of growth in durables employment, and NAICS 311 accounted for essentially all the increase in non-durables employment, even though, as Table 1 shows, its real value-added fell fairly rapidly.

Table 4 shows that in all but three of the 18 industries – NAICS 321, 331, and 323 – the rate of growth of labour productivity declined between 1990-2000 and 2010-2016. All three of those industries had job losses of about 40 per cent during 2000-2010, and all three had more rapid output growth during 2010-2016 than during 1990-2000 – with two (NAICS 321 and 331) experiencing noticeably more rapid growth. Despite the small sample size, for six of the industries in Table 4 as well as several aggregates, all shown in italics, average productivity growth declines between 1990-2000 and 2010-2016 were significant at the 10 per cent level using a two-tailed t-test.[18] In five of the 18 industries, as

18 For 12 of the 18 industries, productivity growth increased between 1990-2000 and 2000-2010. The increase was only significant at 10 per cent on a two-tailed test for two industries, however.

in manufacturing as a whole, real value-added per employee declined absolutely between 2010 and 2016.

Even if the extreme decline in productivity growth in NAICS 334 was in part the result of increased mis-measurement of real value-added in that innovative industry, it is clear from Table 4 that the aggregate manufacturing productivity growth decline reflected factors that affected most other industries. Even excluding NAICS 334, average labour productivity growth fell by almost 3 percentage points between 1990-2000 and 2010-2016.

Arguing against the importance of increased mis-measurement as a source of declines in aggregate productivity growth, Syverson (2016) showed that labour productivity growth in manufacturing fell between 1996-2004 and 2004-2014 for 17 of the 20 OECD nations with available data.

To focus more sharply on leading industrialized nations and to focus on the post-2010 period, I looked at the G-7 nations for which manufacturing labour productivity data were available from the OECD from 1995 to 2015: the U.K., Germany, Italy, France, and Japan. All showed falls in average productivity growth between 1995-2000 and 2011-2015, though none were as dramatic as in the United States, and only the United States showed an absolute fall in productivity in the latter period.[19]

Thus, consistent with the arguments of Byrne *et al.* (2016) and Syverson (2017), the breadth of the productivity growth decline in United States manufacturing and experience in other leading industrialized nations is inconsistent with the notion that the overall productivity slowdown in the United States private economy mainly reflects increasing under-statement of real value-added in a few innovative manufacturing industries. Table 4 shows that this pattern is broadly consistent with several studies that find general declines in business dynamism, particularly among non-leading firms; see, e.g., Decker *et al.* (2017, 2018) and Andrews *et al.* (2016).

Even if increased mis-measurement of real value-added has not been the dominant cause of the collapse of manufacturing productivity growth, it could nonetheless have had some impact. Guvenen *et al.* (2017) argue that shifting profits off-shore led to a small over-statement of business sector productivity growth between 1994 and 2008 but had no effect from 2008 through 2014. This suggests that the productivity growth slowdown may be slightly over-stated in the official statistics. Houseman *et al.* (2011) argue that a shift to the use of lower-cost imported inputs similarly led to an over-statement of manufacturing productivity growth during 1997-2007. The estimated over-statement is again small relative to the productivity growth collapse in manufacturing after 2010, however, so that

19 Like the United States, Germany and the U.K. reported increases in manufacturing employment between 2010 and 2016, though the increases were smaller in percentage terms than in the United States Manufacturing employment fell in the other three nations considered.

**Table 5: Productivity (Real Value-added per Employee) and Employment in U.S. Three-digit NAICS Manufacturing Industries by Recovery Ratio Cluster**

| | Average Annual Percent Growth Rate | | | | |
|---|---|---|---|---|---|
| | Productivity | | | Employment | |
| Recovery Ratio Cluster* | 2010-2016 | 2000-2010 | 1990-2000 | 2010-2016 | 2000-2010 |
| (1) R = 3.29 | 3.50 | 15.33 | 22.56 | -0.73 | -5.09 |
| (2) $1.15 \leq R \geq 1.50$ | 1.26 | 4.34 | 3.70 | 0.98 | -3.05 |
| (3) $0.95 \leq R \geq 1.01$ | -1.00 | 3.82 | -0.39 | 0.97 | -4.10 |
| (4) $0.47 \leq R \geq 0.84$ | -0.13 | 1.97 | 2.33 | 0.39 | -6.02 |

Source: Data from Tables 1 and 4. The recovery ratio, R, is the ratio of an industry's real value-added in 2016 to its real value-added in 2000.
*The industries in each cluster are as follows, ordered by declining recovery ratio: (1) 334, (2) 324, 336, 331, 339, 325, (3) 311FT, 321, 333, 335, 323, (4) 332, 327, 326, 322, 337, 313TT, 315AL.

even a reversal of this shift would seem unlikely to account for much of the aggregate productivity growth collapse. Moreover, the dollar rose by 12.7 per cent between 2010 and 2016, making imported inputs relatively more attractive, so a reversal of this trend is not particularly plausible.[20]

While neither of these measurement problems seems likely to have had a major effect on manufacturing as a whole, changes in the official measures for NAICS 334 have been dramatic, and that industry has been the focus of many discussions of mis-measurement. We accordingly turn to a closer examination of productivity in that industry in the next section.

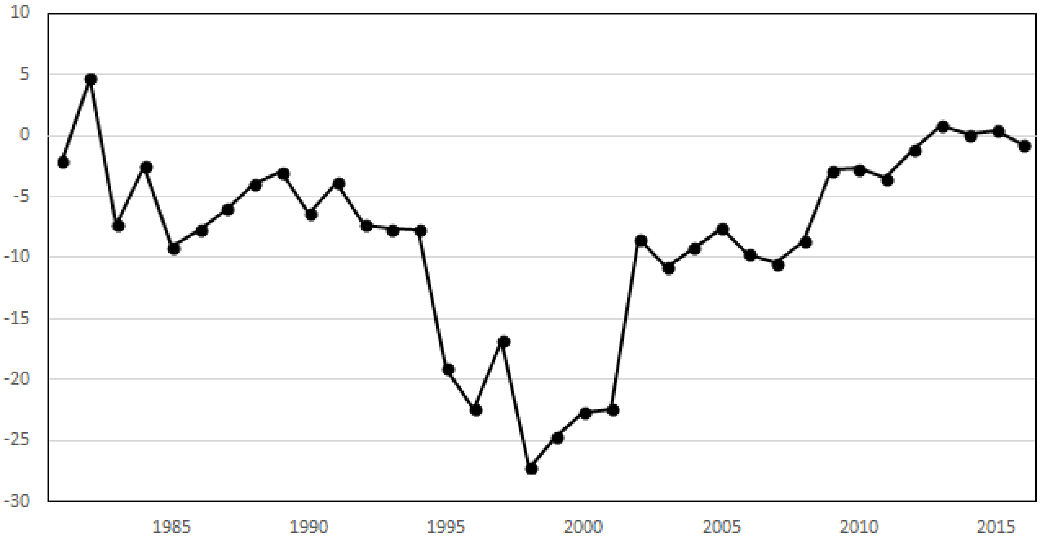
Table 5 follows the same format as Table 2 and computes average rates of growth of productivity and employment for clusters of industries defined by the ratios of their real value-added in 2016 to that in 2000. Because NAICS 334 is such an extreme outlier, it is most instructive to compare clusters (2), (3), and (4). Even though these clusters were defined by cumulative changes in real value-added, not productivity ot employment, industries that did well in those terms also suffered the smallest employment losses in 2000-2010 and the strongest employment gains in 2010-2016. Similarly, industries in cluster (2) had the strongest labour productivity growth on average in all three periods. The directions of causality, if any, among these variables is, of course, unknown. But it is clear that, as Houseman (2018) has stressed, robust labour productivity growth does not automatically lead to declines in employment.

## Productivity Growth in NAICS 334

Baily and Bosworth (2014) and Houseman *et al.* (2015) have stressed the importance of declines in the deflator for the computer and electronic products industry (NAICS 334) for measured

20 The 12.7 per cent figure was computed from annual averages of monthly figures of the Federal Reserve's Price-Adjusted Board Dollar index. For most of the 18 three-digit industries, the ratio of value-added to sales declined slowly over this period, consistent with a continuation of the Houseman *et al.* (2011) trend, not a reversal. The striking exception was NAICS 334, for which this ratio rose substantially. Analysis using the NBER-CES manufacturing database (available at http://www.nber.org/nberces/) indicated that this was entirely due to shifts in the relative importance of the constituent six-digit industries with different average value-added/sales ratios.

**Chart 3: Rates of Change of the Deflator for Computer and Electronic Products (NAICS 334), 1980-2016, per cent**




Source: BEA.

**Table 6: Average Contributions of NAICS 334 Deflation to U.S. Manufacturing Labour Productivity Growth**

| Period | Average Manufacturing Productivity Growth (%) | Avg. Contribution of 334 Deflation Absolute Percentage Points | Avg. Contribution of 334 Deflation Per cent of Total Manufacturing | Avg. 334 Share (%) of Manufacturing Nominal VA |
|---|---|---|---|---|
| 1947 - 1980 | 2.64 | -0.08 | -3.08 | 6.04 |
| 1980 - 1990 | 3.85 | 0.47 | 12.31 | 10.61 |
| 1990 - 2000 | 4.53 | 1.95 | 43.04 | 12.44 |
| 2000 - 2010 | 5.30 | 1.16 | 21.97 | 12.53 |
| 2010 - 2016 | -0.33 | 0.09 | -27.57 | 12.89 |

Source: BEA and BLS data, author's calculations.

manufacturing productivity growth in in the two decades before 2010. Chart 3 shows that the decline of the deflator for NAICS 334 accelerated sharply in the mid-1990s and then decelerated sharply after 2000.

Over the 1990-2000 period, measured labour productivity in NAICS 334 grew 22.6 per cent per annum on average, and 68 per cent of this growth (15.4 percentage points) was accounted for by the decline in the industry-specific deflator.[21] From 2010 to 2016, in contrast, that deflator declined only 0.68 per cent per year on average, suggesting a dramatic fall in the decline in the rate of improvement of computer and electronic products. The dramatic fall in the rate of deflation for NAICS 334 accounted for 77 per cent of the decline in that industry's average annual productivity growth between 1990-2000 and 2010-2016.

Table 6, which uses the same format as Table 3, shows that changes in the NAICS 334 deflator had an important impact on total manufacturing pro-

21 The change in the log of labour productivity growth equals the change in the log of nominal labour productivity growth minus the change in the log of the deflator.

ductivity.[22] Between 1947 and 1980, NAICS 334 was generally unimportant, its deflator increased, and that increase had essentially no impact on aggregate manufacturing productivity. This began to change around 1980 as this industry became more important, and its pace of innovation accelerated. Comparing the first and third lines of Table 6 reveals that between 1947-1980 and 1990-2000 increases in the rate of decline of the NAICS 334 deflator (and increases in its relative weight in Appendix equation (A3)) accounted for 2.03 (=1.95+.08) percentage points of the increase in the average manufacturing productivity growth rate, more than the actual 1.89 (=4.53-2.64) percentage point increase. The contribution of all other manufacturing industries in aggregate was, therefore, negative.

Between 1990 and 2000, the decline in the NAICS 334 deflator accounted for over 40 per cent of estimated aggregate manufacturing productivity growth, and even during the catastrophic 2000-2010 decade it accounted for over 20 per cent. But the pattern changed sharply after 2010. Comparing the third and fifth lines in Table 6 shows that the fall in the rate of decline of the deflator for NAICS 334 between 1990-2000 and 2010-2016 (1.84=1.95-.09 percentage points) accounted for just over 38 per cent of the drop in aggregate manufacturing productivity growth (4.86=4.53+0.33 percentage points) between those periods, even though NAICS 334 accounted for less than 13 per cent of nominal manufacturing value-added on average during these periods. Changes in the rate of decline of the NAICS 334 deflator account for a substantial and disproportionate share of the collapse in aggregate manufacturing productivity growth.

It is important to be clear that the "accounted for" statements in the preceding two paragraphs are in fact only about accounting, not about causation. Suppose that the real price declines of goods produced by some industry have been understated in the official statistics. Correcting that understatement would, of course, increase the measured real output of the corresponding industry. But the effect on broader measures of real output would depend on who bought the industry's production.[23] At one extreme, it might all be exported, and the increase in the industry's measured output would translate directly into an increase in measured real GDP. At the other extreme, the industry's output might all be sold to another domestic industry. In that case, correcting the understatement of deflation would simply increase that other industry's measured purchases of intermediate goods and decrease its measured value-added accordingly, with no impact on real GDP.

To look more closely at the sources of changes in the NAICS 334 deflator and their potential consequences for broader aggregates, I employed the NBER-CES

22 See the Appendix for the decomposition used to create Table 6.

23 See Byrne *et al.* (2017) for a discussion and quantitative analysis.

**Table 7: Decomposition of the Fall in the Rate of Deflation of NAICS 334, 1995-1997 to 2009-2011**

| | | Share of NAICS 334 Value Added | | Annual Percentage Change in Deflator | | % Contribution to Fall in Rate of 334 Deflation | | |
|---|---|---|---|---|---|---|---|---|
| NAICS Code | Description | Mean | Change | Mean | Change | Total | Deflator | Share |
| 334111 | Electronic Computers | 7.91 | -5.61 | -20.64 | 15.49 | 19.84 | 13.72 | 6.12 |
| Other 3341 | Computers & peripheral equipment, other | 5.50 | -2.21 | -11.21 | 10.30 | 7.59 | 5.30 | 2.29 |
| 3342 | Communications equipment | 14.36 | -6.66 | -1.71 | 1.11 | 2.61 | 1.50 | 1.10 |
| 3343 | Audio & video equipment | 0.85 | -0.30 | -1.65 | -0.44 | 0.00 | -0.04 | 0.04 |
| 334413 | Semiconductors & related devices | 26.09 | 2.16 | -21.52 | 29.28 | 65.49 | 70.86 | -5.39 |
| Other 3344 | Semiconductors & other electronic components, other | 10.94 | -2.31 | -1.23 | 2.98 | 3.43 | 3.08 | 0.35 |
| 3345 | Navigational, measuring, electromedical, & control instruments | 32.58 | 16.11 | 0.86 | -0.08 | 0.95 | -0.25 | 1.20 |
| 3346 | Manufacturing & reproducing magnetic & optical media | 1.77 | -1.18 | -2.10 | -0.65 | 0.12 | -0.12 | 0.24 |

Source: NBER-CES manufacturing database, author's calculations.

manufacturing database, which has data on nominal value-added and shipments deflators for 30 six-digit manufacturing industries in NAICS 334 from 1958 through 2011.[24] Chart 3 shows that this period covers most of the post-2000 fall in the rate of decline of the NAICS 334 deflator.[25]

I compared the periods 1995-1997, the first three years of double-digit rates of decline of both official and approximate NAICS 334 deflators, and 2009-2011, the latest three-year period in the NBER-CES database, during which NAICS 334 deflation was less than 4 per cent per annum in each year. For each six-digit industry or broader aggregate considered, the first four columns in Table 7 show the average percentage share of nominal value-added in those two periods, the change in that average share between those two periods, the average percentage change of the corresponding approximate deflator in those two periods, and the percentage point change in that average rate of change. Positive numbers in the fourth column thus correspond to falls in the rate of decrease of the corresponding deflator. For comparison, the average rate of decline of the approx-

24 The database can be accessed at http://www.nber.org/nberces/

25 The methods used to construct an approximate deflator for NAICS 334 from the NBER data and to use it to produce Table 7 are presented in the Appendix.

imate deflator was 13.3 per cent over 1995-97 and 2.9 per cent during 2008-2011, so the change, corresponding to the fourth column in the Table was 10.4 percentage points.

Table 7 shows that computers (NAICS 334111) and semiconductors (NAICS 334413) had much the largest average rates of declines of their deflators, as well as the largest falls in those decline rates between the earlier and later periods. Computer manufacturing experienced a substantial drop in its share of NAICS 334 value-added, corresponding to a 60 per cent drop in average nominal value-added, as computer manufacturing moved rapidly overseas.

The fifth column of Table 7 shows that computers and semiconductors accounted for 85.3 per cent of the drop in the approximate NAICS 334 rate of deflation between 1995-1997 and 2009-2011, even though they accounted for only 34 per cent of nominal value-added on average in those two periods. The last two columns in Table 7 report the percentages of the total difference in the average rate of deflation for NAICS 334 between the two periods accounted for by changes in rates of deflation and changes in shares, respectively. This table shows that change in its components' rates of deflation accounted for 94 per cent of the decline in the aggregate rate of deflation for NAICS 334; changes in the relative importance of the components had very little impact. A substantial drop in the share of computers was almost completely offset by a small increase in the share of semiconductors. Table 7 makes clear that the single most important contributor to the fall in the rate of decline of the deflator for NAICS 334 was the dramatic fall in the rate of decline of the deflator for semiconductors.

On its face, this dramatic fall implies a collapse in the rate of innovation in semiconductors. Estimating rates of quality improvement in innovative industries is, of course, difficult.[26] The business press seems devoid of complaints about a collapse of semiconductor innovation over this period, however, so one should be cautious about accepting that such a dramatic collapse actually occurred. In addition, Byrne and Corrado (2017) and others have argued that the rates of improvement of a wide range of high-tech goods have been understated for some time. For mis-measurement to have made a noticeable contribution to the dramatic slowdown in the rate of deflation of NAICS 334 shown in Table 6, however, mismeasurment would have had to have increased substantially. As it happens, Byrne *et al.* (2018) have argued persuasively that the rate of decline of the deflator for semiconductors *has* been more substantially under-stated in the official statistics since around 2004. Correcting such an understatement would in-

26 For a general discussion of methods used in the United States to adjust for quality change, see Groshen *et al.* (2017). It is worth noting that the BLS did not begin to employ hedonic methods for server microprocessors until mid-2018, and the initial model did not include energy efficiency, though that appears to be an important attribute for server farms (U.S. Bureau of Labour Statistics, 2018).

crease measured real output and labour productivity in NAICS 334413. But, as Byrne *et al.* (2018) stress, semiconductors are an intermediate good for which net exports are small (Platzer and Sargent, 2016), so correcting an understatement in the rate of decline of their deflator would likely have little impact on measured GDP.[27]

## Summary Remarks

The aggregate changes in U.S. manufacturing since the Great Recession have been both dramatic and puzzling, and they have had disproportionately large impacts on the private economy as a whole. This article looked behind those surprising aggregate shifts to examine underlying developments at the three-digit industry level. In important respects the diversity among industry experiences simply pushed puzzles down to the industry level and made clear the need for more research at that level, but the analysis here did reveal a number of interesting patterns.

First, increased foreign competition may have been a significant reason for the slow growth of manufacturing output after 2010 relative to growth in the rest of the private economy, but it does not seem likely to have been the only reason. Second, growth in employment and declines in labour productivity growth occurred in most industries. The pattern of declines in labour productivity growth argues strongly against the notion that the aggregate decline primarily reflects increasing mis-measurement of real output in a few innovative industries, but the analysis here does not supply an alternative explanation.

Third, even though the accounting identity connecting changes in output, employment, and labour productivity suggests that robust productivity growth reduces employment, Table 5 shows that industries that recovered well from the Great Recession in output terms also had average employment growth and above-average productivity growth. As Houseman (2018) has stressed, that accounting identity cannot be treated as a causal relation.

Finally, on essentially all dimensions and in all periods, NAICS 334 is an extreme outlier, and changes in estimates of quality changes in computers and semiconductors have had a substantial impact on aggregate productivity statistics. If, as estimated above, computers and semiconductors accounted for around 85 per cent of the slowdown in the decline of the NAICS 334 deflator, and that slowdown accounted for around 38 per cent of the overall drop in manufacturing productivity growth, then as a rough approximation (taking note of the fact that these percentages were computed for somewhat different periods), falls in the rates of decline of the deflators for computers and semiconductors accounted for around 32 per cent of the overall decline in manufac-

27 Since a change in the deflator for semiconductors will affect both imports and exports, net exports is the relevant measure for the impact on real GDP.

turing productivity growth between the 1990s and the post-2010 period. But there have also been substantial post-Great-Recession changes in other manufacturing industries. Estimates of quality change in NAICS 334 matter greatly for estimates of aggregate manufacturing productivity growth, but they are not all that matters.

## References


Acemoglu, Daron and Pascual Restrepo (2017) "Robots and Jobs: Evidence from US Labor Markets," Working Paper, MIT Department of Economics, March.

Andrews, Dan, Chiara Criscuolo, and Peter N. Gal (2016) "The Best Versus the Rest: The Global Productivity Slowdown, Divergence Across Firms and the Role of Public Policy," OECD Productivity Working Paper No. 05, November.

Autor, David H., David Dorn, and Gordon H. Hanson (2013) "The China Syndrome: Local Labor Market Effects of Import Competition in the United States," *American Economic Review*, Vol. 103 , No. 6. pp. 2121-2168.

Baily, Martin N., and Barry P. Bosworth (2014) "U.S. Manufacturing: Understanding Its Past and Its Potential Future," *Journal of Economic Perspectives*, Vol. 28, No. 1 pp. 3-26.

Baily, Martin N. and Nicholas Montalbano (2016) "Why is U.S. Productivity Growth So Slow?" Brookings Institution, Hutchins Center Working Paper 22, September.

Byrne, David M., and Carol Corrado (2017) "ICT Services and Their Prices: What do They Tell us About Productivity and Technology?" *International Productivity Monitor*, No. 33, Fall, pp. 150-181.

Byrne, David M., John G. Fernald, and Marshall B. Reinsdorf (2016) "Does the United States Have a Productivity Slowdown or a Measurement Problem?" *Brookings Papers on Economic Activity*, pp. 109-157.

Byrne, David M., Stephen D. Oliner, and Daniel E. Sichel (2018) "How Fast Are Semiconductor Prices Falling?" *Review of Income and Wealth*, Vol. 64, Issue 3. pp. 679-702.

Byrne, David M., Stephen D. Oliner, and Daniel E. Sichel (2017) "Prices of High-Tech Products, Mismeasurement, and the Pace of Innovation.," *Business Economics*, Vol. 52, No. 2. pp. 103-113.

Dey, Mathew, Susan N. Houseman, and Anne E. Polikva (2012) "Manufacturers Outsourcing to Staffing Services," *Industrial and Labor Relations Review*, Vol. 65, No. 3, pp. 533-569.

Decker, Ryan A., John C. Haltiwanger, Ron S. Jarmin, and Javier Miranda (2017) "Declining Dynamism, Allocative Efficiency, and the Productivity Slowdown," *American Economic Review Papers and Proceedings*, Vol. 107, No. 5, pp.322-326.

Decker, Ryan A., John C. Haltiwanger, Ron S. Jarmin, and Javier Miranda (2018) "Changing Business Dynamism and Productivity: Shocks vs. Responsiveness," National Bureau of Economic Research, Working Paper 24236, January.

Diewert, Erwin (1978) "Superlative Index Numbers and Consistency in Aggregation," *Econometrica*, Vol. 46, No. 4, pp. 883-900.

Dumagan, Jesus C. (2002) "Comparing the Superlative Törnqvist and Fisher Ideal Indexes," *Economics Letters*, Vol. 76, No. 4, pp.251-258.

Feldstein, Martin (2017) "Underestimating the Real Growth of GDP, Personal Income, and Productivity," *Journal of Economic Perspectives*, Vol. 31, No. 2, pp. 145-164.

Fernald, J. G. (2015) "Productivity and Potential Output Before, During, and After the Great Recession," *NBER Macroeconomics Annual*, Vol. 29, No. 1, pp. 1-51.

Fort, Teresa C., Justin R. Pierce, and Peter K. Schott (2018) "New Perspectives on the Decline of U.S. Manufacturing Employment," *Journal of Economic Perspectives*, Vol. 32, No. 2, pp. 47-72.

Gordon, R. J. (2018) "Why Has Economic Growth Slowed When Innovation Appears to be Accelerating?" Cambridge, MA: National Bureau of Economic Research, Working Paper 24554, April.

Groshen, Erica L., Brian C. Moyer, Ana M. Aizcorbe, Ralph Bradley, and David M. Friedman (2017) "How Government Statistics Adjust for Potential Biases from Quality Change and New Goods in an Age of Digital Technologies: A View from the Trenches," *Journal of Economic Perspectives*, Vol. 31, No. 2, pp. 187-201.

Guvenen, Faith, Raymond J. Mataloni, Jr., Dylan G. Rassier, and Kim J. Ruhl (2017) "Offshore Profit Shifting and Domestic Productivity Measurement," Cambridge, MA: National Bureau of Economic Research, Working Paper 23324, April.

Houseman, Susan H (2018) "Understanding the Decline of U.S. Manufacturing Employment," Upjohn Institute Working Paper 18-287, Kalamazoo.

Houseman, Susan N., Christopher Kurz, Paul Lengermann, and Benjamin Mandel (2011) "Offshoring Bias in U.S. Manufacturing," *Journal of Economic Perspectives*, Vol. 25, No. 2, pp. 111-132.

Houseman, Susan N., Timothy J. Bartik, and Timothy Sturgeon (2015) "Measuring Manufacturing: How the Computer and Semiconductor Industries Affect the Numbers and Perceptions," in Susan N. Houseman and Michael Mandel (eds.) *Measuring Globalization: Better Trade Statistics for Better Policy Volume 1. Biases to Price, Output, and Productivity Statistics from Trade* (Kalamazoo: W.E Upjohn Institute), pp. 151-194.

Lawrence, Robert Z. (2017) "Recent Manufacturing Employment Growth: The Exception that Proves the Rule," National Bureau of Economic Research, Working Paper 24151, December.

Levinson, Marc (2017) "Job Creation in the Manufacturing Revival," Congressional Research Service Report, May 5.

Pierce, Justin R. and Peter K. Schott (2012) "The Surprisingly Swift Decline of US Manufacturing Employment," *American Economic Review*, Vol. 106, No.7, pp. 1632-1662.

Pierce, Justin R. and Emily Wisniewski (2018) "Some Characteristics of the Decline in Manufacturing Capacity Utilization," Washington: Federal Reserve Board of Governors, FEDS Notes, March 1.

Platzer, Michaela D. and John F. Sargent Jr. (2016) "U.S. Semiconductor Manufacturing: Industry Trends, Global Competition, Federal Policy," Washington, DC: Congressional Research Service, R44544, June.

Syverson, Chad (2016) "The Slowdown in Manufacturing Productivity Growth," *Brookings Briefs*, August.

Syverson, Chad (2017) "Challenges to Mismeasurement Explanations for the US Productivity Slowdown," *Journal of Economic Perspectives*, Vol. 31, No. 2, pp. 165-186.

U.S. Bureau of Labor Statistics (2018) "PPI Introduces Hedonic Price Estimation for Server Microprocessors," August 9. Available at https://www.bls.gov/ppi/server-microprocessors-hedonics.htm

Whelan, Karl (2002) "A Guide to U.S. Chain Aggregated NIPA Data," *Review of Income and Wealth*, Vol. 48, No. 2, pp. 217-233.

## Appendix

### The Törnqvist Approximation and Dataset Construction

To compute value-added in the private economy excluding manufacturing, I used the (chained) Törnqvist approximation to the (chained) Fisher Ideal quantity index used by BEA.[28] If $q_{i,t}$ is real value-added for industry $i$ in year $t$, and $Q_t$ is the real value-added of an aggregate of a set of industries in year t, the approximation is as follows:

$$\ln\left(\frac{Q_t}{Q_{t-1}}\right) \approx \sum_i w_{i,t} \ln\left(\frac{q_{i,t}}{q_{i,t-1}}\right), \quad \text{(A1)}$$

where $w_{i,t}$ is the average of industry $i$s share of the nominal value-added of the aggregate in years $t$ and $t-1$. I also used this approximation to combine the real BEA value-added numbers for industries 336MV (motor vehicles, bodies and trailers, and parts) and 3364OT (other transportation equipment). And, because NAICS 334 (computer and electronic products) is an outlier on several dimensions discussed below, I also used it to produce series for real value-added for manufacturing excluding NAICS 334 and for durable goods excluding NAICS 334.

I added BLS employment numbers for industries 313 (textile mills) and 314 (textile product mills) to match BEA value-added data for industry 313FT.

BEA reports real value-added for industry 311FT, which is the sum of 311 (food manufacturing) and 312 (beverage and tobacco product manufacturing), and for BEA industry 315AL, which is the sum of 315 (apparel manufacturing) and 316 (leather and allied product manufacturing). On the other hand, BLS reports average annual employment for 311 and 315 and, as CEU industry 32329, for the sum of average employment in 312 and 316. From 2002 through 2015, it reports May employment figures for 312 and 316 separately, and for those years I simply re-scaled the May numbers so that their total equaled the corresponding 32329 annual average number. The ratio of 316 to 312 employment declined smoothly from 0.238 in 2002 to 0.134 in 2015. I regressed this ratio against a time-trend ($R^2$=0.93) and used the fitted values, which rose to 0.330 in 1990, to allocate 32329 employment between 312 and 316 for the years 1990-2001. I then added the 312 estimates to the BLS numbers for 311 to produce an employment series for 311FT, and I added the 316 estimates to the BLS numbers for 315 to produce a series for 315AL.

I also used a natural extension of the Törnqvist approximation to decompose total private economy labour productivity growth into that due to manufacturing and that due to the rest of the private economy:

28 See Diewert (1978), Whelan (2002), and Dumagan (2002). Houseman *et al.* (2015) use this same approximation.

$$\ln\left(\frac{Q_t}{L_t}\right) - \ln\left(\frac{Q_{t-1}}{L_{t-1}}\right) \approx \sum_i \left[w_{i,t}\ln\left(\frac{q_{i,t}}{q_{i,t-1}}\right) - \eta_{i,t}\ln\left(\frac{l_{i,t}}{l_{i,t-1}}\right)\right], \tag{A2}$$

where $q_{i,t}$ is real value-added in industry $i$ in period $t$, $l_{i,t}$ is employment in industry $i$ in period $t$, and $\eta_{i,t}$ is the average of industry $i$'s share of employment in the aggregate in years $t$ and $t-1$. Then the $i^{\text{th}}$ bracketed term is the absolute contribution of component $i$ to measured aggregate productivity change. Manufacturing's contribution depends on both its rate of productivity improvement and on its shares of nominal value-added and employment.

To examine the importance of the NAICS 334 deflator for aggregate manufacturing productivity changes, I decomposed the term for NAICS 334 on the right of equation (A2) into the (weighted) deflator and weighted nominal productivity:

$$[w_t\ln\left(\frac{q_t}{q_{t-1}}\right) - w_t\ln\left(\frac{q_t^n}{q_{t-1}^n}\right)] + [w_t\ln\left(\frac{q_t^n}{q_{t-1}^n}\right) - \eta_t\ln\left(\frac{l_t}{l_{t-1}}\right)] \equiv [w_t\ln\left(\frac{d_t}{d_{t-1}}\right)] + [w_t\ln\left(\frac{q_t^n}{q_{t-1}^n}\right)\eta_t\ln\left(\frac{l_t}{l_{t-1}}\right)]. \tag{A3}$$

The notation is as above, with $q_n$ denoting nominal value-added.

## Analyzing the NAICS 334 Deflator

I used the (chained) Törnqvist approximation presented above to obtain deflators for four of the six 4-digit industries in NAICS 334, for two important six-digit industries, and for the remainders of the two corresponding four-digit industries, as shown in Table 7. As is common practice (see, e.g., Fort *et al.* 2018), and for lack of an alternative, I treated the shipments deflator as if it applied to value-added, and I used nominal value-added weights in the Törnqvist approximation. The Törnqvist approximation to the rate of change of the deflator for some aggregate k within NAICS 334 is given by

$$D_{k,t} \equiv \sum_{i\in k} w_{i,t}\ln\left(\frac{p_{i,t}}{p_{i,t-1}}\right), \tag{A4}$$

where $w_{i,t}$ is the average of industry $i$s share of aggregate $k$s nominal value-added in periods $t$ and $t-1$, and $p_{i,t}$ is the shipments deflator for industry $i$ in period $t$.

Similarly, I used the (chained) Törnqvist approximation to obtain an approximation to the rate of change of the aggregate deflator for NAICS 334, $P_t$:

$$\ln\left(\frac{P_t}{P_{t-1}}\right) \equiv \sum_k C_{k,t} \equiv \sum_k \sum_{i\in k} \Omega_{i,t}\ln\left(\frac{p_{i,t}}{p_{i,t-1}}\right), \tag{A5}$$

where the second equality defines the $C_{k,t}$, $p_{i,t}$ is as above, and $\Omega_{i,t}$ is the average of industry $i$s share of value-added in NAICS 334 in periods $t$ and $t-1$. Percentage changes in the approximate and official deflators were highly correlated over 1995-2011 ($\rho = 0.81$) and nearly equal in 2009-2011, but the approximate series had lower percentage declines on average.

The contribution of each aggregate in

Table 7 to the change in the average rate of decrease in the approximate NAICS 334 deflator is the change in the within-period averages of their contributions to that deflator, the $C_{k,t}$ in equation (A5). These differences, expressed as percentages of the change in the average rate of decrease of the NAICS 334 deflator, are shown in the fifth column of Table 7.

Define the *average effective weight* of each aggregate in NAICS 334 in each comparison period, T, as

$$\theta_{k,T} \equiv \frac{\sum_{t \in T} C_{k,T}}{\sum_{t \in T} D_{k,t}} = \frac{\sum_{t \in T} \sigma_{k,t} \sum_{i \in k} w_{i,t} \ln\left(\frac{p_{i;t}}{p_{i;t-1}}\right)}{\sum_{t \in T} \sum_{i \in k} w_{i,t} \ln\left(\frac{p_{i;t}}{p_{i;t-1}}\right)}, \tag{A6}$$

where $\sigma_{k,t}$ is the share of aggregate $k$ in manufacturing value-added in period $t$.

If for some aggregate the early-period and late-period values of this average effective weight are $\theta$ and $\theta'$, respectively, and the early and late average rates of change of the corresponding deflator are $\gamma$ and $\gamma'$, we can decompose this aggregate's contribution to the change in the average rate of increase of the overall NAICS 334 deflator as follows:

$$\theta'\gamma' - \theta\gamma \equiv .5(\theta' + \theta)(\gamma' - \gamma) + .5(\gamma + \gamma')(\theta' - \theta) \tag{A7}$$