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Multifactor productivity slowdown in U.S. manufacturing

Multifactor productivity, also known as total factor productivity, relates the change in an industry's real output to changes in the combined inputs used in producing that output. Multifactor productivity in the manufacturing sector grew by an average of 2.0 percent per year from 1992 to 2004. Manufacturers increased their production of goods with relatively fewer inputs. From 2004 through 2016, however, manufacturing multifactor productivity declined by an average of 0.3 percent per year. This article uses detailed industry data to analyze sources of this productivity slowdown. Since 2004, semiconductors and other electronic component manufacturing and computer and peripheral equipment manufacturing contributed the most to the slowdown. Declines in multifactor productivity in petroleum and coal products and in pharmaceuticals and medicines also were important factors.

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After a decade of strong growth, U.S. productivity began to slow in the mid-2000s. Of particular interest is the slowdown of productivity growth in the manufacturing sector. Manufacturing multifactor productivity (MFP) increased during the 1992–2004 period by an average of 2.0 percent per year.[1] (See box.) In contrast, MFP declined from 2004 through 2016 by an average of 0.3 percent per year.

This slowdown has attracted attention in the popular press and has been the focus of a number of academic articles. Many economic observers acknowledge the extraordinary contributions of information technology (IT) to U.S. economic growth in the mid-1990s. Dale W. Jorgenson attributed the growth to the improvements in semiconductor technology and subsequent decline in IT prices, an increase in capital investment, and a widespread reduction of other costs in the mid-1990s.[2] David Byrne, Stephen

Oliner, Daniel Sichel, and, in a separate study, John Fernald attributed the slowdown to a deceleration of the rapid pace of semiconductor technology from the prior decade.[3] Robert J. Gordon contended that there is no productivity slowdown in U.S. manufacturing; rather, the unprecedented surge in productivity growth seen from the mid-1990s to the mid-2000s is over, and productivity growth has reverted to its usual pace.[4]

Economic trends affecting productivity other than IT are also important. Matthew Dey, Susan N. Houseman, and Anne E. Polvika credited manufacturers' outsourcing to staffing services as having contributed as much or even more than IT to manufacturing labor productivity growth in the 1990s to 2006.[5] Kevin L. Kliesen and John A. Tatom found that imports, rather than exports, have a strong, positive effect on manufacturing output and productivity.[6] Roberto Cardarelli and Lusine Lusinyan analyzed MFP across U.S. states and suggested that the slowdown reflects a loss of technical efficiency related to variation in both educational attainment and investment in research and development (R&D).[7] Ryan A. Decker, John Haltiwanger, Ron S. Jarmin, and Javier Miranda pointed to evidence of declines in business dynamism and in productivity-enhancing reallocation in the mid-2000s that can inhibit productivity growth despite technological progress.[8]

This article advances the literature in several ways. First, we take a look at the productivity slowdown through the lens of multifactor productivity, focusing on the U.S. manufacturing sector from 1992 to 2016.[9] Second, we analyze industry contributions to multifactor productivity.[10] This analysis reveals that since the mid-2000s, the petroleum and coal products industry and the pharmaceuticals and medicines industry have substantially reduced MFP for the entire manufacturing sector. These two industries produced over 12 percent of the output for the manufacturing sector in 2016, compared with only 7 percent in 1993.[11] Because of the increasing size and decreasing productivity of these industries, their contributions are worth exploring. Third, we examine the underlying mechanisms that directly impact productivity growth within these two industries. Fourth, we note the changing allocation of inputs into the production process (specifically, the decline of the labor share) that is providing fewer opportunities for innovation across most manufacturing industries.

What is multifactor productivity?

Multifactor productivity (MFP), also known as total factor productivity, relates the change in an industry's real output to the change in combined inputs used in producing that output. Multifactor productivity is related to the economic concept of a **production function**. A production function describes how firms optimally combine inputs (also known as factors of production) in order to produce output. Multifactor productivity is a quantifiable statistic that describes the change in the production function over time. The MFP statistic describes the efficiency gains (or losses) associated with growth (or decline) in output that is not a result of changes in measured inputs. Increases in MFP can result from improvements in technology, improvements in managerial practices, reallocation of resources from sectors that are less productive to those which are more productive, and other unmeasured factors.

Multifactor productivity is calculated as a ratio of the change in output to the change in a combination of inputs. These series are expressed as annual indexes, as shown in equation 1:

(1)

$$\text{MFP} = \frac{\text{Output}}{\text{Combined inputs}}$$

Output represents the real value of goods produced for sale outside the industry. This is known as *sectoral output.*

Inputs in production comprise capital services (*K*), labor hours (*L*), energy (*E*), materials (*M*), and purchased services (*S*)—often referred to by the acronym KLEMS. The annual change in the quantities of these inputs is aggregated as shown in equation 2:

(2)

$$\text{Inputs} = w_K(\text{Capital}) + w_L(\text{Labor}) + w_E(\text{Energy}) + w_M(\text{Materials}) + w_S(\text{Purchased services}) ,$$

where w_K, w_L, w_E, w_M, and w_S = weights representing each input's share of the total cost of producing output, and sum to 1.[12]

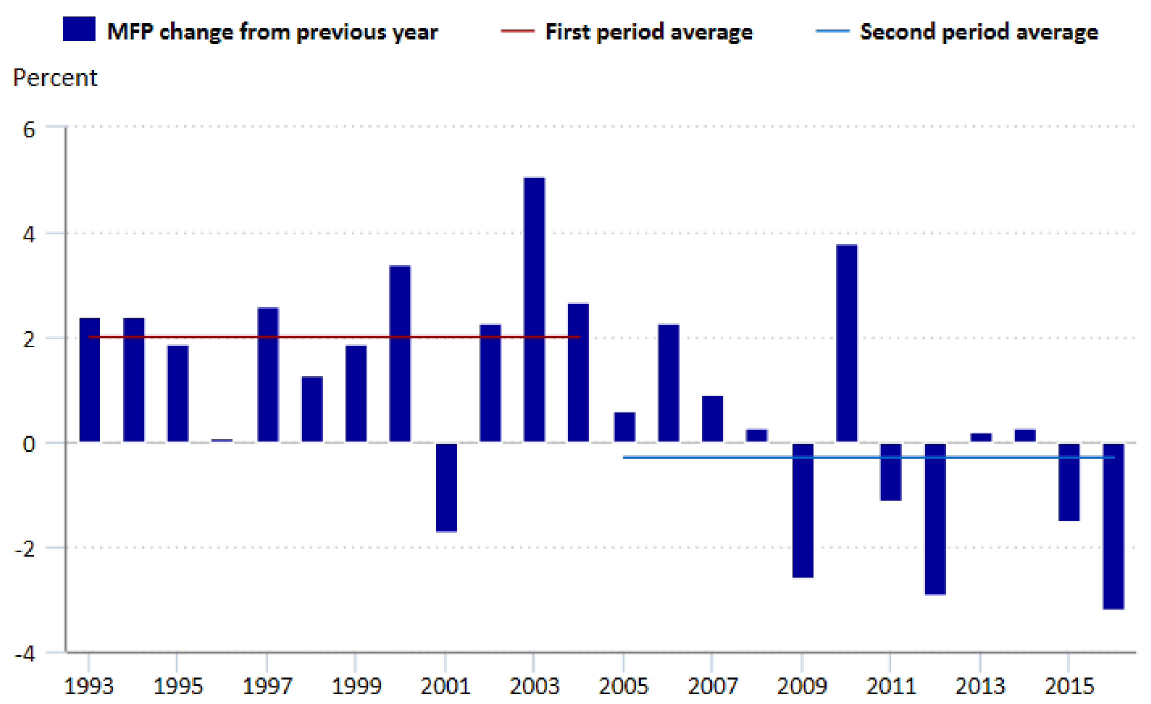
Multifactor productivity growth is important because, in the long run, increases in real hourly earnings and per capita income are tied to productivity gains. Productivity growth enables the economy to increase output without a proportional increase in labor hours.

MFP growth in manufacturing

Multifactor productivity growth in the U.S. manufacturing sector slowed considerably over the past 6 years.

While low or negative MFP growth is typically seen during recessions, it is unusual during economic expansions. This can be seen in figure 1, which shows positive growth in every nonrecessionary year between 1993 and 2010.[13] Since then, MFP has declined in 4 of the past 6 years despite growth of the overall economy.

Figure 1. Multifactor productivity (MFP), percent change from previous year, U.S. manufacturing sector, 1992–2016



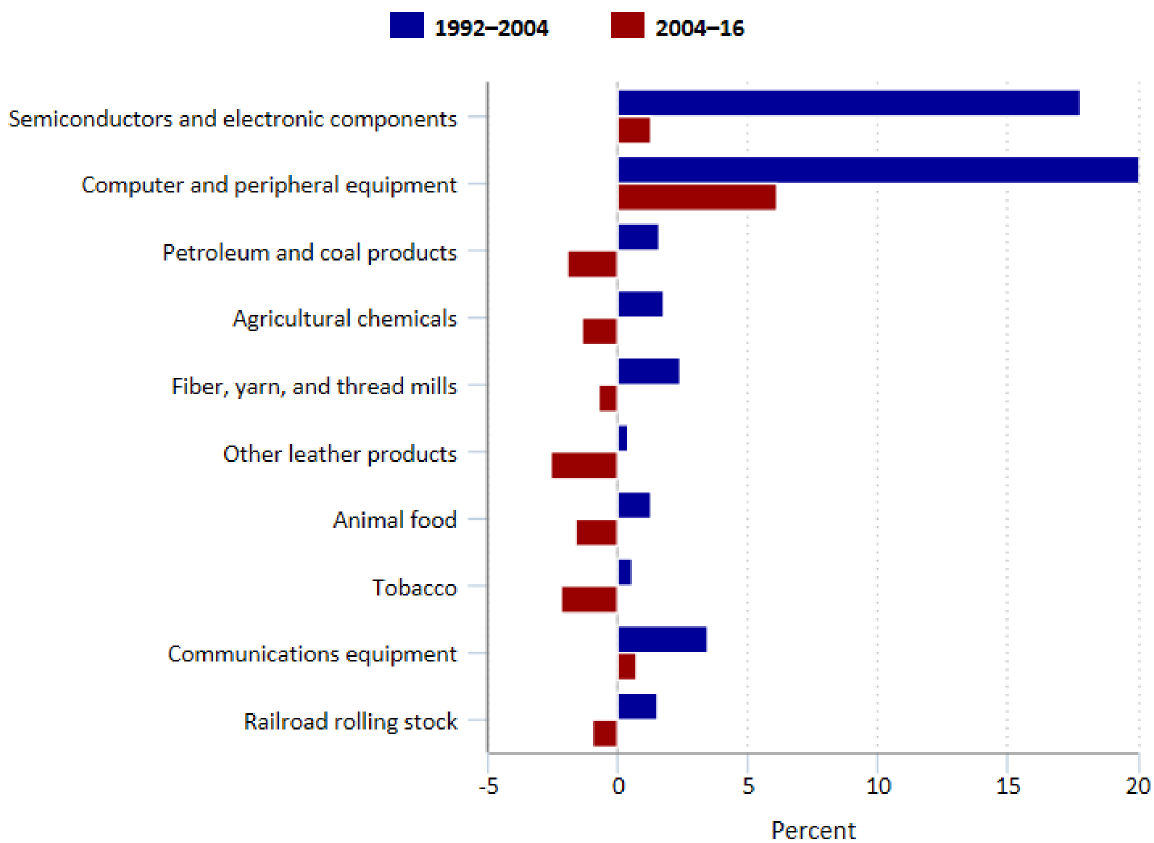
Click legend items to change data display. Hover over chart to view data.
Source: U.S. Bureau of Labor Statistics.

A key question is whether the productivity slowdown is concentrated in a few manufacturing industries or whether it is pervasive across most of manufacturing. As classified by the North American Industry Classification System (NAICS), the manufacturing sector comprises 86 unique 4-digit industries. Multifactor productivity was lower in the

2004–16 period than in the 1992–2004 period for 72 percent of these detailed industries.[14] Fifty-three percent of manufacturing industries had multifactor productivity declines in the slowdown period, with a median decline of 0.2 percent per year. This represents a reversal from the 1992–2004 period, when 76 percent of industries had positive multifactor productivity growth, with a median increase of 0.7 percent per year. These numbers show that the slowdown in manufacturing is not limited to a few influential industries.

The industries with the largest slowdown in MFP are illustrated in figure 2. Semiconductors and electronic components, followed by computer and peripheral equipment, had the largest declines. Although most other manufacturing industries experienced MFP growth increases from 1992 to 2004, by comparison these two industries posted extraordinary gains in MFP growth during the period.

Figure 2. Average annual percent change in multifactor productivity growth among industries with the largest relative declines from 1992–2004 to 2004–16

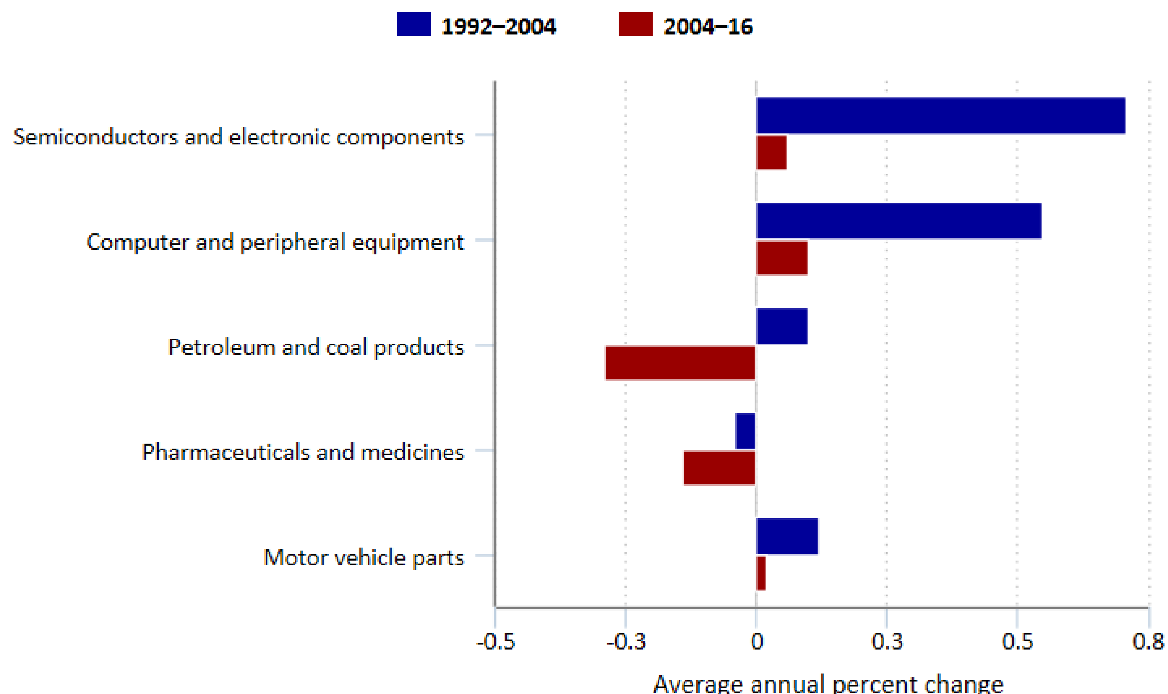


Click legend items to change data display. Hover over chart to view data.
Source: U.S. Bureau of Labor Statistics.

Industries contributing the most to the slowdown

Although it is interesting to look at how many detailed industries experienced a slowdown in productivity, not all industries are the same size nor have the same influence on overall productivity in the manufacturing sector. One way to estimate the effects of individual detailed industries on MFP is to calculate industry contributions.[15] Each industry’s contribution to total manufacturing productivity growth is calculated by multiplying its individual productivity growth rate by its share of manufacturing output.[16] Figure 3 shows industries that contributed the most to the decline in overall manufacturing MFP growth from the 1992–2004 period to the 2004–16 period. As other researchers have shown, semiconductors and other electronic component manufacturing and computer and peripheral equipment manufacturing, while small, were responsible for the majority of MFP growth at the sector level during the 1992–2004 period.[17] Although their contribution remained positive in the later period, the slowdown in these industries had the largest impact on the slowdown in manufacturing MFP. These two industries exhibited both a slowdown in MFP growth and a declining share of manufacturing sector output.[18]

Figure 3. Contributions to manufacturing sector multifactor productivity growth by industries with the largest relative declines in contributions from 1992–2004 to 2004–16



Click legend items to change data display. Hover over chart to view data.
Sources: U.S. Bureau of Labor Statistics and authors' calculations.

The degree to which total manufacturing MFP growth is attributable to each manufacturing industry is shown by the contribution statistic. In other words, the industries that had the greatest effect on the overall sector are with those with the greatest absolute contribution value. For the period 1992 to 2004, semiconductors and other electronic components (0.71) and computer and peripheral equipment (0.55) recorded the largest contributions to MFP among the manufacturing industries. However, during the slowdown that started after 2004, the two greatest contributions came from industries with MFP declines: petroleum and coal products (−0.29) and pharmaceuticals and medicines (−0.14). See appendix table A-1 for the contribution statistics for all manufacturing industries.

Petroleum and coal products manufacturing

As shown in table 1, the petroleum and coal products industry had the largest negative influence on overall MFP growth of the manufacturing sector since 2004. The most important segment of this industry is petroleum refineries, which accounted for over 90 percent of the value of industry production every year from 2000 to 2016.

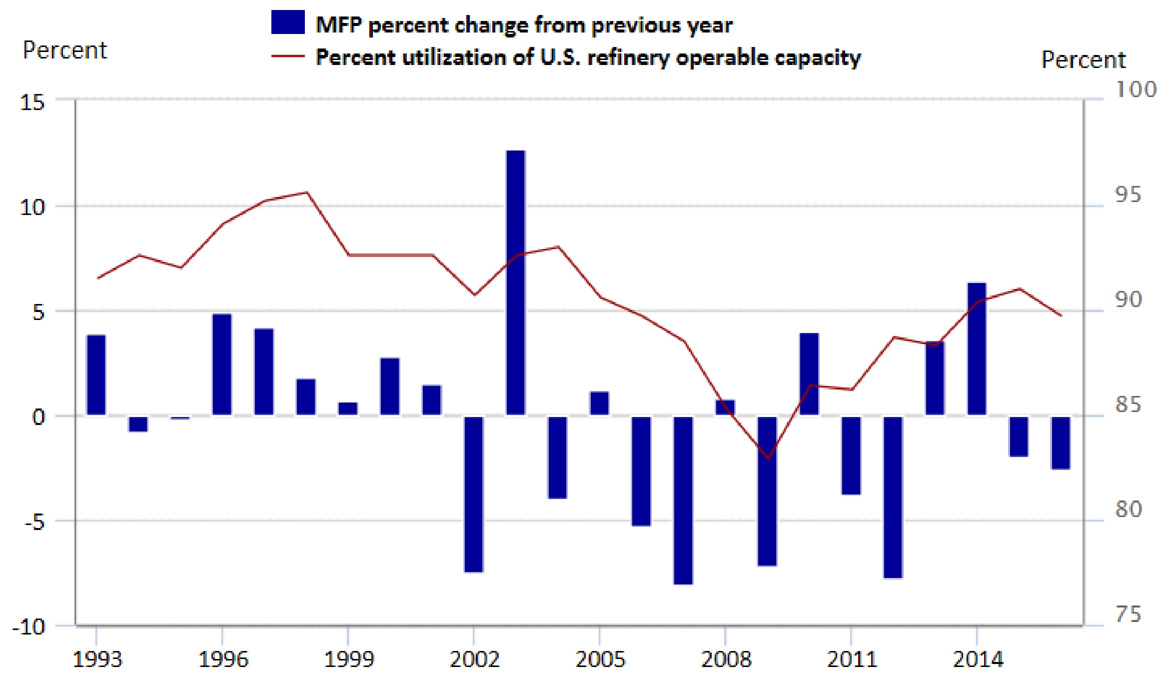
Table 1. Industry contributions to manufacturing multifactor productivity (MFP), selected industries, 1992–2004 and 2004–16

Industry	1992–2004			2004–16		
	Average annual change in MFP (percent)	Average share of manufacturing output (percent)	Contribution to manufacturing MFP growth	Average annual change in MFP (percent)	Average share of manufacturing output (percent)	Contribution to manufacturing MFP growth
Semiconductors and other electronic components	17.8	4.3	0.71	1.3	2.6	0.06
Computer and peripheral equipment	20.2	2.9	0.55	6.1	1.1	0.10
Motor vehicle parts	1.9	6.5	0.12	0.3	5.1	0.02
Petroleum and coal products	1.6	6.8	0.10	-1.9	15.8	-0.29
Communications equipment	3.5	2.5	0.08	0.7	1.2	0.01
Pharmaceuticals and medicine	-1.3	3.4	-0.04	-3.2	4.4	-0.14
Agriculture, construction, and mining machinery	0.8	1.8	0.01	-1.5	2.3	-0.03

Sources: U.S. Bureau of Labor Statistics and authors' calculations.

The Energy Information Administration of the U.S. Department of Energy produces data on the capacity utilization of petroleum refineries. As does MFP, this measure indicates how efficiently establishments operate. Figure 4 shows both of these measures.

Figure 4. Petroleum and coal products manufacturing multifactor productivity (MFP) and petroleum refinery capacity utilization rate, 1993–2016



Click legend items to change data display. Hover over chart to view data.
Sources: U.S. Bureau of Labor Statistics and U.S. Energy Information Agency.

Substantial declines in MFP occurred in most years from 2002 to 2012. This period began shortly before the productivity slowdown and accounts for the negative contributions seen in table 1. Meanwhile, petroleum refinery capacity utilization declined from a peak of 96 percent in 1998 to a trough of 83 percent in 2009.

The efficiency of petroleum refinery operations can be affected by changes in the price and availability of different grades of crude oil. Crude oil is differentiated by density (heavy versus light) and sulfur content (referred to as “sweet” or “sour”). Different grades of crude oil require different methods of refining and transportation. As relative prices and supplies of different types of crude oil change (which can happen frequently), refineries adapt to the new situation.[19] For example, rising domestic production of light sweet crude has led to refineries developing new strategies to acquire and process this relatively cheaper type of oil.[20] The development of new petroleum acquisition and production systems can decrease the overall efficiency of the U.S. refinery system, as some operations must devote significant resources in order to adapt.

The industry has also been subject to severe external shocks, such as Hurricanes Katrina and Rita, which hit the Gulf of Mexico region in 2005. At the time, this region accounted for 47 percent of U.S. oil refining capacity. These storms shut down refineries for several months, and two large refineries in Louisiana did not reopen until spring 2006.[21]

Pharmaceutical and medicine manufacturing

As seen in table 1, the second-largest influence on manufacturing MFP in the 2004–16 period was the decline in the pharmaceutical and medicine manufacturing industry. MFP fell by 3.2 percent as output dropped by an average annual rate of 2.2 percent and combined inputs rose by 1.0 percent.

As shown in table 2, pharmaceuticals and medicines recorded gains in MFP in only 2 out of the 12 years of this period. The years 2010 and 2012 had particularly large declines in MFP, driven by large drops in the output index.

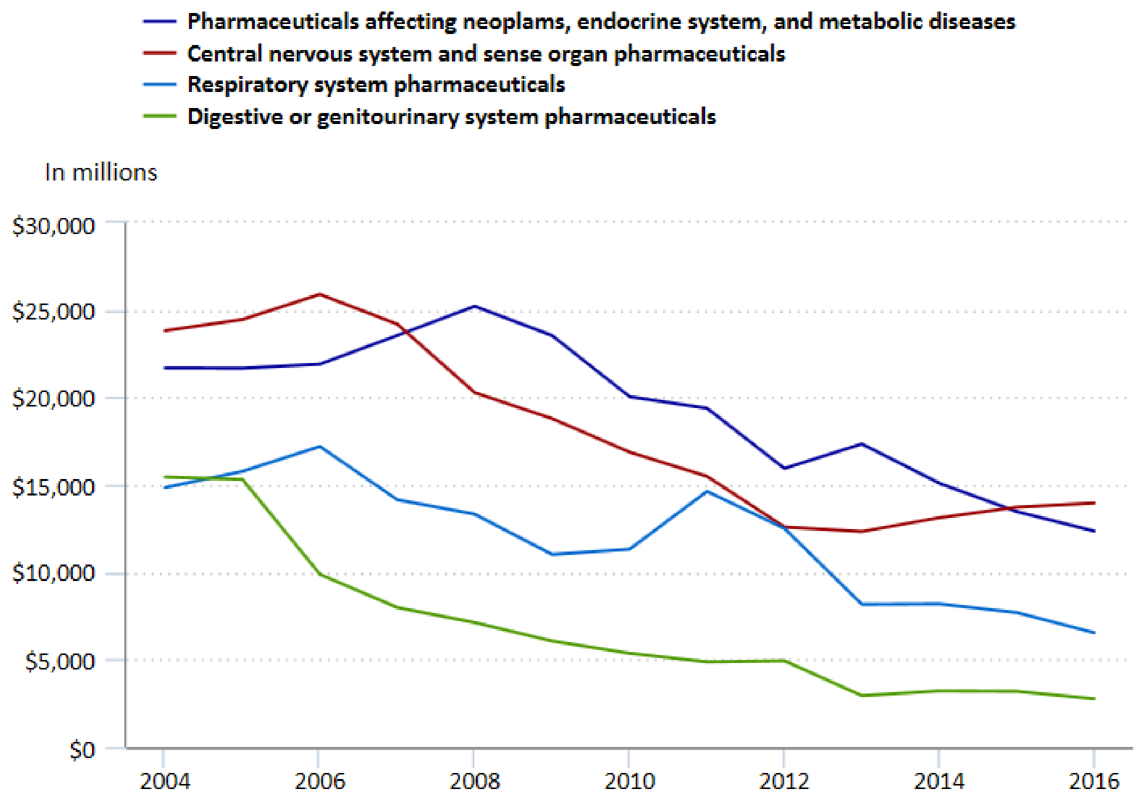
Table 2. Over-the-year percent change in pharmaceuticals and medicines manufacturing multifactor productivity (MFP) and related indexes, 2004–16

Period	MFP	Output	Combined inputs
2004–16	-3.2	-2.2	1.0
2004–05	1.4	1.8	0.3
2005–06	-4.8	0.3	5.4
2006–07	0.0	-0.9	-0.9
2007–08	-1.9	-5.0	-3.1
2008-09	-2.0	-7.4	-5.5
2009–10	-8.8	-5.9	3.2
2010–11	0.3	0.2	-0.1
2011–12	-11.1	-8.9	2.4
2012–13	-1.1	-0.7	0.4
2013–14	-2.0	2.2	4.3
2014–15	-2.6	2.1	4.8
2015–16	-4.8	-3.4	1.4

Source: U.S. Bureau of Labor Statistics.

Given the general increases in medical spending, why would the output index of pharmaceuticals and medicines have gone down? To answer that question, we examine constant dollar production of various classes of medicines and pharmaceuticals. There were four classes of pharmaceuticals, each with value of production worth over $14 billion in 2004 and together comprising more than half of total production for the industry. Adjusted for inflation, value of production of each of these classes of pharmaceuticals fell substantially during the productivity slowdown. (See figure 5.)

Figure 5. Value of production for large classes of pharmaceutical products, in constant dollars, 2004–16



Click legend items to change data display. Hover over chart to view data.
Sources: U.S. Bureau of Labor Statistics and authors' calculations.

This downward trend in production is likely due to a combination of factors. First, the healthcare sector was not immune to the downturn of the U.S. Great Recession. Both the number of discretionary procedures (such as cosmetic surgery) and the number of prescriptions declined.[22]

Second, the industry saw a large decline in output in 2012. Table 2 shows that after the recession ended in 2010, there was a small uptick in pharmaceutical and medicine manufacturing output in 2011. However, in 2012 the industry experienced its largest decrease in output—8.9 percent—which was likely the result of the so-called “patent cliff.” In 2011 and 2012, the patents for many important and profitable drugs expired. Notable examples include Lipitor, whose patent expired in 2011, and Plavix and Singulair, whose patents expired in 2012. This resulted in the introduction of lower priced generic versions of these pharmaceuticals.[23]

This shift toward increasing consumption of generic drugs exacerbated the trend of offshoring pharmaceutical production. Over the last decade, drug manufacturers have moved production of many products to developing nations to access lower costs and a more lax regulatory environment. Overseas production is particularly prevalent among generic pharmaceuticals. According to the *New York Times*, “Of the 1,154 pharmaceutical plants mentioned in generic drug applications to the Food and Drug Administration in 2007, only 13 percent were in the United States, 43 percent in China, and 39 percent in India.”[24] The Federal Drug Administration (FDA) reported that imported drugs doubled between 2004 and 2009.[25] In 2017, the FDA reported that “Approximately 80 percent of active pharmaceutical ingredients manufacturers are located outside of the U.S." The FDA also noted that, on the basis of dollar values, about 55 percent of biologics (medications derived from animal products or other biological sources) are imported.[26]

Factor share analysis

As described previously in equation 1, MFP relates the growth rate of industry output to the growth rates of measurable inputs. Equation 2 shows how capital, labor, energy, materials, and purchased services are combined using cost-share weights.

The cost-share weights represent the proportion of total resources industries put into each type of input per year. The greater an input's cost-share weight, the more importance the input has in the production process. In theory, firms adjust the relative usage of these inputs in order to maximize productivity. Evidence shows that the interaction between the factors of production may itself affect productivity. To explore this concept, we examine the shift in factor shares over the past two decades.

Table 3 displays the shares of factors of production during the acceleration and slowdown periods for the manufacturing sector. From the 1992–2004 period to the 2004–16 period, labor's share of total costs declined by 7 percentage points, with materials and capital gaining 5 and 3 percentage points, respectively.[27]

Table 3. Average value share weights for the manufacturing sector, in percent, 1992–2004 and 2004–16

Average input	1992–2004	2004–16
Capital share	21	24
Labor share	32	25
Energy share	3	2
Materials share	28	33
Purchased-services share	17	16

Sources: U.S. Bureau of Labor Statistics and authors' calculations.

A shift in production from labor to materials (or purchased services) is known as "outsourcing." When firms outsource, they purchase more materials and services that used to be produced in-house.[28] Instead of building their own materials, they buy them from other firms in other industries. Instead of doing their own engineering, advertising, legal services, etc., they hire outside firms to do that work on their behalf.

The trend in factor shares was not driven by only a few large industries. Rather, most manufacturing industries have exhibited similar patterns. Of the 86 4-digit NAICS manufacturing industries, 51 saw both an increase in average materials share and a decline in average labor share from the 1992–2004 period to the 2004–16 period. And only 14 industries reported growth in labor's average share of production during the same period.

Changes in factor shares appear to be related to changes in MFP growth. The average annual rate of MFP growth was lower from 2004 to 2016 than during the 1992–2004 period in 62 out of the 86 manufacturing industries. Of these 62 industries, 42 had increases in the average factor-share weight of materials, 53 had decreases in the average factor-share weight of labor, and 39 recorded both these changes.

Recent research indicates that the relationship between factor shares and MFP growth may be causal. Simon Baptist and Cameron Hepburn found a negative relationship between intermediate purchases intensity and MFP growth across U.S. manufacturing subsectors.[29] Moreover, they found a positive relationship between labor intensity and MFP. Baptist and Hepburn suggest that labor input may produce a positive spillover effect toward MFP growth, which is smaller in materials-intensive industries.

In their analysis of manufacturing sector productivity, Susan Helper, Timothy Krueger, and Howard Wial identified outsourcing, specifically overseas, as a causal factor in the slowdown.[30] They argue that the separation of R&D and production has led to a loss of American innovative capacity. The researchers identify battery manufacturing as an example of an industry in which offshoring of manufacturing processes has led to East Asian countries overtaking the United States in the field. Similarly, they argue that the offshoring of semiconductor manufacturing has inhibited innovation and productivity in that industry as well as in the related industry of solar energy materials manufacturing.

Multifactor productivity growth often is thought to result from innovation. If more of the production process happens without the input of workers (i.e., labor share decreases), this may lead to a less conducive atmosphere for innovations. While the practice of outsourcing may have short-term cost advantages, in the longer term its prevalence may have a depressing impact on productivity growth.

Conclusion

The manufacturing sector experienced a period of high MFP growth that lasted from the mid-1990s until the mid-2000s, when it began to slow. This productivity slowdown has attracted the attention of economists, many of whom have pointed to the culmination of the late 1990s IT boom as the primary cause. Our contribution analysis shows that two IT-related industries, computer and peripheral equipment manufacturing and semiconductors and other electronic component manufacturing, accounted for about 60 percent of MFP growth for the manufacturing sector during the high-growth period. During the MFP slowdown, productivity growth in these two industries declined to a level more typical of the average manufacturing industry. Two other industries—petroleum and coal products manufacturing and pharmaceutical and medicine manufacturing—have exerted the greatest influence on total manufacturing MFP growth by their large declines in productivity.

There are reasons for both optimism and pessimism concerning the future of MFP growth in manufacturing. Both of the aforementioned industries that have acted as drags on productivity have experienced external shocks that could be considered unusual. The effects of hurricanes and the “patent cliff” dramatically decreased productivity in the petroleum refining and pharmaceuticals industries, respectively. If such events are rare, productivity in these two industries may improve in the future, which would serve to boost the sector’s productivity performance because of these industries’ relative importance.

On the other hand, we have also encountered evidence of systemic trends that may be harmful to productivity growth. While by no means conclusive, this article adds to the growing body of evidence that (manufacturing) industries that shift their production process toward greater use of intermediate purchases may be doing so at the expense of innovation. Consequently, productivity gains may be depressed. This trend is worth watching closely.

SUGGESTED CITATION

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NOTES

1 Whereas labor productivity relates the change in output to the change in one input—labor—multifactor productivity relates the change in output to the change in a combination of inputs. Although the amount and complexity of the data required to calculate multifactor productivity are much greater than those needed to calculate labor productivity, multifactor productivity measures yield valuable insights into efficiency beyond those derived from labor productivity. Multifactor productivity reflects many of the same influences as the labor productivity measure, but by explicitly accounting for inputs of capital and intermediate purchases, the multifactor productivity residual reflects only changes in overall efficiency that are due to other, unmeasured influences.

2 Dale W. Jorgenson, "Information technology and the U.S. economy," *American Economic Review,* vol. 91, no. 1, March 2001, pp. 1–32.

3 See David Byrne, Stephen Oliner, and Daniel Sichel, "Is the information technology revolution over?" *International Productivity Monitor*, no. 25, Spring 2013, pp. 20–36. The authors suggest that semiconductor technology is continuing to advance rapidly and that the IT revolution is not over. Also see John Fernald, "Productivity and potential output before, during, and after the great recession," in Jonathan A. Parker and Michael Woodford, ed., *NBER Macroeconomics Annual 2014*, vol. 29 (Chicago: University of Chicago Press, July 2015).

4 Robert J. Gordon, "U.S. productivity growth: the slowdown has returned after a temporary revival," *International Productivity Monitor*, no. 25, Spring 2013, pp. 13–19, http://csls.ca/ipm/25/IPM-25-Gordon.pdf.

5 Matthew Dey, Susan N. Houseman, and Anne E. Polivka, "Manufacturers' outsourcing to staffing services," *ILR Review,* vol. 65, no. 3, 2012, pp. 533–59.

6 Kevin L. Kliesen and John A. Tatom, "U.S. manufacturing and the importance of international trade: it's not what you think," *Federal Reserve Bank of St. Louis Review,* vol. 95, no. 1, January–February 2013, pp. 27–49, https://files.stlouisfed.org/files/htdocs/publications/review/13/01/Kliesen.pdf.

7 Roberto Cardarelli and Lusine Lusinyan, "U.S. total factor productivity slowdown: evidence from the U.S. states," IMF Working Paper, May 2015, https://www.imf.org/external/pubs/ft/wp/2015/wp15116.pdf.

8 Ryan A. Decker, John Haltiwanger, Ron S. Jarmin, and Javier Miranda, "Declining dynamism, allocative efficiency, and the productivity slowdown," *American Economic Review*, vol. 107, no. 5, May 2017, pp. 322–326.

9 Following the precedent of Gordon in "Productivity growth" and Fernald in "Productivity and potential output," we divide this period into a productivity speedup (1992 through 2004) and a productivity slowdown (2005 through 2015). Productivity analysis in this article begins with the change from 1992 to 1993. Those years correspond to a period of increased MFP growth specifically in the manufacturing sector, although the speedup for the economy as a whole is generally recognized as having begun a few years later.

10 In this article, 4-digit NAICS industry groups are referred to as industries, for the sake of brevity.

11 In comparison, value of production for the computers and peripheral equipment manufacturing and semiconductors and other electronic component manufacturing industries decreased from about 5 percent of total manufacturing output in 1993 to 2 percent in 2016.

12 The index of combined inputs is a Törnqvist aggregation of separate quantity indexes of capital, labor, and intermediate purchases (including fuels, electricity, materials, and purchased services). The annual growth rates of the various inputs are aggregated using their relative cost shares as weights. The labor weight is based on labor compensation, including fringe benefits. The weight for intermediate purchases is based on the total cost of materials, fuels, electricity, and purchased services. The capital weight is based on total capital cost, which is calculated as the value of sectoral production minus the costs of labor compensation and intermediate purchases.

13 Although the National Bureau of Economic Research reports March 2001 as the peak of the business cycle, manufacturing output on an annual basis peaked in 2000. For business cycle peaks, see http://www.nber.org/cycles.html.

14 Regarding time periods referenced in this article: The productivity speedup is referenced as 1992–2004. The speedup during this period includes the annual change in multifactor productivity each year from 1993 through 2004. In other words, the change in MFP that occurred from 1992 to 1993 is included, but the change from 1991 to 1992 is not included. This is because the first year referenced (in this case 1992) is the base from which the subsequent year's change in MFP is measured. The same is true for the productivity slowdown period, 2004–16.

15 This method was developed by Evsey Domar, "On the measurement of technological change," *Economic Journal*, vol. 71, no. 284, December 1961.

16 In other words, how much an industry contributes to total manufacturing MFP growth is determined by its MFP growth rate and its share of output relative to total manufacturing output. For example, in 1992–2004, the computers and peripheral equipment industry comprised about 2.9 percent of manufacturing output, and industry MFP grew at an average annual rate of 20.2 percent. MFP for the manufacturing sector grew at an average annual rate of about 2.0 percent. Multiplying the industry's productivity growth rate by its share of manufacturing output reveals that 0.55 percentage point of the 2.0-percent sector growth was attributable to computers.

17 For example, see table 7 in Jorgenson, "Information technology."

18 Combined value of production for these two industries hit a peak in 2000 and then declined 60 percent by 2015. This decline appears to be largely the result of increased offshoring of production. For evidence of a slowdown in productivity growth for microprocessors, see Unni Pillai, "A model of technological progress in the microprocessor industry," *Journal of Industrial Economics*, vol. LXI, no. 4, December 2013.

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27 Michael D. Giandrea and Shawn A. Sprague, "Estimating the U.S. labor share," *Monthly Labor Review*, February 2017, https://doi.org/10.21916/mlr.2017.7. The authors discuss changes in the U.S. labor share over time, including changes in the manufacturing sector.

28 The term "materials" refers to raw materials as well as manufactured parts used in the process of goods manufacturing.

29 See Simon Baptist and Cameron Hepburn, “Intermediate inputs and economic productivity,” *Philosophical Transactions of the Royal Society*, January 28, 2013, http://dx.doi.org/10.1098/rsta.2011.0565. Baptist and Hepburn’s analysis “indicates that lower intermediate input intensity is positively associated with higher TFP [total factor productivity], both across the US subsectors and across the South Korean firms. In other words, firms and industries that employ modes of production that use more labour and fewer intermediate inputs appear to have overall higher TFP.”

30 Susan Helper, Timothy Krueger, and Howard Wial, “Why does manufacturing matter? Which manufacturing matters? A policy framework,” Brookings Institute, February 2012, https://www.brookings.edu/wp-content/uploads/2016/06/0222_manufacturing_helper_krueger_wial.pdf.

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