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A NEW INTERPRETATION OF PRODUCTIVITY GROWTH DYNAMICS IN THE PRE-PANDEMIC AND PANDEMIC ERA U.S. ECONOMY, 1950-2022

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ABSTRACT

The dismal decade of 2010-19 recorded the slowest productivity growth of any decade in U.S. history, only 1.1 percent per year in the business sector. Yet the pandemic appears to have created a resurgence in productivity growth with a 4.1 percent rate achieved in the four quarters of 2020. This paper provides a unified framework that explains productivity growth in both the pre-pandemic and pandemic-era U.S. economy. The key insight is that in their panicked reaction to the collapse of output in the 2008-09 recession, business firms overreacted with “excess layoffs,” adjusting hours to the output decline with a far higher elasticity than normal. Our regression analysis, which allows post-recession rehiring that gradually unwinds the excess layoffs, explains why productivity growth was countercyclical in 2009 and why it was so slow in 2010-16 as rehiring boosted hours growth. Post-sample simulations explain why productivity growth was so high in 2020 and why it fell to only 0.6 percent in the five quarters of 2021-22. The paper includes implications for the future long-term evolution of productivity growth in the business sector and total economy. A new data file on quarterly productivity levels and changes for 17 industries provides new perspectives for 2006-22 and particularly for the nine pandemic quarters of 2020-22. Positive pandemic-era productivity growth can be entirely explained by a surge in the performance of work-from-home service industries, while goods industries soared and then slumped, while contact services recorded strongly negative productivity growth throughout 2020-22.

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1. Introduction

The decade of the "teens" in the American economy was marked by the slowest productivity growth of the postwar era. For the business sector growth in output per hour over the ten years between 2010 and 2019 was only 1.1 percent per year, well under half of the average of 2.5 percent for the postwar era from 1950 to 2009.[1] The 2010-19 rate fell even further short of the 3.2 percent rate registered during the first near-quarter-century of the postwar era (1950-72) and of the 3.3 percent achieved during the "dot.com" ICT-based productivity growth revival of 1996-2004.[2] The slowdown of the teens was even more pronounced in the manufacturing sector, where productivity growth in 2010-19 was actually a negative -0.3 percent as compared to 2.9 percent for 1950-2009.

This slow productivity growth between 2010 and 2019 accounts for much of the stagnation in the growth of real wages over that decade, and has frustrated analysts who have struggled to explain why real GDP growth was so much slower than in prior economic expansions. For the total economy, including government, farms, households, and nonprofit institutions, the ten-year average productivity growth rate for 2010-19 was only 0.8 percent per year.[3] If this slow rate were to continue, it would require a further downward revision in the official estimate of the future growth of potential output issued by the Congressional Budget Office (CBO), which assumes future output growth over the 2020-30 decade of 1.8 percent, consisting of 1.4 percent total-economy productivity growth and 0.4 percent growth in labor hours.[4]

Is the long-awaited revival of productivity growth at hand? Many observers have noticed that hours of work declined substantially more than output in the recession of 2020 and point to the 4.1 percent business-sector productivity growth rate achieved in the four quarters of 2020. This apparent productivity growth revival has been interpreted as caused by automation, artificial intelligence, and a massive investment by households in the equipment and software needed to conduct work from home. The strong performance of productivity growth during the 2020 recession seems to be especially impressive in light of evidence for earlier periods in the postwar era showing that productivity growth is procyclical.

This paper provides a new interpretation of productivity growth dynamics. Unlike the frequent assumption that cyclical or quarter-to-quarter changes in productivity reflect

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[1] In this paper all productivity and TFP growth rates for the business sector are taken from John Fernald's database, which differs from the published BLS data by defining the numerator of output per hour as the geometric average of business sector gross domestic product (GDP) and gross domestic income (GDI). See http://www.johnfernald.net/TFP.

[2] These growth rates are calculated as averages of one-quarter annualized growth rates, e.g., for 2010-19 the average between the one-quarter annualized growth rates of 2010:Q1 through 2019:Q4.

[3] The 0.77 rate for 2010-19 for the total economy compares to a rate of 2.09 percent for 1889-2009 (data file from Gordon 2016, Chapter 16).

[4] The CBO forecast is dated January 2020 and is taken from p. 46 of https://www.cbo.gov/system/files/2020-01/56020-CBO-Outlook.pdf.

autonomous "productivity shocks," instead we suggest that the shocks originate in components of GDP including consumption, fixed investment, government spending, net exports, and particularly inventory investment. Hours of work adjust gradually to these short-run output changes, and productivity growth is determined as a simple residual: output growth minus hours growth. Because hours adjust only partially in the current quarter and adjust further in subsequent quarters, productivity growth is characterized by a sharp positive response to output changes followed by subsequent negative changes. If the total of current and lagged responses is significantly positive, then productivity growth is said to be procyclical.

The literature on productivity dynamics has contrasted a consistent and significant procyclical pattern for productivity in the postwar era up to 1985 with a disappearance of procyclicality after 1985. We confirm the pre-1985 procyclical response with a highly significant productivity response to output changes of 0.28, similar to the one-third response in the original version of Okun's Law. However we take a new look at the post-1985 evidence. Our point of departure is to focus on the recession of 2008-09, in which output collapsed suddenly in the fall of 2008 following the Lehman failure. In our interpretation business firms panicked and "threw all lifeboats overboard," adjusting hours with a much higher elasticity to output changes than in business expansions or prior recessions. To distinguish this episode from earlier recessions, we conduct our regression analysis for three sample periods: 1950-85, 1986-2006, and 2007-2019.

The phenomenon of "excess layoffs" is incorporated into our regression analysis in which the change in hours depends on two sets of response coefficients to changes in output. The first set of current and lagged coefficients is applied to all output changes; the second set only to output changes in recessions. The sum of coefficients for the recession response is large and highly significant; it implies that the extra cumulative decline in hours in the six-quarter 2008-09 recession was -10 percent as compared to the normal response of hours. But that reduction in hours was not permanent; we allow post-recession rehiring in what we call the "recovery effect". This is defined to cancel out completely the recession impact on hours over a recovery period that is allowed to persist over a number of years. While we estimate productivity growth equations that are the "dual" of our hours equations, they are unnecessary since the predicted growth of productivity is simply the actual growth of output minus the predicted growth of hours.

The combined recession/recovery treatment in our hours regression opens up a new interpretation both of the 2007-19 pre-pandemic economy and also the 2020-22 pandemic-era economy. It explains why productivity growth was strongly positive in 2009 as the downward hours adjustment overshot the output decline and as that hours decline continued with a lag after output began to recover. Since the recession effect explains the countercyclical movement of productivity change, it allows the normal coefficients applied to all years to reveal strongly procyclical productivity growth behavior in 2010-19. This contradicts the previous literature that emphasized the disappearance of productivity's procyclicality after 1985.

The new treatment of the 2008-09 recession and subsequent recovery not only improves our understanding of productivity behavior during 2007-19 but can also be applied to the pandemic era of 2020-22. A post-sample simulation of the 2007-19 hours equation can explain the 2020-22 pandemic-era behavior of hours and productivity almost exactly. The rapid growth of productivity in 2020 is explained by the same pattern of excess layoffs as in 2008-09, but with a faster adjustment due to the shorter duration of the 2020 recession. The marked slowdown of productivity growth from 4.0 percent in 2020 to 0.6 percent in the five quarters of 2021-22 is explained by a repeat of the post-recession rehiring recovery that occurred after 2009.

Which industries contributed to the pattern of aggregate productivity growth observed in the nine quarters of 2020:Q1 to 2022:Q1? We develop a new quarterly data file of output, hours, and productivity for 17 industries. Then we use the data to show how severely the quarterly pattern of aggregate productivity growth is distorted in 2020 by the change of the industry mix in which low-productivity industries suffered disproportionate losses of output. To avoid this measurement issue, we develop a separate aggregate productivity index for the 17 industries that holds constant 2019 industry shares of total output.

The 2020-22 average productivity growth rates of the 17 industries are highly heterogeneous, ranging from +10 percent to -9 percent at an annual rate. To provide insight, we divide the 17 industries into three groups: goods, work-from-home (WFH) services, and contact services. We show that WFH industries account for more than all of the positive productivity growth during 2020-22 and discuss reasons why WFH activities may have been so productive.

The paper discusses implications for the long-run future growth trend of productivity in both the business sector and total economy. It ends by pointing to the current paradox in mid-2022 of negative real GDP growth for the first half of the year combined with robust positive employment growth. That combination of continued growth in hours of work combined with negative productivity growth is just what is predicted by the post-sample simulations of the recession/recovery regression analysis.

Section 2 conducts a brief review of the relevant literature. Sections 3 documents basic trends in post-war productivity growth, while Section 4 zooms in on pre-pandemic productivity trends. Section 5 our baseline regression analysis of the procyclicality of productivity. We use this approach to conduct post-sample simulations that captures the brief productivity “revival” of 2017-2019 in Section 6. Section 7 breaks down the role of changing industry weights in the pandemic productivity surge, Section 8 uses our simulation analysis to estimate this surge, Section 9 concludes.

2. Review of the Literature on the Cyclicality of Labor Productivity

A substantial literature has documented the post-1980s decline or disappearance of a procyclical productivity response. Fernald and Wang (2016) argue that labor productivity turned countercyclical and total factor productivity (TFP) became more acyclical after the mid-

1980s using a correlation methodology. Earlier support for this finding was provided by Stiroh (2009) in an aggregate and industry-level investigation of decreased output volatility. Gali and Gambetti (2010) utilized a VAR framework to show a weakened response of productivity and heightened response of hours to non-technological shocks. Barnichon (2010) used a neo-Keynesian search and matching model to attribute productivity's weakening cyclicality to increased flexibility in labor markets beginning in the 1990s. Gordon (2010) documented the disappearance of the procyclical productivity response in the context of an increased cyclical response of hours and employment, which he attributed to increased managerial emphasis on maximizing shareholder value.

Papers supporting the procyclical productivity response tend to have been written earlier than those that find no effect, but several of them were written after the year 2000, by which time 15 years of evidence had accumulated covering years during which the procyclical effect appears to have vanished. These include Basu and Fernald (2001) who titled their paper "Why Is Productivity Procyclical?" as well as a paper in the real business cycle (RBC) tradition by Wen (2004), and a plant-level data study conducted by Baily *et al.* (2001).

Most studies of the cyclicality of productivity changes focus on the relationship between productivity and output. At least one study concerns the relationship between productivity and employment. With data running through 2006, Hagedorn and Manovskii (2011) reported that the procyclicality of productivity, as measured by its correlation with fluctuations in employment levels, was dependent on which employment series was utilized. At the time of publication, labor productivity was more highly correlated with Current Population Survey (CPS) measures of employment rather than Current Employment Statistics (CES). A weak relationship between productivity and employment using the CES measure seemingly contradicted tight correlations as would be predicted by the Mortensen-Pissarides (1994) search and matching model. However, this research does not discuss any dramatic shifts of productivity across decades, nor its erratic behavior during the Great Recession.

Most recent literature supports the reduction or disappearance since the 1980s of the procyclical response of productivity. Daly *et al.* (2013) use both a "labor-market" model to divide hours growth into hours-per-employee and employment, as well as a "capital" model that decomposes productivity into total factor productivity, capital deepening, labor quality, and utilization. While their "capital" model finds that most of the newfound acyclicality of productivity is driven by a decrease in the role of procyclical utilization relative to countercyclical capital deepening and labor quality, their "labor market" model shows that most of the procyclical shift results from an increased response of the employment rate to the business cycle. Galí and Van Rens (2021) propose a model of the labor market where a reduction in hiring frictions increases the volatility of employment, thereby decreasing the procyclicality of labor productivity. Biddle (2014) suggests that a fall in the cost to firms of adjusting employment means that labor-hoarding, once thought to be one of the potential drivers of procyclical productivity, has become less frequently practiced. Wang (2014) uses industry level data to show that much of the increased acyclicality of productivity can be attributed to the sectoral shift away from commodities production towards the more acyclical services sector as well as an increased sensitivity of TFP to persistent technological shocks that are negatively correlated with inputs.

3. The Growth Rates of Labor Productivity and TFP by Major Sector

We begin with the identity in equation (1), which states that total output *(Y)* is divided between output per hour *(Y/H)* and hours of work. *(H)*. We adopt the convention of using lower case levels for growth rates.

$$Y \equiv \frac{Y}{H} \cdot H \text{ and } y \equiv (y - h) + h \tag{1}$$

Table 1 introduces the behavior of productivity *(Y/H)* growth from 1950 to 2022. The rows divide this long span of seven decades into separate intervals that mark off different eras of productivity growth. First comes the rapid growth era of 1950:Q1-1972:Q4, followed by the slowdown interval of 1973:Q1-1995:Q4 that received so much attention during the 1970s and 1980s.[5] Next comes the return of rapid growth during the "dot.com" era between 1996:Q1 and 2004:Q4, a revival usually attributed to the effects of high investment in the information technology revolution and the impact on TFP of personal computers, the internet, and search engines (see the interpretations by Jorgenson and Stiroh (2000), Oliner and Sichel (2000), and Jorgenson *et al.* (2008)).

Table 1. Annual Growth Rates of Labor Productivity and TFP by Sector, Selected Intervals, 1950:Q1-2022:Q1

	Labor Productivity				TFP*
Time Period	**Total Economy**	**Business**	**Non-Business**	**Manufacturing**	**Business**
1950:Q1-1972:Q4	2.85	3.23	1.71	2.63	2.21
1973:Q1-1995:Q4	1.28	1.52	0.53	2.59	0.52
1996:Q1-2004:Q4	2.61	3.31	0.51	4.67	1.81
2005:Q1-2009:Q4	1.79	2.04	1.03	2.57	0.09
2010:Q1-2016:Q4	0.64	0.88	-0.09	0.10	0.54
2017:Q1-2019:Q4	1.06	1.47	-0.18	-1.11	0.76
2020:Q1-2022:Q1	1.87	2.11	1.16	1.88	1.27

Total economy output data calculated as geometric average of real GDP and GDI from BEA NIPA Table 1.17.6; unpublished hours data from BLS. Business sector productivity and TFP data from John Fernald of the San Francisco Federal Reserve (http://www.johnfernald.net/TFP), where output data are geometric averages of income and production sides of the business sector. Manufacturing data from BLS Labor Productivity and Costs (https://www.bls.gov/lpc/). Non-business sector calculated based on a weight of 0.25 in the total economy.

[5] The literature on the productivity growth slowdown of the 1970s and 1980s often pointed to the lower skills and experience of teenagers and women as an important cause of the slowdown (see Baily (1981), Perry *et al.* (1977), Wachter and Perloff (1980) and a more recent article by Vandenbroucke (2017)).

The subsequent post-2004 interval is divided into four sub-periods. The first of these, 2005:Q1-2009:Q4, includes the last stages of the 2001-07 economic expansion, the 2007-09 recession, and the first two recovery quarters after the end of the recession. We treat 2010:Q1-2016:Q4 as a distinct sub-period marked by unusually slow productivity growth and then break out the 12 quarters of 2017-19 that show a modest but noticeable revival. The last line of Table 1 includes the nine pandemic quarters 2020:Q1-2022:Q1, with a further acceleration beyond 2017-19 in every column of the table.

The first two columns of Table 1 provide the annual growth rates of labor productivity for both the total economy and the business sector, where total output is measured by the geometric average of GDP and gross domestic income (GDI), following the analysis of Nalewaik (2011), who showed that the average of GDP and GDI is more accurate than either one examined separately. This distinction turns out to be important for pandemic-era growth in 2020-22, when GDI grew considerably faster than GDP, implying that productivity growth rates based on the average of GDP and GDI, as in Table 1, outpaced by a substantial margin the BLS-published productivity growth rates calculated with GDP as the sole measure of output. Thus, the Table 1 business growth rate for 2020-22 of 2.11 percent contrasts with the BLS-published growth rate that is a much slower 1.15 percent. There is no published BLS equivalent of our data for the total economy in the first column, as our numbers are based on the average of aggregate GDP and GDI divided by an unpublished BLS series on hours in the total economy.

As expected, the growth rate for the business sector in the second column is always more rapid than in the total economy, due to the relatively slow measured productivity growth for those portions of the economy excluded from the business sector, notably the government and nonprofit sectors (shown separately in the third column). The shortfall of productivity growth in the total economy compared to the business sector was similar in 2010-16 (0.24 percent) and in 2017-19 (0.41 percent). This difference was a much larger 0.70 percent during the dot.com era of 1996-2004. Thus, the slowdown from 1996-2004 to 2010-19 was substantially greater for the business sector than for the total economy. Recall that it is productivity growth in the total economy, not just the business sector, that matters for the growth of potential output and real income per capita, i.e., the standard of living.

The contrast between the total economy and business sector was reversed in 2020-22. The revival from 2017-19 to 2020-22 was an impressive 0.81 percentage points in the total economy compared to 0.64 in the business sector. As a result, productivity growth in the non-business sector jumped from -0.18 to 1.16 percent, and this is the fastest productivity growth registered by the non-business sector since 1950-72. Why? We will return to this puzzle in a subsequent section which examines the widely differing pandemic-era productivity experiences of particular industries within the business sector.

Shown in the fourth column of Table 1 are the growth rates for the manufacturing sector, which is notable because unlike the total economy or the business sector, it had virtually no slowdown from 1950-72 to 1973-95. During that interval of more than two decades, healthy productivity growth in the manufacturing sector contrasted with a disappointing record for the rest of the economy. The manufacturing sector also enjoyed a robust revival in excess of two percentage points during the dot.com interval. But then the tables were turned as the manufacturing sector suffered a stunning 4.93 percentage point growth slowdown from 1996-2004 to 2010-19, much larger than the slowdown in either the total economy or the business sector. The unusually poor relative performance of the manufacturing sector after 2009 has not yet received much attention in the productivity growth literature.[6] The 2020-22 bounce-back of manufacturing productivity growth is much greater than for the total economy or the business sector.

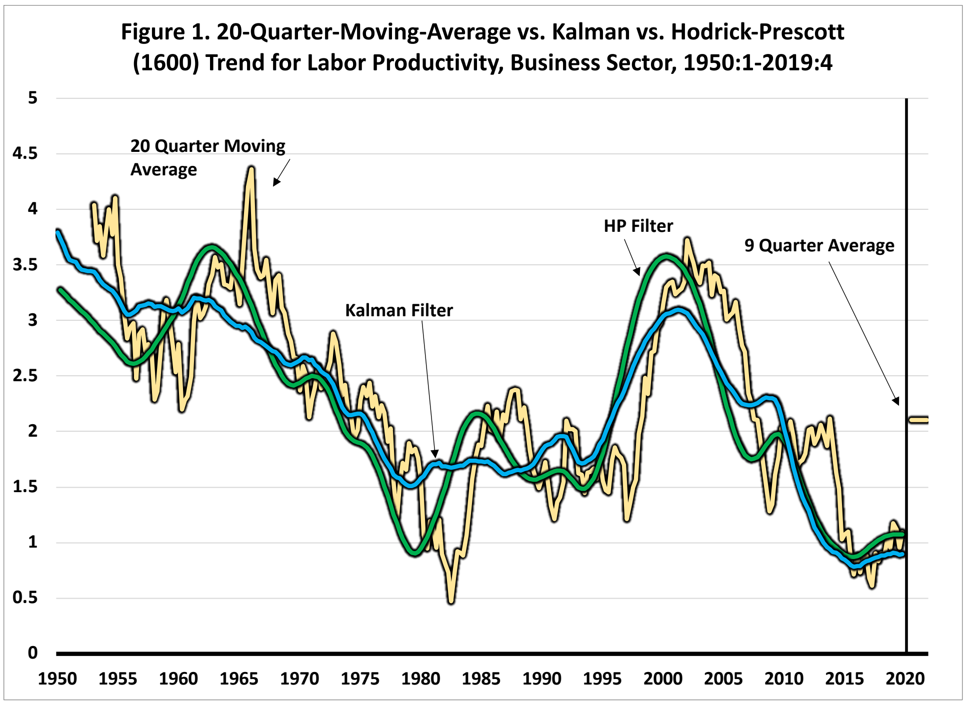
Further insight into the performance of the business sector is provided in the fifth column, which lists growth in total factor productivity (TFP). The growth in TFP is usually smaller than that of labor productivity, differing by the normally positive contribution of capital deepening, with a minor additional contribution from improving labor quality. TFP growth was less than labor productivity growth in the business sector by 1.02 points in 1950-72 and a similar 1.00 points in 1972-95 but by a larger 1.50 points in 1996-2004, reflecting the marked rise in the growth rate of investment (i.e., capital deepening) in the dot.com era. Somewhat surprisingly, the TFP shortfall rose to an even larger 1.95 percent in 2005-2009 before dropping to 0.34 percent in 2010-16, 0.71 in 2017-19, and a similar 0.84 in 2020-22. The growth revival from 2010-16 to 2017-19 for TFP of 0.22 percent was substantially less than the revival of 0.59 percent for business-sector productivity, indicating that capital deepening contributed to the 2017-19 revival. The further revival of TFP growth from 2017-19 to 2020-22 of 0.51 percent was somewhat less than the 0.81 percent rebound of business-sector productivity growth. We return in Table 5 below to a detailed decomposition of the difference between business-sector labor productivity and TFP growth in 2010-16, 2017-19, and 2020-22.

4. Pre-Pandemic Trends of Labor Productivity and TFP

The first step in our analysis is to estimate the underlying growth trends of labor productivity and TFP in the pre-pandemic economy. Our preferred method is the Kalman filter which removes correlations between any time series and the unemployment gap, defined as the difference between the unemployment rate and the "long-run NAIRU" estimated by the Congressional Budget Office. Thus, if a decline in productivity growth occurs at the same time as a rise in the unemployment gap, as during the 1981-82 recession, the Kalman procedure uses that correlation to eliminate the decline in productivity growth and instead show a smooth evolution of the productivity growth trend. In contrast, the commonly used Hodrick-Prescott (H-P) filter is univariate and smooths a series using only information on deviations from average growth of the series itself, without any "outside information" on the behavior of the unemployment gap. In practice the H-P filtered series for productivity growth still exhibits substantial fluctuations at business cycle frequencies.

[6] A recent analysis of the productivity slowdown by industry is provided by Sprague (2021).

Our examination of trends in this section terminates the data in 2019 and leaves the interpretation of 2020-22 for later in the paper, where we deal with unique aspects of the evolution of productivity during the pandemic era. Figure 1 contrasts our Kalman filter for business sector productivity growth, shown in blue, with two alternative series. One is a simple 20-quarter moving average of one-quarter annualized changes, shown in yellow, and the other, plotted in green, is the H-P filtered series based on the same data (using the standard H-P quarterly smoothing parameter of 1600). Note that the H-P filter retains considerable cyclical sensitivity and appears to be a slightly smoothed replica of the 20-quarter moving average. For reference, shown on the right side of Figure 1 as a horizontal line to the right of the black vertical bar is the average annual growth rate of business-sector productivity for the nine quarters between 2020:Q1 an 2022:Q1.

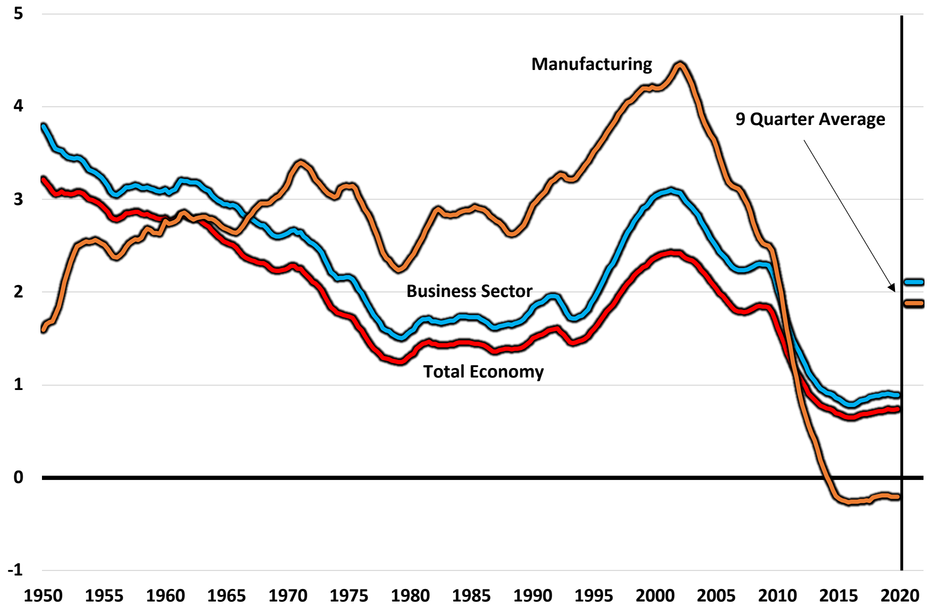


In comparison with the Kalman filter, the H-P filter exaggerates the trend upsurge of productivity growth in the business cycle expansions of the 1960s and late 1990s. The H-P filter erroneously depicts a marked acceleration of the trend from the 1950s to the 1960s, whereas the Kalman trend indicates a relatively steady decline in trend productivity growth from the early 1950s through the early 1980s. Likewise, the H-P technique depicts a decline in trend productivity growth in the 1981-82 recession in contrast to the Kalman trend that indicates no dip in 1981-82. H-P trends for output growth *(y)* and hours growth *(h)* are even more subject to displaying spurious cycles than for productivity growth *(y-h)*, and thus gaps between actual and trend growth rates are systematically understated when H-P trends are used.

In constructing the Kalman trends we make two adjustments to the single trend using the official CBO NAIRU series to measure the unemployment gap. First, in light of the absence of accelerating inflation in 2018-2019, we adjust the NAIRU downward from the CBO value (4.60 percent in 2018:Q1) to 4.0 percent in 2018:Q1 and maintain it at 4.0 percent throughout 2018 and 2019.[7] We note that the Federal Reserve has made a similar adjustment.[8] The NAIRU is assumed to decline in a straight line from its CBO value of 4.91 in 2007:Q4 to the assumed value of 4.0 in 2018:Q1, and the NAIRU is set equal to the CBO value for all quarters before 2007:Q4 back to 1950. The second adjustment is that, since the relationship between the output gap and hours gap changed after 1986 (see below), we conduct the Kalman detrending separately for 1950-85 and 1986-2019 and blend the two series together during 1984-87.[9]

Figure 2 copies the Kalman trend for productivity growth in the business sector in blue from Figure 1 and supplements it with the Kalman trends for productivity growth for the total economy in red and for the manufacturing sector in orange. The blue and red series rise and fall together, with the gap between them visibly widening in the late 1990s and narrowing after 2008. The Kalman trend for manufacturing, shown in orange, remains relatively steady at around 3 percent from 1960 to 1990, registers a sharp peak of 4.5 percent in 2002, and then collapses to a slightly negative growth rate after 2015.

Figure 2. Kalman Trends for Labor Productivity Growth: Total Economy, Business Sector, Manufacturing Sector, 1950:1-2019:4



Without any need to conduct an analysis of cyclical behavior, the Kalman trends in Figure 2 already provide one possible answer to the question of how much the productivity growth trend revived in 2017-19. The trend for the business sector rises only a little, from a

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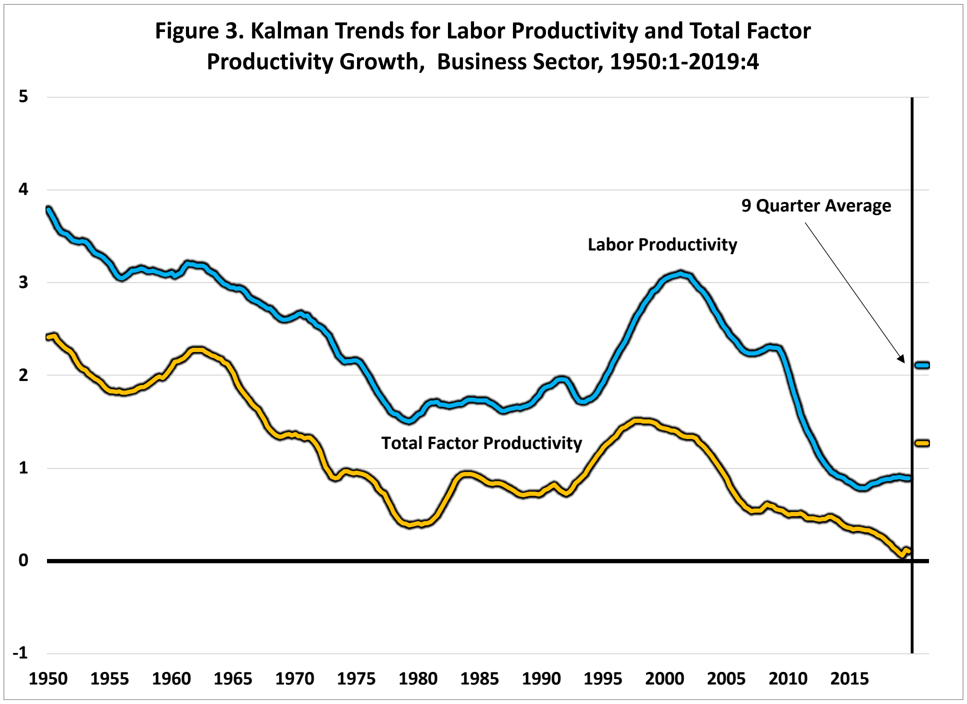
[7] The CBO NAIRU as listed on FRED declines from 4.84 percent in 2010:Q1 to 4.54 percent in 2019:Q1.

[8] The Fed indicated after its meeting of June 19, 2019, that it had lowered its projected range for the NAIRU to between 3.6 and 4.5 percent, i.e., an average of 4.05 percent. See the ranges shown in the right side of the table in: https://www.federalreserve.gov/newsevents/pressreleases/monetary20190619b.htm.

[9] The weight on the 1950-85 series is taken to be 100% in 1983:Q4, then steadily declines to zero by 1988:Q1.

trough of 0.78 percent in 2015:Q4 to an end-value of 0.89 percent in 2019:Q4. The verdict for the total economy is a parallel rise from 0.65 to 0.74. The revival for the manufacturing trend is negligible. Figure 3 supplements Figure 2 by contrasting the business sector trend for labor productivity growth with that for TFP. The difference between the two trends evolves just as the difference between the respective growth rates in Table 1, and the TFP trend declines rather than rises at the end, falling from 0.35 percent in 2015:Q4 to 0.10 at the end of 2019.



We have noted in Table 1 that business productivity growth in 2017-19 increased relative to 2010-16 by a greater amount than the turnaround in the Kalman trend, indicating by definition a positive change in the gap between actual and trend growth rates. Our subsequent analysis determines how much of that change in the gap reflects a procyclical response to the 2017-19 aggregate demand expansion and how much remains to represent an increase in the trend above that suggested by the Kalman technique, which incorporates a smoothing parameter that limits the extent to which the trend can "bend" in response to short-run changes in actual values.

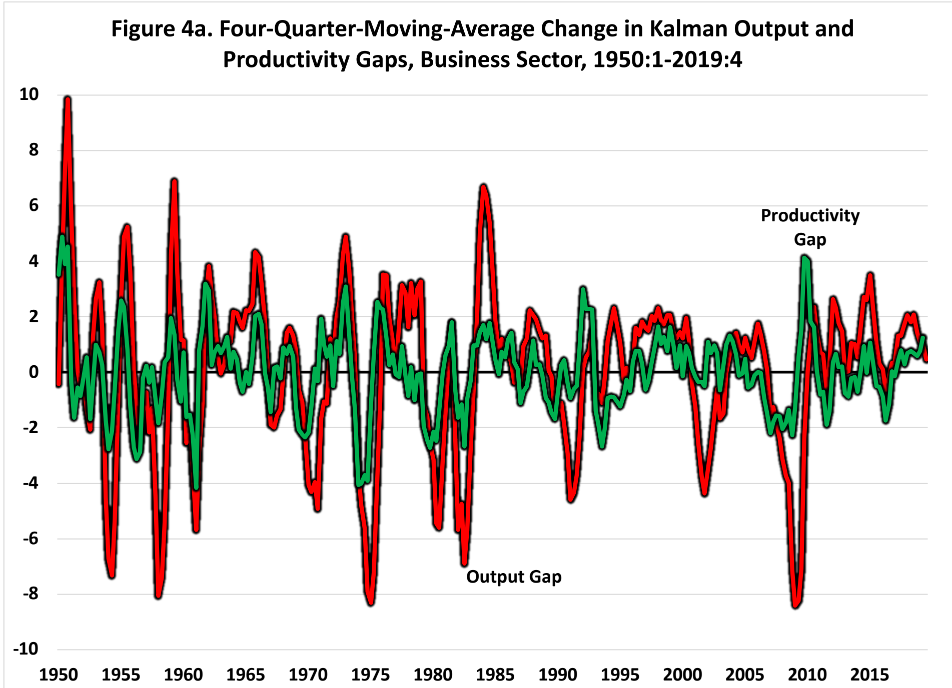
5. Regression Analysis of the Productivity and Hours Gaps through 2019

In this section we develop a framework that analyzes the cyclical relationship between deviations from trend, or "gaps," between the actual and trend growth rates of output, hours, and productivity. Our approach characterizes the basic adjustment mechanism as a gradual response of changes in the hours gap to changes in the output gap. The observed cyclical behavior of changes in the gap in productivity, or output per hour, is then shown to be simply a residual implied by the underlying hours adjustment mechanism. We allow the adjustment process to occur over the current and four lagged quarters, and we use the term "long run" to apply to the complete response after the full five quarter adjustment is completed. When hours exhibit a partial long-run response to the output gap change, then the positive residual long-run response is recorded for the change in the productivity gap.

Thus, we interpret what are often called "productivity shocks" in the macroeconomics literature not as autonomous shocks but rather as the automatic byproduct of incomplete hours adjustment to quarter-to-quarter output movements that may have nothing to do with productivity but rather may reflect short-run changes in the dynamics of inventories, net exports, or other components of GDP. When hours exhibit a 100 percent long-run response to output gap changes, there is no room left for a productivity response, and we record the productivity gap change as being acyclical, that is, displaying no long-run output response. Using the notation * for trends and ' for gaps, the percent level gap of a variable such as output can be written as the first term in equation (2) and the first difference of the gap as the second term:

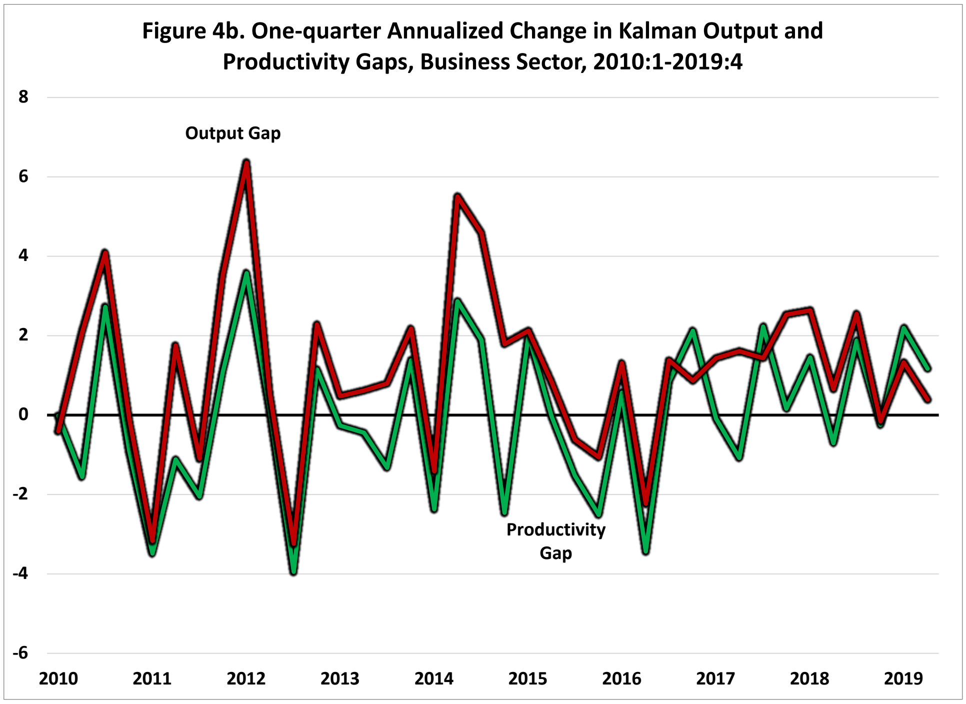
$$\mathrm{Y}' = LN(\frac{\mathrm{Y}}{\mathrm{Y}^*}) \text{ and } \mathrm{y}' = y - y^* \quad (2)$$

The postwar relationship of the four-quarter gap changes for output *(y')* in red and productivity *(y'-h')* in green for the business sector is displayed in Figure 4a. When the displayed change meets the horizontal black line at zero, then, by definition, the actual change in the series is equal to the change in the underlying Kalman trend. The graph shows a marked change in behavior after the mid-1980s. Between the starting year of 1950 and 1985 a positive or negative output gap change was accompanied by a simultaneous movement of the productivity gap change in the same direction with an elasticity of between 0.3 and 0.7. The time interval 1977-79, when a series of positive output gap changes was accompanied by a zero productivity gap change, appears to be the only exception to this regular procyclical behavior prior to the mid-1980s. In at least two episodes, the recession of 1960-61 and the expansion of 1971-73, the cyclical response of the productivity gap change can be visually estimated to be substantially greater than 0.5.



But between 1985 and 2010 the previous regular procyclical relationship was muted or absent. There were no downward responses of the productivity gap changes in the two recessions of 1990-91 or 2001. There were two brief exceptions -- a distinct procyclical response to the positive output gap change of 1999-2000 and to the negative output gap change of 2007-08. However, the simultaneous procyclical timing was different, with a distinct lead in time of the sharp positive change of the productivity gap changes of 1992 and 2009 in advance of the subsequent positive output gap changes.

The pattern changed again after 2009. During the 2010-19 interval, the green productivity line displays a distinct procyclical response to the red output line. This relatively tight procyclical relationship is more evident in Figure 4b, which displays the *one-quarter* (rather than four-quarter) changes in the output and productivity gaps. The change in the hours gap can be discerned on the graph as the difference between the red and green lines. Virtually every upward or downward swing in the red output gap change is mimicked by a simultaneous movement in the same direction of the green productivity gap change, while the hours gap response is minimal. This reappearance of procyclical productivity behavior suggests that our subsequent regression analysis should split the postwar era into three time intervals rather than two (1950-85, 1986-2006, 2007-19).



The regression analysis quantifies the extent to which hours gap changes respond to the current and four lags of the output gap change. Productivity gap changes are treated as the residual implied by the identity that productivity gap changes are defined as output gap changes minus hours gap changes. As we shall see, an important aspect of the cyclical behavior of the hours gap is gradual adjustment, with a relatively small response of hours to output in the current quarter. This implies that the residual productivity change exhibits overshooting, responding with a sharp positive response in the quarter followed by negative responses in the lagged quarters as hours complete their adjustment. This overshooting phenomenon characterizes the data up to 2006 but not afterwards, due to the simultaneity of the output-productivity relationship during 2010-19 that is evident in Figure 4b.

The basic regression equation allows changes in the hours gap (h_t') to respond to the current output gap change (y_t') and four lagged changes:

$$h_t' = \gamma + \sum_{i=0}^{4} \alpha_i y_{t-i}' + \eta_t \tag{3}$$

This constant term γ in equation (3) gives the average value of the hours gap change h_t'' across the regression time interval that is not explained by current and lagged output gap changes y_t'. That is, γ is the average value of the hours gap change when the output gap change y_t' = 0, which occurs when actual output is growing at the same rate as potential (trend) output. Using the identity that the productivity gap change is the difference between the output gap change and the hours gap change, equation (3) implies our productivity gap change ($y_t' - h_t'$) regression equation:

$$y_t' - h_t' = -\gamma + (1 - \alpha_0)y_t' - \sum_{i=1}^{4} \alpha_i y_{t-i}' - \eta_t \tag{4}$$

The responses of each dependent variable, hours or productivity, to current and lagged values of the output gap changes are given by the α_i coefficients. By definition, the coefficients on current output gap changes across the hours and productivity equations must sum to unity, while the coefficients across the two equations for the four lagged values of α_i must sum to zero.

While the model in (3) and (4) allows us to capture the dynamics of hours and productivity before 2007, it misses an important extra component of behavior that occurred in the recession of 2008-09. The sharp downward path of output during that recession occurred when business firms were in a state of panic following the post-Lehman collapse on Wall Street. Firms "threw everyone overboard," cutting hours by much more in response to the output decline than in previous recessions. To capture this phenomenon of "excess layoffs," we allow the response of hours and productivity to differ in recession quarters from other quarters. This recession response is equal to a set of response coefficients multiplied by the value of the change in the output gap for the quarters of the NBER-defined recessions, that is, for each quarter starting with the quarter after the business cycle peak to the quarter of the business cycle trough and is equal to zero otherwise. After discussing our initial results with this definition, we amend it below to allow for a "recovery effect" in which the excess layoffs are gradually unwound by subsequent excess hiring.

To take account of the recession effect, we modify the specification of our hours gap change equation:

$$h_t' = \gamma + \sum_{i=0}^{4} \alpha_i y_{t-i}' + \sum_{i=0}^{4} \beta_i * recess_{t-i} y_{t-i}' + \eta_t \tag{5}$$

Here, "*recess*" is equal to 1 if quarter *t* is marked an NBER recession quarter and 0 otherwise. The α_i coefficients capture the response of the hours gap to the output gap, while the β_i coefficients capture the *additional* response of the hours gap during recessions. Using the identity that the productivity gap change is the difference between the output gap change and the hours gap change, equation (5) implies our productivity gap change ($y_t' - h_t'$) regression equation (6):

$$y_t' - h_t' = -\gamma + (1 - \alpha_0)y_t' - \sum_{i=0}^{4} \alpha_i y_{t-i}' - \sum_{i=0}^{4} \beta_i * recess_{t-i} y_{t-i}' - \eta_t \tag{6}$$

If there is a substantial positive sum of the recession $\beta_i$coefficients, it is possible for the productivity gap change $(y_t' - h_t')$ to be *procyclical* in non-recession quarters but *countercyclical* in recession quarters, and we shall see that this is what happened in 2007-19.

Equations (5) and (6) are the models that we estimate in our empirical analysis of the relationship between the hours, productivity, and output gap changes. Splitting up the regressions in equations (5) and (6) across different time periods will result in different estimates for the procyclicality of productivity (i.e., the sum of the α_is), for the additional recession effects (i.e., the sum of the β_is), along with different constant terms γ.

Our examination of the historical data in Figures 4a and 4b above suggests that there are three eras of cyclical productivity gap changes. The first extending from 1950 to 1985 marks the regular procyclical response of roughly 0.3 in virtually every expansion and recession episode. The second covering 1986-2006 witnessed a more muted and inconsistent procyclical response. And the third from 2007 to 2019 combined the strong excess adjustment of hours during the 2008-09 recession with the reappearance of a regular procyclical productivity response after 2009.

The left pair of columns in Table 2 describe the response of the hours and productivity gap changes to output gap changes in the initial period, 1950-85. In the current quarter a change in the output gap creates a 0.47 to 0.53 division between the hours and productivity gap change responses. In the subsequent four quarters hours respond positively by an additional 0.26, reducing the productivity response by exactly the same amount. Thus the long-run response of hours is 0.47+0.26 or 0.72 while that of productivity is 0.53-0.26 or 0.28 (the lack of exact addition or subtraction here is due to rounding of each coefficient to two places after the decimal). This long-run productivity response of 0.28 is highly significant and can be interpreted as a reflection of labor hoarding, the incomplete adjustment of labor input to fluctuations in output, and is similar to the one-third response of productivity that was a component of the original (1963) version of Okun's law.

Table 2. Regression Response to Changes in Output Gap for Labor Productivity and Hours, 1950:Q1-2019:Q4, Business Sector									
	1950-1985		1986-2006		2007-2019 (No Recovery)			2007-2019 (Recovery)	
	Hours	Prod.	Hours	Prod.	Hours	Prod.		Hours	Prod.
Effect of Current Output	0.47**	0.53**	0.37**	0.63**	0.31**	0.69**		0.29**	0.71**
Effect of Output Lags 1-4	0.26**	-0.26**	0.43*	-0.43*	0.11	-0.11		0.05	-0.05
Total Effect of Output	**0.72****	**0.28****	**0.80****	**0.20**	**0.43****	**0.57****		**0.34***	**0.66****
Recession Effect of Current Output	0.11	-0.11	-0.04	-0.04	0.18	-0.18		0.17	-0.17
Recession Effect of Output Lags 1-4	0.05	-0.05	0.32	-0.32	0.65**	-0.65**		0.65**	-0.65
Total Recession Effect of Output	**0.17**	**-0.17**	**0.37**	**-0.37**	**0.84****	**-0.84****		**0.83****	**-0.83****
Constant	**0.23**	**-0.23**	**0.11**	**-0.11**	**0.62****	**-0.62****		**-0.06**	**0.06**
Adjusted R^2	**0.70**	**0.55**	**0.49**	**0.45**	**0.87**	**0.78**		**0.89**	**0.81**
RMSE	**2.15**	**2.15**	**1.61**	**1.61**	**1.10**	**1.10**		**1.03**	**1.03**
* indicates statistical significance at 5% level, ** indicates statistical significance at 1% level.									

Results for the middle period 1986-2006 are displayed in the two central columns of Table 2. During the current quarter a change in the output gap is divided 0.37 and 0.63 between the hours and productivity gap responses, indicating a somewhat greater productivity response and lower hours response than in the earlier 1950-85 period. But the subsequent hours response over the following four quarters is a substantially greater 0.43, yielding a long-run response of hours of 0.37+0.43 = 0.80 while the long-run productivity response correspondingly drops to somewhat less than in the earlier period (0.63-0.43=0.20) and is statistically insignificant. This set of results provides an important contrast to those in the previous literature. In going from 1950-85 to 1986-2006, the long-run hours response increases only modestly from 0.72 to 0.80 while the productivity response declines not to zero but just from 0.28 to 0.20. Thus it appears that the previous literature has exaggerated the difference in behavior of the pre-1986 and post-1986 intervals, although admittedly the 0.20 long-run response for 1986-2006 is statistically insignificant. The fact that the current-quarter productivity response is greater in 1986-2006 than before 1986 is not addressed in the previous literature.

The minor pre/post 1986 difference calls into question the importance of two types of explanations of a more complete post-1986 hours response. This phenomenon has been previously interpreted by Gordon (2010) and others as a reflection of an increased emphasis by management on maximizing shareholder value, achieved in part by reducing labor hoarding. A complementary explanation is that the hours response to output changes was more complete during 1986-2006 as a result of the "Great Moderation;" the variance of output changes was much smaller in the middle period than in the earlier period (with a standard deviation of the quarterly output gap change of 2.51 for 1986-2006, less than half of the 5.34 standard deviation for 1950-85). Because the variance of output gap changes was so much less during 1986-2006 than before, a given response of labor input comes out as a larger percent of the output gap change. As in the earlier period, the coefficients on an extra response of the hours gap to changes in the output gap during recession quarters (shown in the second section of each column) are positive but insignificant, indicating a slight but insignificant tendency for the positive response of hours to the output gap changes to be larger in recession quarters.

The next two columns of Table 2 show the results for 2007-2019 and indicate that the current-quarter responses of hours and productivity are 0.31 and 0.69, respectively, very close to the current-quarter responses in the middle 1986-2006 interval. But the subsequent adjustment in the next four quarters is quite different, a modest and insignificant 0.11 for hours and -0.11 for productivity, even smaller than the equivalent coefficients of 0.26 and -0.26 for the 1950-1985 interval. Thus, the long-run response of productivity changes to output changes over the five quarters taken together is a highly significant 0.57 during 2007-19, double the 0.28 long-run response of productivity changes during the 1950-85 interval that has previously been characterized as representing labor hoarding.

To understand the reasons for this shift in the productivity and hours gap responses after 2006, we need to look at the second set of rows where we find a highly significant recession response of hours and productivity changes to output gap changes of 0.84 and -0.84, respectively. Thus during the six recession quarters between 2008:Q1 and 2009:Q2, negative output gap changes were followed with a lag by overshooting of the hours gap, that is, a more than proportionate response of the hours gap consisting of the normal long-run response of 0.43 and the extra recession response of 0.84, for a total hours gap response of 1.27. The corresponding productivity gap coefficients are 0.57 plus -0.84, for a total long-run response of -0.27. This is the countercyclical reaction of productivity gap changes to output gap changes that is clearly visible for 2009 in Figure 4a above.

As suggested above, a plausible interpretation of this episode is that business firms were thrown into a panic by the unexpected collapse of the economy in the fall of 2008 and cut hours more than proportionately, expecting an evolution of output even worse than that which actually occurred in 2009. This occurred with a substantial lag; the employment-population ratio which had reached a peak of 63.4 percent in December, 2006, reached its low point of 58.2 percent in July 2011, more than two years after the official June 2009 trough date of the output recession. The hours gap in our quarterly data, which reached a trough of -10.5 percent in 2009:Q3, was still a severely depressed -8.8 percent as late as 2011:Q3.

This leaves the question as to why, after the recession was over in the 2010-2019 interval, productivity changes exhibited a strong procyclical response to quarter-to-quarter changes in output. A hint is provided by the highly significant constant terms in the 2007-2019 regressions, 0.62 for hours and -0.62 for productivity. Our interpretation is that the overshooting of hours in a downward direction in 2008-2009 was gradually reversed by a steady pace of rehiring and hours gap recovery that proceeded relatively independently of changes in the output gap. Thus the large positive constant in the hours equation, the relatively small long-run response of the hours gap change and the relatively large coefficient on the productivity gap change are part of the same process of gradual recovery of the hours gap after the 2009 trauma. Recalling that the coefficients on the productivity gap change and hours gap sum to unity, these results indicate that the observed procyclicality of productivity was the counterpart of relatively unresponsive hours growth over the 2010-19 interval.

This pattern did not fade away a few years after the 2008-09 recession but persisted through 2019. When we estimate the Table 2 regressions separately for 2010-14 and 2015-19, the constant term in the hours equation remains relatively large, declining only from 1.01 to 0.63 between the two sub-periods, with both values at a high significance level. And the lack of response of the hours gap change to the output gap change becomes even more pronounced in the second sub-period, declining from 0.48 to 0.10. Thus the entire decade between 2010 and 2019, as shown above in Figure 4b, is characterized by a strong procyclical long-run response of the productivity gap change to the output gap change, rising from a significant 0.52 in the 2010-14 sub-period to a significant 0.90 in the second sub-period.

Rather than leave the post-2009 recovery of hours hidden away in the constant term in the Table 2, we prefer to model the recovery process explicitly as part of the recession effect, with the magnitude of the recession and recovery effects estimated by the series of β_i recession coefficients. Let *t=0* be the business cycle peak quarter of 2007:Q4 and the length of the recession be M quarters, 6 in this case. For quarters *t=1* to *t=M,* the recession variable entered into the regression is y'_t, as shown in equations (5) and (6) above. Then during the recovery period lasting *N* quarters beyond *t=M*, the recession variable is equal to a constant term v' repeated *N* times, namely the *negative* of the cumulative recession values of y'_t, divided by the number of quarters *N* over which the recovery period is allowed to persist:

$$v_t{}' = -\frac{1}{N}\sum_{t=M+1}^{M+N} y'_t \tag{7}$$

By definition Nv' equals the negative of the summation term in (7), so the sum of the recession values of y'_t and the *N* recovery values of the constant v' adds up to zero. This allows us to modify the previous hours equation (5) to incorporate both the recession effect and the recovery effect together. Let $recess_t$ again be a dummy equal to 1 if and only if time *t* is a recession quarter. Let $recov_t$ be a dummy equal to 1 if and only if *t* is a recovery period *M*+1 through *M*+*N*. Then the hours gap change equation that we estimate is (8):

$$h'_t = \gamma + \sum_{i=0}^{4} \alpha_i y'_{t-i} + \sum_{i=0}^{4} \beta_i * (recess_{t-i} * y_{t-i}{}' + recov_{t-i} * v_{t-i}{}') + \eta_t \tag{8}$$

The estimated β_i recession coefficients reflect the combined impact of the recession and subsequent recovery.

The two right-hand columns in Table 2 labeled "2007-2019 (Recovery)" report on regressions that are identical to those in the table labeled "(No Recovery)" except for the addition of the N repetitions of the v' constant for the N quarters of the recovery beyond $t=M$. Rather than terminate the recovery process at an arbitrary point within the 2010-19 post-recession interval, we have chosen to extend it through the end of 2016, implying that the value of N is 30 quarters. We choose to end the recovery in 2016:Q4 because this is precisely when the post-2008 unemployment rate again reaches its pre-recession 2007:Q4 value of 4.8 percent. Moreover, we estimate a highly significant constant of 0.95 when the basic hours equation lacking the recession term is estimated only for 2010-16, the last half of the 2010-19 post-recession interval, as opposed to an insignificant constant when the equation is estimated for 2017-19. The lack of a significant constant term in other columns of Table 2 suggests a lack of any significant recovery effect in earlier time intervals.

Because the sum of the output gap changes in the six recession quarters of 2008-09 is -10.3, the value of the constant v' is 10.3/30, which equals 0.34 at a quarterly rate or about 1.4 at an annual rate. The addition of the recovery constant term v' as part of the recession/recovery variable has the desired effect of eliminating the significant 0.62 constant term present in the "no recovery" columns of Table 2. The sums of the estimated α_i and β_i coefficients rise modestly in the "recovery" columns compared to the "no recovery" columns.

Has the cyclical behavior of TFP changed through time to echo that of labor productivity? Table 3 repeats the productivity gap change regressions of Table 2 with the change in the TFP gap substituted as dependent variable for the change in the labor productivity gap. The main results of Table 2 are replicated here for the same three sample periods of 1950-85, 1986-2006, and 2007-2019, where the 2007-19 results repeat the recovery treatment of the right side of Table 2. The current-quarter TFP gap response to a change in the output gap is strongly positive — 0.71, 0.81, and 0.88 across the three intervals. The long-run response of TFP is significantly positive in all three periods, although substantially higher in the first (0.50) and third (0.66) intervals than in the middle interval (0.39). The long-run recession responses are insignificant in the first two periods but a highly significant -0.52 in the third period. The constant terms for all three periods are insignificant and close to zero.

Table 3. Regression Response to Changes in Output Gap for Total Factor Productivity, 1950:Q1-2019:Q4, Business Sector			
	1950-1985	**1986-2006**	**2007-2019**
	TFP	**TFP**	**TFP**
Effect of Current Output	0.71**	0.81**	0.88**
Effect of Output Lags 1-4	-0.21**	-0.43**	-0.21
Total Effect of Output	**0.50****	**0.39***	**0.66****
Recession Effect of Current Output	-0.08	-0.11	-0.14
Recession Effect of Output Lags 1-4	-0.07	-0.26	-0.38**
Total Recession Effect of Output	**-0.15**	**-0.37**	**-0.52****
Constant	**-0.09**	**-0.12**	**0.01**
Adjusted R^2	**0.83**	**0.64**	**0.87**
RMSE	**1.52**	**1.42**	**0.96**

* indicates statistical significance at 5% level, ** indicates statistical significance at 1% level.

6. A Post-Sample Simulation to Detect a Productivity Growth Revival in the Pre-Pandemic Economy, 2017-19

The 2017-19 partial revival of productivity growth reported in Table 1 for the total economy and business sector can be interpreted as a procyclical response, a revival in the productivity trend, or a combination of the two. We cannot use our Kalman trend technique to detect the revival in trend in 2017-19, because the smoothing procedure makes the Kalman trend series unable to "bend" sufficiently in that short three-year time interval.

Instead, an alternative method to detect a revival in trend productivity growth would be to estimate our productivity growth gap equation (8) through a particular end date and then for the period after that sample end date simulate its predictions of the change in the productivity growth gap, given the actual historical behavior of the output growth gap. If the productivity growth gap during the simulation period is calculated using the trend value as of the sample end date, then the resulting productivity growth gap simulation will reveal the equation's prediction on the assumption of no revival in the productivity growth trend. If actual productivity growth consistently exceeds this prediction of the equation, then that autocorrelated series of errors would imply that the trend growth rate of productivity has risen relative to the assumed constant trend growth value. For short periods like 2017-19, this procedure has the advantage over the Kalman trend estimation that the use of specification errors to estimate the increase in the trend is not constrained by the smoothing procedure inherent in the Kalman estimation.

For perspective on the magnitude and trajectory of 2017-19 productivity growth behavior, we first perform the same procedure on the productivity growth revival that we know occurred in the late 1990s. To match the three-year duration of the 2017-19 experience, we examine only the first three years of the late 1990s revival during 1996-98. Figure 5 illustrates how our procedure reveals a revival of productivity trend growth during this three-year interval. We re-estimate the change gap version of our labor productivity equation for the business sector from 1986 to 1995 (instead of 1986-2006 as in Table 2) and calculate the predicted growth rate of productivity during 1996 to 1998, holding constant throughout the 1996-98 interval the value of the Kalman productivity growth trend at its 1995:Q4 value of 2.13 percent per year. The difference between the actual and predicted growth rates of productivity measures the estimated increase in trend relative to the 1995:Q4 starting point.

Figure 5. Four-quarter Growth Rates of Actual Output and Actual and Predicted Labor Productivity, Business Sector, 1991:1-1998:4, Simulation Starts in 1996:1

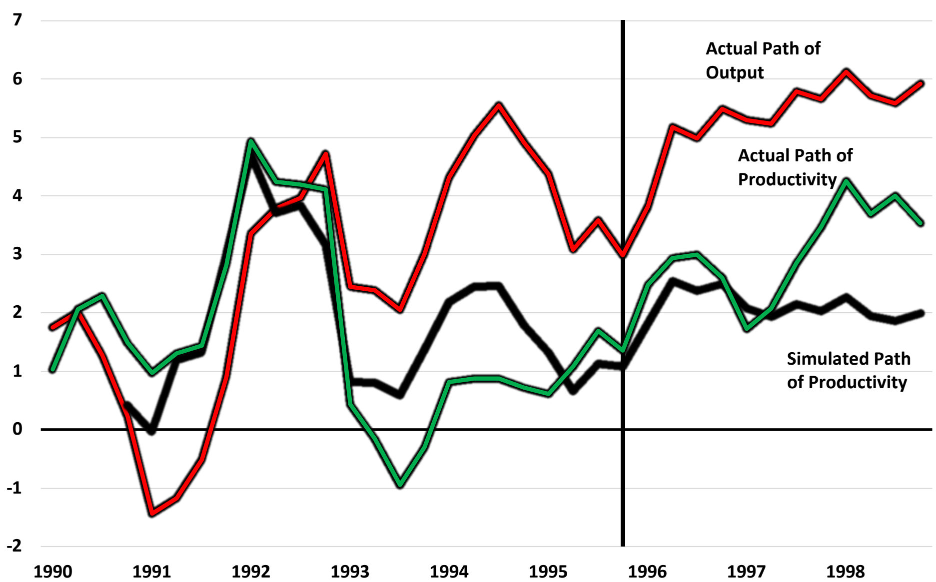


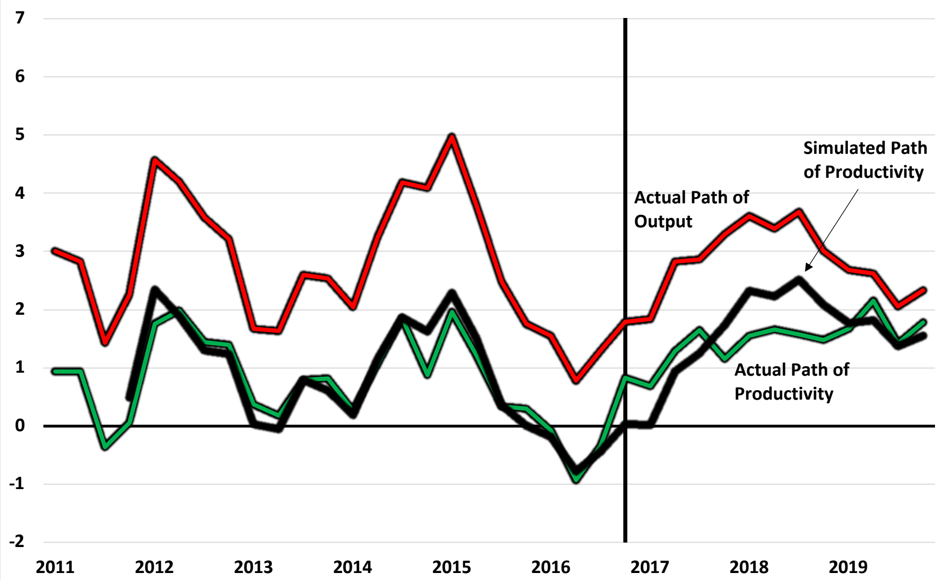
Figure 5 extends from 1990:Q1 to 1998:Q4 and plots in red a four-quarter moving average of the actual growth rate of output and in green displays a similar average of the actual growth rate of productivity. The black line through 1995:Q4 is the four-quarter moving average of the predicted productivity gap change from the 1986-95 equation plus the Kalman trend that was used to calculate that gap, hence the predicted value for productivity change (gap plus trend). The continuation of the black line from 1996:Q1 to 1998:Q4 is the calculated prediction of the equation when the Kalman trend is fixed at its value of 2.13 percent for 1995:Q4.

The fitted values do a relatively good job of predicting the change in productivity growth during the 1990-95 interval shown in Figure 5 to the left of the vertical bar; in particular the 1992-93 early recovery "hump" following the 1990-91 recession is tracked very closely. This was the episode christened at the time as "the jobless recovery" (Gordon, 1993).

During the simulation period to the right of the vertical bar, the predicted value starts out tracking the actual values in 1996 and early 1997 but then substantially underestimates the upsurge in the actual values from mid-1997 to the end of 1998. The four-quarter moving average change of actual productivity in 1998:Q4 is 3.54 percent, fully 1.60 percent higher than the predicted change of 1.94 percent. Thus, our simulation approach reveals the magnitude and timing of the rise in the productivity growth trend that occurred in the late 1990s.

Does productivity behavior in 2017-19 display a similar response of actual productivity change to the prediction of the Table 2 equation? Figure 6 copies the same format and color scheme of Figure 5. The sample period for the gap change regression now extends from 2007:Q1 to 2016:Q4 (instead of to 2019:Q4 as in Table 2). The graph covers the interval 2011:Q1 to 2019:Q4; as before the red and green lines depict the four-quarter moving average of actual output and productivity growth, respectively. The black line shows predicted productivity growth, consisting of the fitted value of the estimated equation through 2016:Q4 and then the projection to 2019:Q4 based on the regression's response of the productivity gap change to the output gap change, plus the fixed 2016:Q4 value of the Kalman productivity trend of 0.83 percent.

Figure 6. Four-quarter Growth Rates of Actual Output and Actual and Predicted Labor Productivity, Business Sector, 2011:1-2019:4, Simulation Starts in 2017:1



The fitted values are very accurate through 2016:Q4, tracking the ups and downs of productivity growth as it responds to changes in output growth. But during 2017:Q1 to 2019:Q4 the predicted value of the productivity growth simulation goes off track, initially underpredicting actual productivity growth in 2017 and then overpredicting it in 2018 and early 2019. The four-quarter average of the actual values of productivity change in 2019:Q4 is 1.78 percent, only slightly higher than the predicted value of 1.55.

Table 4 displays averages of simulation errors and implied trends for business sector labor productivity and also parallel results for business sector TFP, both for the 1996-98 simulations of Figure 5 and the 2017-19 simulations of Figure 6. The first line displays the value of the Kalman trends for the final estimation quarter of 1995:Q4 in the first two columns and 2016:Q4 in the right-hand two columns. The first column for the early simulation shows that actual productivity growth on average for 1996-98 was 3.20 percent, predicted growth was 2.17 and the prediction error was 1.03. Adding the error to the initial trend of 2.13 yields an estimated 1996-98 trend of 3.16 percent, almost identical to the actual growth of 3.20 percent.

Table 4. Implied Trends from Business Sector Labor Productivity and TFP Simulations Post-1995 and Post-2016

	Labor Productivity	Total Factor Productivity	Labor Productivity	Total Factor Productivity
	End of Estimation 1995:Q4		End of Estimation 2016:Q4	
Kalman Trend, End of Estimation Interval	2.13	1.32	0.83	0.32
	Simulation Results, Average for 1996:Q1-1998:Q4		Simulation Results, Average for 2017:Q1-2019:Q4	
Actual Growth	3.20	2.06	1.47	0.76
Predicted Growth	2.17	1.88	1.79	1.35
Error	1.03	0.18	-0.32	-0.59
Implied Trend	3.16	1.49	0.52	-0.28

The TFP results for 1996-98 are in the second column. Actual TFP growth in 1996-98 was 2.06 percent, predicted growth was 1.88 and the prediction error was 0.18. When that error is added to the initial trend of 1.32, the estimated TFP trend for 1996-98 is 1.49 percent, slower than the actual growth of 2.06 percent. The smaller error for TFP growth than labor productivity growth reflects both the larger coefficient on output in the TFP equation and also the role of faster growth of capital deepening in raising labor productivity growth relative to TFP growth during the late 1990s.

The 2017-19 results on the right side of Table 4 show that actual productivity growth was 1.47 percent (as we first learned in Table 1), while predicted growth was a slightly larger 1.79 percent. This implies an error of -0.32 percent and an implied trend of 0.52 percent, substantially lower than actual growth of 1.47 percent. The productivity prediction error in 2017-19 is lower than the error of 1.08 percent for 1996-98 in relative terms as well. The 2017-19 error was 39 percent of the initial trend (0.32/0.83), whereas the 1996-98 error was a larger 51 percent of its initial trend (1.08/2.13).

As was true for the 1996-98 simulations, the TFP results for 2017-19 reveals a larger and substantially more negative TFP growth error than the corresponding productivity growth error. The 2017-19 TFP growth error is -0.59, larger in magnitude than the -0.32 percent productivity growth error. The more negative TFP errors are due primarily to the role of capital deepening in pulling up labor productivity growth relative to TFP growth in 2017-19. The long-run 2007-19 regression response (sum of the estimated α_i coefficients) is similar for TFP (0.66 in Table 3) and labor productivity (0.66 in Table 2).

Stepping back from these results, we need to assess the role of innovation is driving the 2017-19 productivity growth revival. The role of innovation is captured by TFP growth, and so the much larger 2017-19 decrease in the TFP growth trend (-0.59 percentage points) than in the labor productivity growth trend (-0.32) implies a relatively small contribution from innovation. This provides evidence against the claims of those who proclaim that the U.S. economy experienced a new wave of innovation in the later part of the 2010-19 decade, or that Trump-era deregulation spurred a major acceleration in TFP growth. More broadly, these results suggest a very different story in the late 2010s than in the late 1990s. While the underpredictions of the late 1990s are driven by secular increases in productivity trends due to the ICT revolution, the overpredictions of the post-2016 simulations suggest either an undetected decrease in the trend growth of productivity or an overestimation of productivity's procyclicality.

The relatively slow growth of TFP in 2017-19 compared to labor productivity implies that capital deepening — the main difference between TFP and productivity growth — accelerated in 2017-19. Table 5 shows for 2010-16, 2017-19, and 2020-22 a decomposition of how TFP is calculated from the original data on growth in labor productivity, capital input, hours input, and labor composition, where all the business-sector data as in Table 1 come from John Fernald's San Francisco Fed web site. The last two columns show the changes from one interval to the next. Between 2010-16 and 2017-19 productivity growth increased by 0.59 percentage points, capital growth increased by 0.43 points, while hours growth decreased by 0.49 points, implying a sharp acceleration of capital deepening (capital minus hours growth) of 0.92 points. When multiplied by capital's income share of 0.38, the acceleration of the contribution of capital deepening accounts for 0.34 points of the 0.59 point revival of productivity growth. TFP growth increased by 0.21 points, with 0.03 points contributed by labor quality.

	Table 5. Relationship Between Changes in Business Sector Labor Productivity and TFP, Selected Intervals, 2010-2021					
					Change from	
	Annual Rate Changes Over Interval	2010-16	2017-19	2020-22	2010-16 to 2017-19	2017-19 to 2020-22
		[1]	[2]	[3]	[4]	[5]
1	Labor Productivity	0.88	1.47	2.11	0.59	0.63
2	Capital Input	2.36	2.79	2.33	0.43	-0.46
3	Labor Hours	1.89	1.41	0.34	-0.49	-1.07
4	Capital Deepening (line 2-3)	0.46	1.38	1.99	0.92	0.61
5	Labor Quality	0.26	0.31	0.15	0.05	-0.17
6	Contribution of Capital Deepening (line 4*9)	0.18	0.52	0.75	0.34	0.23
7	Contribution of Labor Quality (line 5*(1-9))	0.16	0.20	0.09	0.03	-0.10
8	Total Factor Productivity (line 1-6-7)	0.54	0.76	1.27	0.21	0.51
9	Memo: Capital Income Share	0.39	0.38	0.38		

Capital input, labor hours, labor quality, and labor share data taken from John Fernald of the San Francisco Federal Reserve (http://www.johnfernald.net/TFP , updated June 2, 2022).

Subsequent sections of the paper examine the further productivity growth revival of 2020-22, where our data extend through 2022:Q1. Here our analysis is limited to the relative roles of capital deepening and TFP growth in contributing to pandemic-era productivity growth. TFP growth accounted for only about one-third of the 2017-19 productivity growth revival (0.21/0.59), and column [5] of Table 5 shows that TFP growth accounted for a much larger share (0.51/0.63) of the 2020-22 productivity growth revival. The rest was accounted for by the contributions of capital deepening (0.23) and labor quality (-0.10). Note in column [5] that capital deepening increased in 2020-22 compared to 2017-19 even though the growth of capital slowed down, because the growth of hours decelerated sharply from 1.41 percent to 0.34 percent. In subsequent sections we will look more closely at explanations for the faster growth of pandemic-era productivity than in the pre-pandemic decade.

7. Productivity Growth during the Pandemic: The Role of Changing Weights

We now turn to an interpretation of productivity behavior in the nine quarters between 2020:Q1 and 2022:Q1, the "pandemic economy." This includes the period of the sharp lockdown of the economy in 2020:Q2, the rapid but partial opening up in 2020:Q3, and the subsequent recovery of the following six quarters. We are immediately confronted by a marked departure from the procyclical relationship between the productivity and output growth gaps that characterized the 2010-19 decade. As output collapsed in 2020:Q2, business-sector productivity growth moved in the opposite direction, rising at an annual rate of 6.6 percent in that quarter.

The apparent countercyclical behavior of productivity in 2020:Q2 reflected not a sudden outburst of creative innovation, but rather in large part a shift in the mix of output and employment toward higher productivity sectors of the economy. While output and employment dropped everywhere, they declined at a much faster rate in the sectors where labor productivity and wages are relatively low. This shift in the industry mix reflects a relatively large decline in the employment of workers in low-paid industries where work involves close contact among employees, customers, or both, such as bricks-and-mortar retail trade and leisure/hospitality, and a relative increase in the employment of workers who could continue to work at home in relatively high-paid industries such as finance and information technology. The importance of this mix shift is highlighted by the enormous 9-to-1 difference in the *level* of productivity between the highest and lowest industries, as we see in Table 6 below.

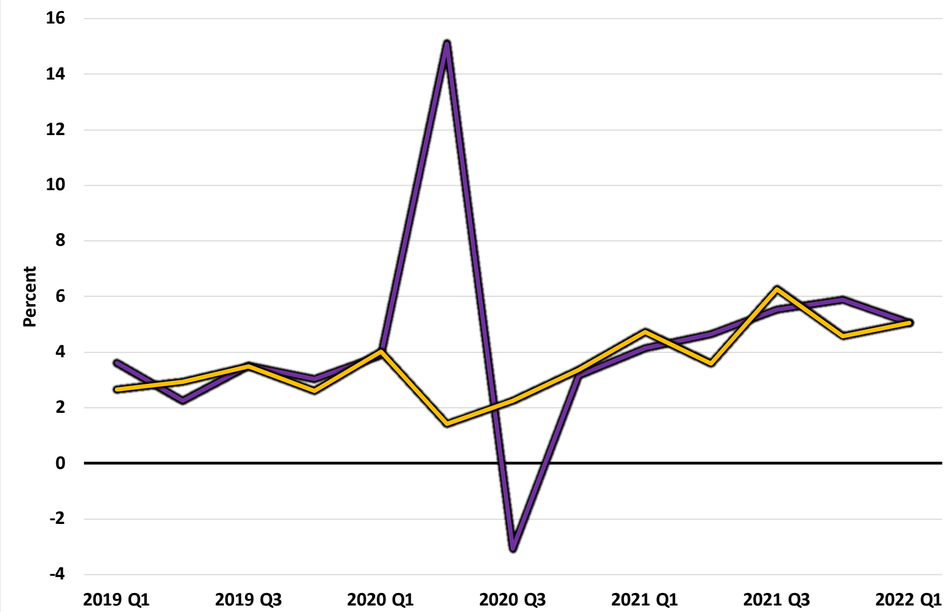
Table 6. Fixed-Weight Examples for Two Industries and Two Quartiles

	Productivity ($/hour)			Output Share (percent)			Hours Share (percent)			%Δ in Prod'y (Ann. Rate)	
	19:Q4	20:Q2	20:Q3	19:Q4	20:Q2	20:Q3	19:Q4	20:Q2	20:Q3	20:Q2	20:Q3
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Two Selected Industries											
Information Services	235.4	251.9	262.7	7.7	8.4	8.2	2.4	2.5	2.4	13.6	16.8
Accommodation and Food Services	27.2	23.8	27.1	3.2	1.8	2.5	8.5	5.8	6.9	-26.9	51.9
Aggregate (CW)	72.7	92.4	87.1							47.9	-23.4
Average, 2019:Q4 Output Weights	125.3	126.4	135.2							1.7	27.0
Average, 2019:Q4 Hours Weights	43.6	39.8	44.5							-18.1	44.2
Top and Bottom Quartiles											
76-100 Quartile	252.3	263.2	264.7	33.8	36.8	34.8	11.1	12.1	11.4	8.5	2.3
1-25 Quartile	35.3	34.4	35.8	22.9	20.6	21.8	44.9	42.6	43.7	-5.2	16.0
Aggregate (CW)	73.8	77.9	77.5							10.6	-2.0
Average, 2019:Q4 Output Weights	114.1	115.8	118.0							3.0	7.8
Average, 2019:Q4 Hours Weights	52.1	51.5	53.2							-2.5	13.2

Sources: Numerator of productivity is set equal to real value added from BEA Output by Industry. Denominatora of productivity and hours share are from BLS Current Employment Statistics (CES).

The impact of this shift in the employment mix is immediately evident for wages in Figure 7, where we compare annualized quarterly changes of average hourly earnings (AHE) with those for the fixed-weight Employment Cost Index (ECI). The change in AHE, which divides total earnings by total hours, is jolted by a sharp annualized quarterly increase of 15.1 percent in 2020:Q2 due to the disproportionate decline in hours of relatively low-paid employees, followed by a decrease of 3.1 percent in the following quarter reflecting the partial recovery of those hours. In contrast the ECI, which holds fixed the relative shares of high-paid and low-paid employees, increased at moderate positive rates in those two quarters (1.4 and 2.3 percent annualized).

Figure 7: Average Hourly Earnings (Purple) vs Employment Cost Index (Gold) for Wages and Salaries, 2019:1-2022:1



To assess the impact of changing weights on quarterly movements in productivity, we need to disaggregate business-sector productivity to the industry level. Published BLS productivity indexes provide industry detail only in annual data that have not yet been updated for 2021. To address the mix issue for productivity in up-to-date quarterly data, we have constructed a quarterly data base of output and hours for 17 two-digit industry groups, measuring output by real value added (from the BEA quarterly data on output by industry), and measuring hours as the product of industry employment and weekly hours (from the Current Population Survey).[10]

To avoid the weighting distortion that would occur if current weights (CW) were used, instead we employ a fixed output- weighted (FYW) growth measure based on weighting the productivity change for all 17 industries by their 2019:Q4 share of total real value added. As an additional index that highlights the behavior of industries with a relatively low level of productivity, we also compute a fixed hours-weighted (FHW) index based on weighting by each industry's share of total hours. We use the following to notate industry aggregate output and aggregate hours:

$$Y_t^{agg} = \sum_i Y_{it} \text{ and } H_t^{agg} = \sum_i H_{it}$$

[10] Since real value added is at an annual rate, BLS hours are multiplied by 52 so that the level of output per hour is in the correct units of dollars per hour, as shown in the productivity columns of Table 6.

where *i* sums output and hours across industries. Then, using our previous notation in which lower-case letters designate log growth rates, the formal definitions of the CW, FYW and FHW productivity growth rates are written as:

$$cw_t = y_{\boldsymbol{t}}^{agg} - h_t^{agg} \tag{9}$$

$$fyw_t = \sum_i (y_{it} - h_{it}) * \frac{Y_{i,2019:Q4}}{\sum_i Y_{i,2019:Q4}} \tag{10}$$

$$fhw_t = \sum_i (y_{it} - h_{it}) * \frac{H_{i,2019:Q4}}{\sum_i H_{i,2019:Q4}} \tag{11}$$

In particular, the FYW and FHW methods represent aggregate labor productivity growth as the sum of the *productivity contributions* of all industries to growth, where the productivity contribution is the weight of a sector (measured via its hours or output share) times the labor productivity growth of that industry.

Table 6 provides examples that show intuitively why the CW growth index, which measures productivity growth by the difference between the growth rates of aggregate output and aggregate hours (as in published BLS productivity indexes) significantly distorts actual productivity changes at the industry level. The quarter-to-quarter change during the lockdown quarter of 2020:Q2 followed by the partial reopening quarter of 2020:Q3 is drastically altered by the mix effect.

The top frame of Table 6 provides an example of this distorting effect for just two industries rather than all 17 industries. We copy from our data file the dollar levels of productivity and percentage output and hours shares for one high-productivity industry, information services, where average real value added per hour in 2019:Q4 was $235. For contrast we compare this with the lowest productivity industry, accommodation and food services, which had a value added per hour level of only $27 per hour in the same quarter. Note that the output share of information grew between 2019:Q4 and 2020:Q2 from 7.7 to 8.4 percent of the total, while the output share accommodation declined by almost half from 3.2 to 1.8 percent of total real value added.

The distorting mix effect is quite clear in this example and is shown by the annualized growth rates in columns (10 and (11). While information services had a productivity increase between 2019:Q4 and 2020:Q2 of 13.6 percent and accommodation had a decrease of -26.9 percent (both calculated with logs at annual rates), the average level of combined productivity (total current real value added divided by total current hours) shot up by 47.9 percent. Weighted instead by 2019:Q4 output shares in both quarters, there was a much smaller increase of 1.7 percent, and weighted alternatively by 2019:Q4 hours shares there was a decline of -18.1 percent. Thus the use of current values yields a strongly distorted impression of what was happening to productivity growth at the industry level, implying explosive growth in 2020:Q2 at a much higher rate than in the average of the two industries whether weighted by fixed 2019:Q4 output or hours. Column (11) shows that the CW index for 2020:Q3 even has the wrong sign, decreasing at a -23.4 percent rate while both industries had respective positive growth rates of 16.8 and 51.9 percent.

This two-industry example, by choosing extremes, exaggerates the practical importance of the mix effect. A more relevant example is shown in the bottom frame, where instead of two industries we compare the top and bottom quartile of the 17 industries when they are ranked by their 2019:Q4 level of productivity. Just as in the two-industry example, there is a substantial twist in the output and hours shares between 2019:Q4 and 2020:Q2, with the shares rising in the top quartile and declining in the bottom quartile. Once again, the use of current weights leads to an upward biased average of productivity growth, with the CW index in column (10) growing by 10.6 percent in contrast to productivity growth of 8.5 percent in the top quartile and a decline of -5.2 percent in the bottom quartile.

A more accurate rendering of average industry behavior is achieved by the FYW fixed 2019:Q4 output weighted index, indicating an increase of 3.0 percent. As an additional indicator to highlight the experience of industries with a relatively low level of productivity, the FHW fixed hours weighted index *declines* by 2.5 percent. Column (11) shows the growth rates for the rebound quarter 2020:Q3 where the CW index has the wrong sign, indicating negative productivity growth despite positive growth in both quartiles. Overall, we see that productivity growth at the industry level is severely distorted by the CW index used in official data on aggregate productivity behavior.

How do the alternative indexes behave when all 17 industry groups are included? As shown in Figure 8, the annualized one-quarter change in 2020:Q2 for the CW index is a massive 13.0 percent, as contrasted to -2.2 percent for the FYW index. The graph shows a zig-zag pattern, with the FYW index bouncing back in the subsequent quarter 2020:Q3 when its annualized one-quarter change is 17.1 percent in contrast to 6.3 percent for the CW index. These large quarter-to-quarter differences in growth rates across the two indexes apply only to the middle two quarters of 2020, and Figure 8 shows that the two indexes record similar growth rates for the other quarters of 2020-22.

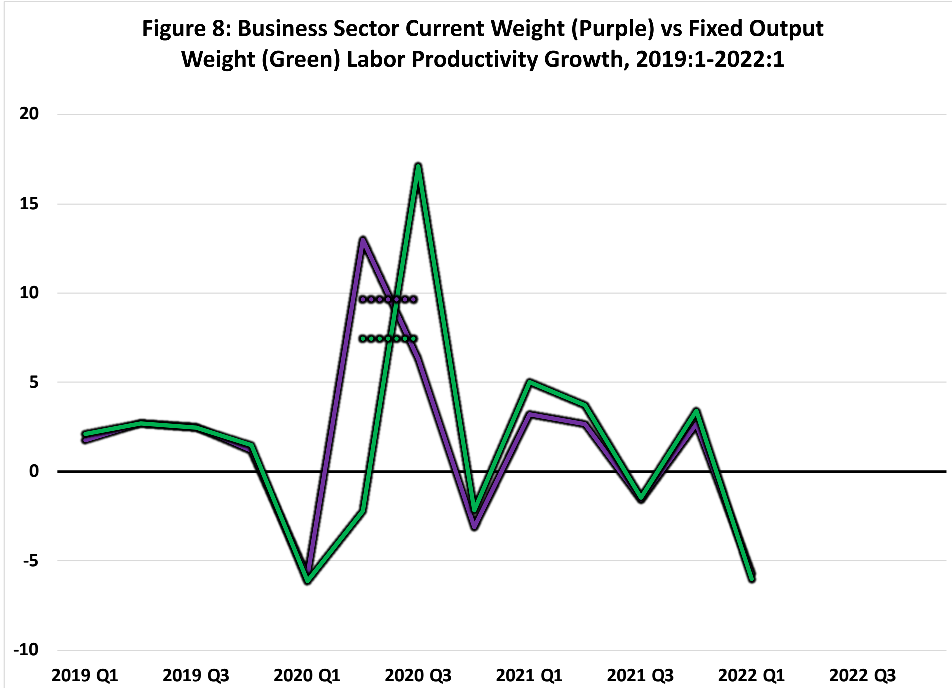


Figure 8 also shows that the difference between the CW and FYW indexes in the middle two quarters of 2020 is much reduced when the average growth rates for those two quarters taken together are plotted. As shown by the horizontal dashed lines drawn for the two-quarters taken together, the average CW growth rate of 9.6 percent is only modestly higher than the FYW growth rate of 7.5 percent. Thus most if not all of the shifting-weight phenomenon can be avoided by merging those two quarters together.

Cumulative annual growth rates over the nine quarters of 2020:Q1 to 2022:Q1 are almost the same: the CW and FYW indexes grow at almost identical rates of 1.31 and 1.27 percent respectively. These growth rates are slower than the 2020-22 growth rate for the business sector of 2.11 percent as recorded in Table 1, because the numerator of CW productivity is real value added, i.e., GDP, whereas the business-sector data used in earlier sections of the paper base the numerator of productivity on the average of GDP and Gross Domestic Income (GDI), and GDI grew substantially faster than GDP in 2020-22 (business sector productivity grew during 2020-22 on average at 1.15 percent based on GDP alone, 3.06 percent based on GDI alone, and 2.11 percent as in Table 1 when based on the preferred average of GDP and GDI).

The FHW index registers a cumulative 2020-22 annual growth rate of only 0.20 percent, indicating that the industries with low productivity levels like accommodation, food services, and retailing experienced slower cumulative productivity growth during 2020-22 than the high-productivity industries like finance, insurance, and information services. We return below to a discussion of productivity behavior during 2020-22 in the disaggregated behavior of the 17 separate industries.

8. A Simulation Approach to Understanding Pandemic-era Productivity Growth Changes

Previously in Figures 5 and 6 and Table 4, we have used a simulation analysis to measure the extent of the productivity growth revival in 2017-19 and to contrast it with the productivity revival that occurred at the beginning of the dot.com era in 1996-98. In each case we contrasted the evolution of actual productivity growth with the prediction of our Table 2 regression equations estimated up to the quarter prior to the three-year simulation interval. Since the regression data are gap changes rather than actual changes, we calculate the predicted value from our regression equations as the predicted gap change calculated from the estimated coefficients multiplied by the output gap change. Then we add to those predicted productivity gap changes the value of the productivity trend in the final quarter prior to the beginning of the simulation period to arrive at the predicted values of total productivity change (gap plus trend).

The same simulation approach can be applied to the nine quarters of 2020-22, where we can calculate the predicted values of the productivity gap change based on multiplying estimated coefficients from the 2007-19 regression equations (from Table 2 above) times the data on output gap changes, using the estimated trend value of 2019:Q4 to calculate the output and productivity gap changes from the actual change data. If the cumulative actual productivity gap change exceeds the predicted gap change, this would imply that the productivity growth trend increased above the 2019:Q4 value for 2020-22 taken together, just as we previously concluded that the trend increased in the three year 1996-98 and 2017-19 intervals.

The estimated 2007-19 regressions used in this simulation exercise are characterized not only by a procyclical response of productivity gap changes to output gap changes, but also to the recession/recovery effect in which the hours gap changes overreacted to negative output gap changes during the 2008-09 recession, followed by a recovery interval in which the overreaction was gradually eliminated. As discussed above in the context of Table 2 the cumulative negative values of the output gap during the six quarters of the 2008-09 recession are balanced by adding in a recovery term consisting of the reverse of the cumulative negative output gap values spread out over N quarters of the recovery.

In order to use the estimated 2007-19 Table 2 coefficients for the 2020-22 post-sample simulation, we need to employ the same business-sector productivity data used to estimate the regressions. This raises the issue of the distortion to measured productivity changes in 2020:Q2 and Q3 previously discussed for the CW and FYW index changes in Figure 8. As we learned there, averaging the changes over those two quarters eliminates most of the effect of the shift in output mix. Thus in our simulations we calculate the predicted value of hours from our Table 2 2007-19 hours equation using data in which the values of output and hours gap changes are averaged together for the two middle quarters of 2020.

We use the estimated coefficients for the basic output response (the α_is) as presented in Table 2, with the sum of the α_i coefficients in the hours gap equation of 0.25. But for the β_i

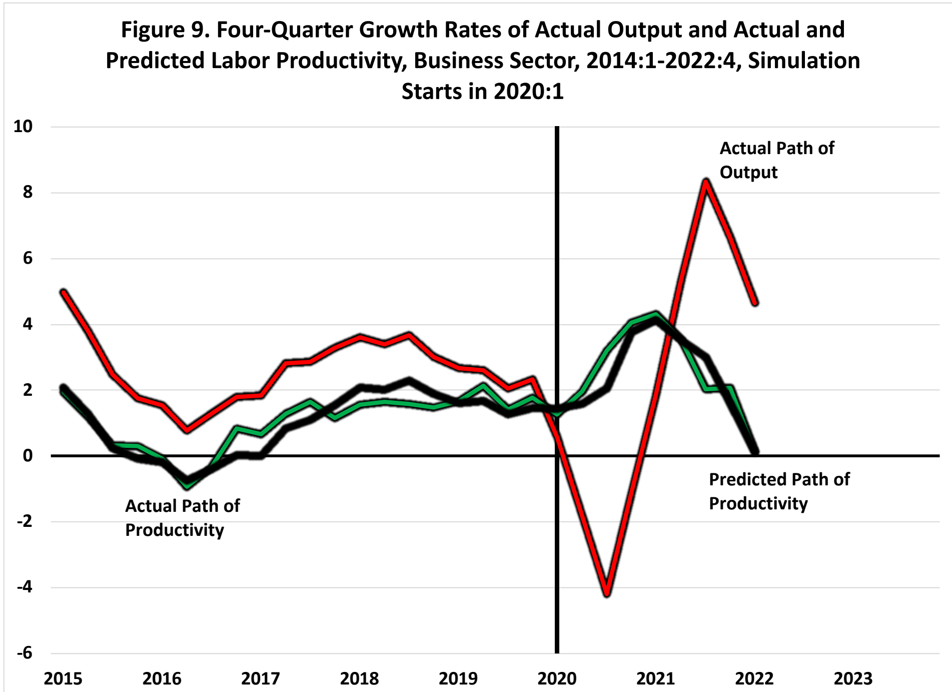
recession effect we recognize that the 2020 recession was much sharper and shorter than the 2008-09 recession. To allow for a faster response, we shorten the recession adjustment period by combining the current and four lagged β_i coefficients into a single lag-zero coefficient equal to the sum of the estimated β_is, which is 0.83 in Table 2.

Not only was the recession much shorter in 2020 than in 2008-09, but so was the recovery period. In the earlier episode there was a duration of 10.5 years from 2006:Q4 when the unemployment rate reached its pre-recession low of 4.4 percent until that value of 4.4 percent was achieved again in 2017:Q2. In contrast, only 25 months or 2.1 years elapsed between the pre-recession low unemployment rate of 3.5 percent in February 2020 to the achievement of almost the same rate, 3.6 percent, in March 2022. In our treatment of the post-2009 recovery in Table 2, we allowed for a 7.5-year recovery period during which the excess layoffs of 2008-09 were gradually unwound.

Since the economy is still evolving, the length of the post-2020 recovery period is currently uncertain, but is clearly much shorter than in 2009-16. Recall that the post-2009 recovery term in the Table 2 regression is calculated as the cumulative negative values of the output gap change in the recession with sign reversed, divided by the length of the recovery (N quarters). Similarly in our 2020-22 simulation we calculate the recovery effect as the cumulative negative values of the output gap change in 2020:Q1 to Q3 with sign reversed, divided by N quarters. We have experimented with alternative *N* values of 4, 8, and 12 quarters. (Recall that we average changes in 2020:Q2 and Q3, so this treats the recession as extending from 2020:Q1 to Q3, not Q2).

The cumulative negative values of the output gap change in 2020:Q1 to Q3 were -6.0 percent, which when multiplied by the sum of the β_i coefficients of 0.83 equals -5.0 percent. This is the predicted extra recession-caused decline in hours beyond the contribution of the basic α_i coefficients from Table 2. If we choose a recovery duration of 8 quarters, then we add +5.0/8 = 0.63 to the predicted value of hours in the 8 quarters starting in 2020:Q4, or 2.5 percent at an annual rate.

Figure 9 shows the simulation results for 2020-22 in the same format as the earlier simulations for 1996-98 and 2017-19. All plotted values are four-quarter moving average changes, and gaps have been added to the 2019:Q4 trend so that the values shown are data values, not gaps. The red line is the actual output change, the green line is the actual productivity change, and the black line is the predicted productivity change. Even though output changes are averaged for 2020:Q2 and Q3, the plotted output change still displays a sharp zig-zag from -4.2 percent in 2020:Q3 to +8.3 percent in 2021:Q3. The black predicted productivity change series is remarkably close to the green actual series, with a cumulative residual of only 0.04 at an annual rate.



Thus the puzzle of soaring productivity growth during and after the recession of 2020 can be explained as a remarkably similar repeat of the productivity growth bubble of 2009. In both cases an unexpected shock to the economy caused an overreaction by business firms, which cut hours more than would have been predicted based on their response in non-recession quarters. Why then did business sector productivity growth slow down sharply from 4.0 percent in the four quarters of 2020 to a mere 0.6 percent in the subsequent five quarters of 2021-22? The excess layoffs of 2020 were followed by the same recovery effect that had occurred after 2009 but more rapidly — as business firms rehired employees to replace those who had been laid off, and as they posted record-high vacancies — hours growth remained strong while productivity growth slumped (for the five quarters of 2021-22 output growth averaged 5.3 percent, hours growth 4.7 percent, and productivity growth 0.6 percent).

Table 7 explores the effect of varying the post-recession recovery interval from 4 to 8 to 12 quarters. Shown in the middle column is the result of assuming the recovery period to last 8 quarters (from 2020:Q4 to 2022:Q3), as plotted in Figure 9. This yields a predicted value of productivity growth of 2.06 percent compared to the actual of 2.11 percent, an error of 0.04 percent, and an implied trend growth rate equal to the 2019:Q4 value of 0.89 + 0.04, or 0.93 percent. Alternatively assuming a recovery period of 4 quarters in the first column yields an error of 0.60 percent and an implied trend growth rate of 1.49 percent, whereas assuming a recovery period of 12 quarters in the third column yields an error of -0.51 percent and an implied trend growth rate of only 0.38 percent.

Table 7. Implied Trends from Business Sector Labor Productivity Simulations Post-2019, Varying Recovery Length			
	Four Quarters	**Eight Quarters**	**Twelve Quarters**
End of Estimation 2019:Q4			
Kalman Trend, End of Estimation Interval	0.89	0.89	0.89
Simulation Results, Average for 2020:Q1-2022:Q1			
Actual Growth	2.11	2.11	2.11
Predicted Growth	1.51	2.06	2.62
Error	0.60	0.04	-0.51
Implied Trend	1.49	0.94	0.38

Intuitively the longer the recovery period, the smaller is the addition each quarter to the predicted change of hours and so the larger the addition to the predicted change in productivity. Consequently a relatively large predicted value of productivity growth implies that *actual* observed productivity growth was less than that prediction, implying a lower underlying trend. In choosing among the three options in Table 7, we view the choice of a short 4-quarter recovery interval for hours as implausibly short, given the strong observed growth of hours in the first half of 2022. And the choice of a 12-quarter recovery seems implausibly long, given the very low implied underlying trend growth that emerges from the Table 7 calculation.

We conclude that the 8-quarter recovery assumption is consistent with the observed evolution of productivity growth in 2020-22, as illustrated by the close similarity of the plotted predicted productivity series in Figure 9 compared to the actual series. Our interpretation explains not only the rapid growth rate of productivity in 2020 followed by very slow growth in 2021-22, but also a phenomenon that has puzzled observers of the economy in mid-2022 when negative real GDP growth in 2022:Q1 appears to have been followed by another quarter of negative growth in 2022:Q2. How could employment continue to grow robustly when accompanied by negative real GDP growth? Our recession/recovery analysis provides the answer. While productivity growth data are not yet available for 2022:Q2, the results are likely to be negative as in 2022:Q1 when hours grew at an annual rate of 5.5 percent and productivity declined by -5.6 percent.

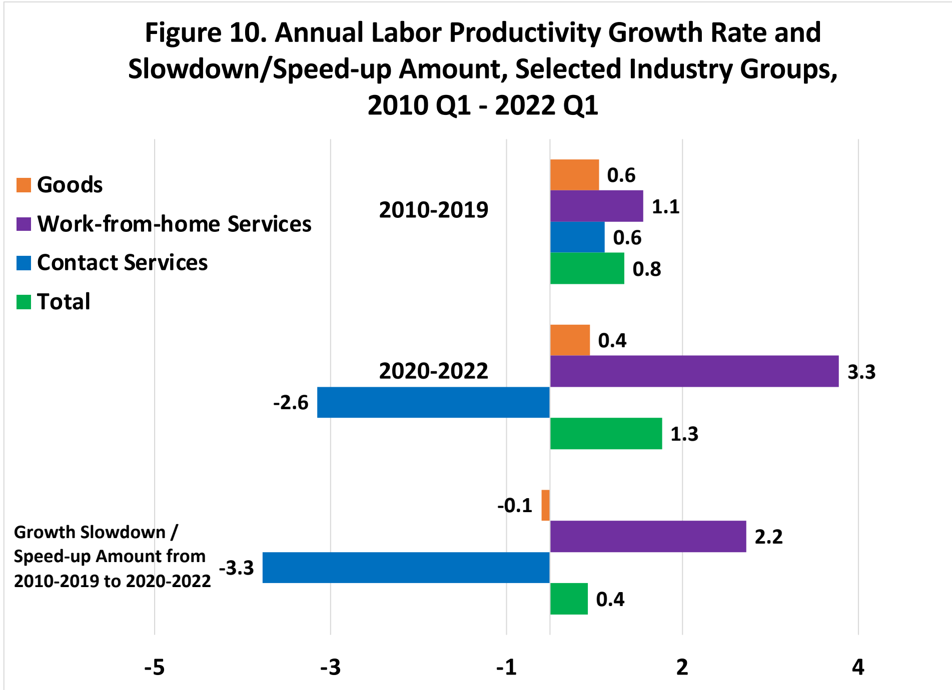
9. Pandemic-Era Productivity Change of Industry Groups and Individual Industries

Previously we introduced the distinction between our current weight (CW) index and the fixed output-weight (FYW) index created from our new quarterly productivity data base covering 17 industries from 2006:Q2 to 2022:Q1. Because the numerator of productivity for each industry is real value added, i.e., GDP, the quarter-to-quarter and interval average growth rates of the aggregate CW index differ from the business-sector data previously used in the regression and simulation analysis, which as in Table 1 is based on a productivity numerator that is the average of GDP and GDI. Because GDI grew considerably faster than GDP during 2020-22, the average growth rate for that nine-quarter interval of the CW index is 1.31 percent, slower than the Table 1 business-sector growth rate of 2.11 percent.

As we shall see the behavior of the 17 industries during 2020-22 is highly heterogeneous, with average growth rates over those nine quarters ranging from +10.5 for information services to -9.6 percent for transportation and warehousing. To simplify the industry discussion, we combine the 17 industries into three groups as listed in Table 8. The goods group includes manufacturing, mining, utilities, and construction. Services are divided into two groups, with those industries where work was primarily done remotely at home in the "work-from home services" (WFH) group and the remaining industries combined into the "contact services" group. The share in total 2019:Q4 real value added was 30 percent for goods, 45 percent for WFH services, and 25 percent for contact services.

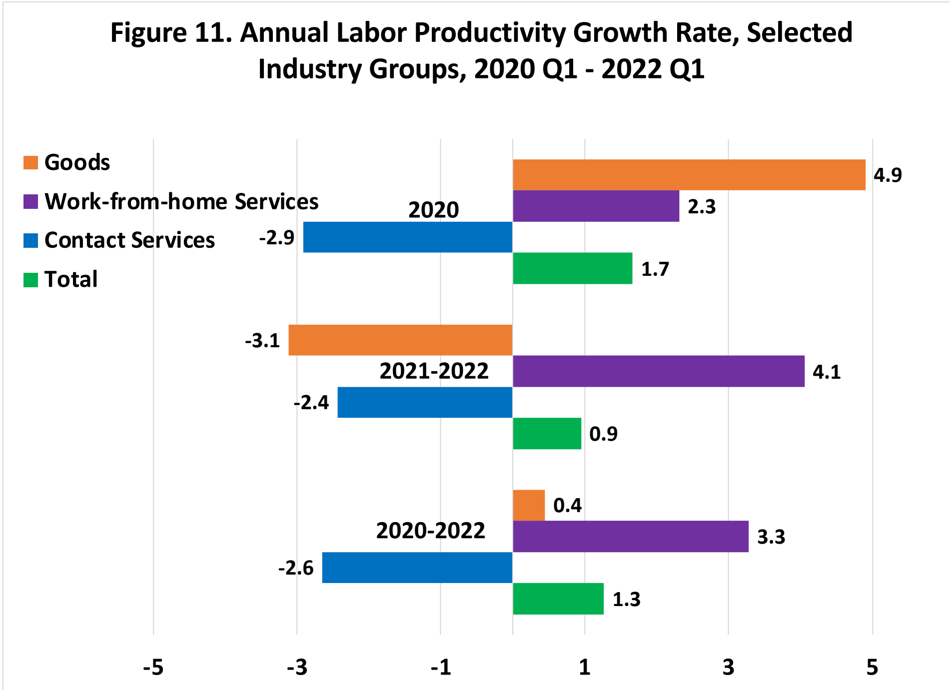
The table arranges individual industries within each group by the level of their value added per hour in 2019:Q4. For goods this ranges from $311 for mining to $44 for construction. For WFH services the range is from $235 for information to $35 for administrative services. And for contact services the range is smaller, from $93 for wholesale trade to $27 for accommodation and food services. The wide range of productivity levels across the individual industries provided our previous example in Table 6 that illustrates the importance of using fixed-weight indexes to describe productivity changes during the year 2020.

How do productivity changes in the three industry groups compare when the nine quarters of 2020-22 are compared with the previous ten years, 2010-19? This comparison is based on fixed output-weight (FYW) indexes for each group and is shown in Figure 10. During 2010-19 average productivity growth was relatively similar across the three groups, with respective growth rates of 0.6, 1.1, and 0.6 percent, implying an average of 0.8 percent annual growth for the FYW index of all three groups taken together.



The experience in 2020-22 could not have been more different. Productivity growth in the goods group slowed slightly from 0.6 percent in 2010-19 to 0.4 percent in 2020-22. But productivity growth for WFH services soared from 1.1 percent in 2010-19 to 3.3 percent in 2020-22. In contrast the performance of contact services slumped from 0.6 to -2.6 percent. Changes between the two intervals are plotted separately in the bottom section of Figure 10. Growth for the total of all three groups increased from 0.8 to 1.3 percent (recall again that the industry data are based on the GDP measure of productivity and exhibit slower growth in 2020-22 than the business-sector data used in Table 1 and our previous regression/simulation analysis based on the average of GDP and GDI in the numerator of productivity).

Further insight into the industry composition of 2020-22 productivity growth behavior is provided in Figure 11, which splits the nine-quarter 2020-22 interval into the four quarters of 2020 and the five quarters of 2021-22. Growth in the goods group declined from the exceedingly rapid rate of 4.9 percent in 2020 to -3.1 percent in 2021-22. This suggests that the phenomenon of excess layoffs (boosting productivity growth) in 2020 followed by a recovery of hours (reducing productivity growth) in 2021-22 was concentrated in the goods group. The buoyant performance of WFH services went in the opposite direction, increasing from 2.3 percent in 2020 to 4.1 percent in 2021-22. In contrast productivity growth in contact services remained negative, improving slightly from -2.9 percent to -2.4 percent. The average for all industries decreased from 1.7 percent in 2020 to 0.9 percent in 2021-22, very close to the 0.8 percent average for all industries recorded for 2010-19.



The phenomenon of increased productivity growth in WFH services is consistent with the results of a large survey of 30,000 respondents conducted in 2020 and 2021 by Barrero, Bloom, and Davis (2021). In one of their most important findings, respondents reported that their WFH productivity was on average 7.1 percent higher "than expected" (Appendix Table A-2). While "expected" is an ambiguous comparison, it seems natural to interpret this as productivity as experienced previously in the office. 48 percent of respondents reported being more productive, and 21 percent reported being 20 or more percent more productive. Only 14 percent reported being less productive.

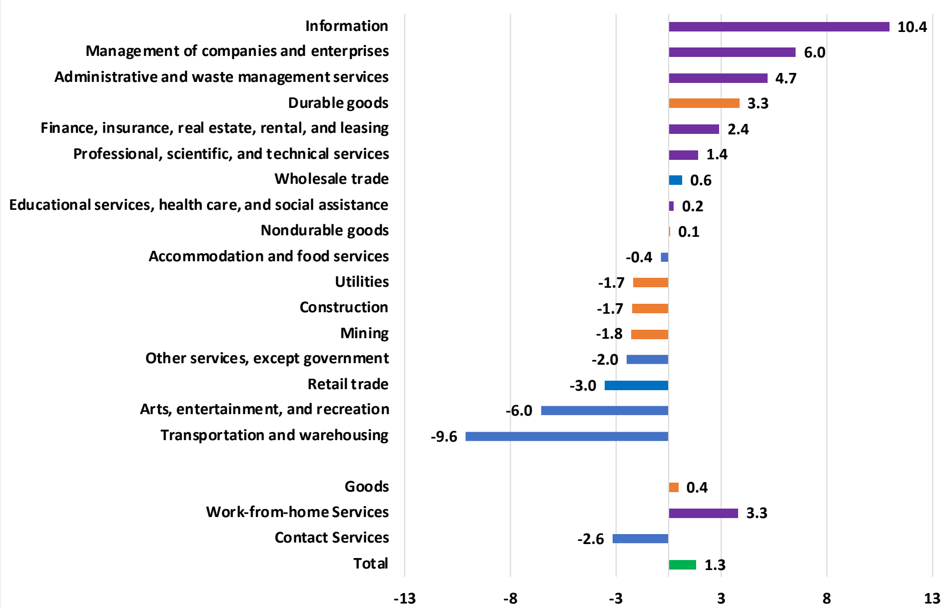
In another finding respondents reported that they spent most of the time previously engaged in commuting at work from home rather than in other home activities. If WFH employees reallocated commuting time toward work, then actual working hours increased relative to measured hours which are assumed to remain unchanged. If so this would suggest that hours of WFH employees are understated in official data on hours per employee, implying a reverse overstatement of productivity. In sum the surge of productivity growth in the WFH group as shown in Figures 10 and 11 may be a combination of a real phenomenon and an element of mismeasurement.

In a complementary study Eberly, Haskell, and Mizen (2022) point to another aspect of WFH, what they call the "unprecedented and spontaneous" deployment of what they call "potential capital." This term refers to the residential capital redeployed to work activities as well as the investment in communication technology, both hardware and software, that allowed WFH activities to occur. They translate potential capital into a GDP equivalent and provide the surprising estimate that its contribution roughly halved the sharp decline in measured GDP that occurred in 2020:Q2 at the trough of the recession.

The rapid productivity growth of WFH services that continued into 2021-22 stands in marked contrast to the continued negative growth experience of contact services. Some of this may represent the traditional effect of slumping utilization on worker productivity as airline pilots and ground crew transported fewer airline passengers per plane and restaurant staff faced unoccupied or sparsely occupied tables during the pandemic lockdowns and their aftermath. The continued negative productivity growth of contact services in 2021-22 after the lockdowns were largely lifted seems surprising, as does the extent of negative productivity growth in the goods group.

For reference Figure 12 provides the 2020-22 productivity growth rates of all 17 industries, arranged in descending order of their productivity growth rates. Color coding identifies the top-performing industries as mainly the WFH services colored in purple. In the gold-colored goods group the contrast between durable goods manufacturing (3.3 percent) and nondurable goods (0.1) percent is interesting, presumably reflecting the shift of consumer spending during the pandemic away from services to durable goods. All of the contact services colored in blue recorded negative productivity growth except for a slight +0.6 percent positive performance of wholesale trade.

Figure 12. Average Productivity Growth Rate of 17 Industries, 2020:Q1-2022:Q1, in Descending Order of Productivity Growth



Our simulation exercise of Figure 9 and Table 7, carried out with the business data in which output is measured as the average of GDP and GDI, computes a predicted path of productivity growth that soars in 2020 as a result of excess layoffs (repeating the 2009 experience) and then slumps in 2021-22 as a result of a gradual recovery in hours. Our industry data show that this pattern is consistent with the behavior of goods group. But the rapid 2021-

22 productivity performance of WFH services and the continued slump of contact services suggests that aggregate productivity performance reflects a more complex reality than summarized in the layoff/rebound paradigm.

10. Conclusion

The paper begins by contrasting the dismal decade of 2010-19, when business sector productivity growth proceeded at only 1.1 percent per year, with the ebullient nine years 1996-2004 when productivity growth reached 3.3 percent or the entire 1950-2009 postwar era with its productivity growth achievement of 2.5 percent. Could the slow growth of the 2010-19 decade imply another disappointing decade in the 2020's or might the 2020's become a decade of robust growth propelled by technological breakthroughs, robots, and artificial intelligence? The decade opened on an optimistic note with business-sector productivity reaching 4.1 percent during the four quarters of 2020.

This paper provides a new interpretation of variations of productivity growth for the entire postwar era with particular emphasis on the 15 years since the start of the financial crisis recession of 2008-09. Our first insight is that short-term productivity changes during recessions and business expansions, and from one quarter to the next, do not reflect autonomous gyrations of productivity growth itself, the so-called "productivity shocks" that have played such a large role in the macroeconomics literature. Instead the behavior to be explained is the response of the change in hours of work to autonomous movements in output, which themselves are driven by demand-induced fluctuations in consumption, fixed investment, government spending, net exports, and particularly short-run changes in inventory accumulation. Output growth proceeds with sharp irregular quarter-to-quarter ups and downs during both expansions and recessions, with additional sustained downward movements during recessions.

Hours respond partially and gradually to these output changes, and productivity changes are a residual, the definitional difference between output changes and the induced hours changes. Because of the gradual adjustment of hours, the residual productivity changes typically involve a large positive response in the current quarter followed by negative reactions in the next few subsequent quarters as hours complete their adjustment. If the sum of the positive initial productivity response and the negative lagged responses is significantly positive, then productivity growth is said to be procyclical. We concur with the previous literature that productivity growth was strongly procyclical during 1950-85; our coefficient of the response of productivity growth to output changes over the current quarter and four lagged quarters is a highly significant 0.28, similar to the one-third response embedded in the original formulation of Okun's Law.

With our focus on the gradual adjustment of hours, we make a distinction between the normal response of hours and an extra reaction to output changes that occurs in recessions and was particularly marked in 2008-09. During that recession hours declined with a much higher elasticity to output changes than in other periods, which we interpret as "excess layoffs" due to the panic of business firms as output collapsed during and after the financial crisis of 2008. Since productivity change is a residual, equal to output change minus hours change, it behaved counter-cyclically and rose in the four quarters of 2009 by a massive 6.4 percent. This counter-cyclical episode when combined with non-recession data has led much of the previous literature to conclude that productivity growth was no longer procyclical after 1985.

The excess layoffs of 2008-09 did not occur in isolation; eventually the lost jobs returned as workers were rehired in the post-recession recovery. We model the total recession and recovery effect as netting out to zero, so the cumulative extra rehiring addition of jobs in the recovery exactly offsets the estimated excess reduction of jobs during the recession. Because the excess adjustment of hours in 2008-09 was a special phenomenon, we divide up our regression analysis into three eras (1950-85, 1986-2006, 2007-19) rather than two divided at 1986. The set of current and lagged coefficients on our combined recession-recovery variable is highly significant for the 2007-19 interval but not for the earlier periods. As for the "normal" non-recession long-term response of productivity to output changes, when the current quarter response is combined with four lagged quarters, we conclude that procyclicality did not disappear after 1985. Our long-run sum of coefficients is 0.28 for 1950-85, 0.20 for 1986-2006, and 0.66 for 2007-19 (although the 0.20 for the middle interval is insignificant).

Our novel recession/recovery treatment has six important implications that resolve several of the puzzles about productivity behavior that have emerged both in the pre-pandemic interval of 2007- 19 and in the pandemic era of 2020-22. First, the estimated coefficients for the 2008-09 recession/recovery effect imply that average annual productivity growth in the two years 2008-09 would have been -0.8 percent instead of the actual 3.2 percent if the excess layoff phenomenon had not occurred. Second, our estimated recession/recovery coefficients imply that a major explanation for slow productivity growth in 2010-16 was the extra post-recession rehiring that offset the excess hours reduction that had previously occurred in the recession. We estimate that without that post-recession rehiring spread out over the seven years 2010-16, the annual rate of productivity growth on average would have been almost twice as high — 1.7 percent per year rather than 0.9 percent per year.

Third, the appearance in the productivity data of a growth revival from 2010-16 to 2017-19 is more than explained by the winding down of post-recession recovery rehiring that had characterized the 2010-16 period. Fourth, when allowance is made for the recession/recovery effect, the regression coefficients indicate that productivity growth was strongly procyclical in 2007-19.

Regarding the pandemic era, our fifth conclusion emerges when our estimated 2007-19 regression coefficients are applied in a post-sample simulation to actual data for 2020-22. We find that our coefficients are able to track almost exactly the marked acceleration of productivity growth during 2020, once adjustments are made for the shorter duration of the 2020 recession in comparison with the 2008-09 recession. Sixth, our post-recession rehiring treatment in the same simulations explains why productivity growth slowed so markedly from 4.1 percent at an annual rate in the four quarters of 2020 to only 0.6 percent in the following five quarters of 2020-22.

Further insight into productivity behavior in 2020-22 is provided by our new quarterly data base of productivity levels and changes for 17 separate industries in the private business sector extending from 2006:Q2 to 2022:Q1. The numerator of our industry indexes is real-value-added, that is, the business component of GDP. The aggregate growth rate of the industry indexes in 2020-22 is 1.3 percent, which is slower than the 2.1 percent growth rate of the business-sector data used elsewhere in the paper for which the numerator is the average of GDP and GDI (GDI grew considerably faster than GDP in 2020-22).

Our first insight from the quarterly industry data is that published productivity indexes greatly exaggerate aggregate productivity growth in 2020:Q2 and understate it in 2020:Q3 as a result of the lockdown's effect in causing sharp shift in the industry mix away from industries like restaurants and hotels with low levels of productivity toward work-from-home industries like information and financial services that have high levels of productivity. We illustrate this distortion by creating an alternative aggregate of the 17-industry data that holds constant industry output weights at the 2019 level.

Because 2020-22 productivity growth across the 17 industries is so heterogeneous, we combine these industries into three groups: goods, work-from-home (WFH) services, and contact services. The three groups behave very differently. For the nine quarters of 2020-22 taken together, productivity growth in the goods group is near zero, in WFH services is a strongly positive 3.3 percent, while in contact services is a mediocre -2.6 percent. The average across the three groups is 1.3 percent. Comparing the four quarters of 2020 with the five quarters of 2021-22, productivity growth in the goods group declines from strongly positive to strongly negative, which is consistent with the hypothesis of excess layoffs followed by a gradual rehiring recovery. In WFH services productivity growth actually improved from 2020 to 2021-22, suggesting a more permanent phenomenon. In contact services productivity growth remained negative by about the same amount in both 2020 and 2021-22.

Thus it appears that the apparent revival of productivity growth in 2020-22 was entirely caused by the outstanding performance of the WFH services. We cite a recent survey study showing that the WFH respondents assess their own productivity as substantially higher than their expectations, which may provide a comparison between productivity of WFH activity compared to the productivity of the same individuals in their previous office environments. We cite another study suggesting that pandemic-era GDP growth may be understated by neglecting the shift of residential capital from non-work to work activities and the large personal investment in technology hardware and communications software needed to make WFH effective.

Where does this leave our assessment of the long-run trend in productivity growth? The paper has suggested that productivity growth was distorted by excess layoffs in 2008-09, shifting some productivity growth into that two-year period and moving it away from 2010-16 when rehiring cancelled the effects of the excess layoffs. The business-sector data displayed in Table 1 and used in our regressions and simulations records growth rates of 1.3 percent in 2005-07, 3.2 percent in 2008-09, and 0.9 percent in 2010-16. The underlying trend of productivity growth is better represented by averaging across these three intervals, resulting in a 2005-16 growth rate of 1.4 percent. This is remarkably close to the 1.5 percent in the apparent revival interval of 2017-19 and also close to the 1.5 percent achieved in the long "slowdown" period of 1973-95.

A cautionary note is that a suggestion of 1.5 percent for the long-term growth of productivity in the business sector translates into only 1.1 percent for the total economy, since productivity in the total economy grew an average of 0.4 percent slower than in the business sector during 1950-2019. This 1.1 percent suggestion is relevant for predictions of future potential output growth and is slower than the current CBO ten-year forecast of 1.4 percent total-economy productivity growth. Our conclusion is thus consistent with the long-term forecast of 1.2 percent for the total economy included in our previous long-term evaluations (Gordon, 2016, 2018).

Economic commentary in mid-2022 is dominated by speculation about the imminence of a new recession. There is much puzzlement about the reality of negative GDP growth in the first quarter of 2022 and the likelihood of negative GDP growth again in the second quarter, juxtaposed with continued robust growth in payroll employment. Our paper resolves this puzzle in its post-recession recovery simulation which indicates that hours growth in 2021-22 is 2.5 percent faster at an annual rate in each quarter than otherwise, due to rehiring of workers to replace those who lost their jobs in the excess layoffs of 2020. The paper predicts also that continued rehiring will result in significant negative productivity growth in 2022:Q2 and likely in subsequent quarters, having the effect of further reducing the 2020-22 average productivity growth rate down from 2.1 percent closer to the 1.4 percent average of 2005-19. This assessment leaves no room for a pandemic-era revival in productivity growth as has been widely suggested. Instead, there appears to be a consistent growth rate of 1.4 percent (2005-19) roughly equal to 1.5 percent (1973-95), leaving the dot.com achievement of 3.3 percent as a historic outlier as it recedes further into the past.

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