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A New Interpretation of U.S. Productivity Growth Dynamics, 1950-2023

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1. Introduction

The decade of the "teens" in the American economy witnessed the slowest productivity growth of any decade in recorded U.S. history.[1] Growth in output per hour for the private business sector over 2010-2019 was only 1.1 percent per year, well under half of the average of 2.4 percent from 1950 to 2009.[2] The 2010-19 rate fell even further short of the 3.3 percent achieved during the ICT-based "dot.com" productivity revival of 1996-2004.[3]

This paper uniquely links three puzzles. First, why was productivity growth s so slow during the 2010-19 decade? Second, why did the response of productivity growth to output growth shift from procyclical in 1950-85 to acyclical in 1986-2006 back to procyclical in 2010-19? Third, why was that transition interrupted by a strongly *countercyclical* response in the 2008-09 and 2020 recessions? Dating back to Okun's famous "Law" (Okun, 1963; see also Ball *et al.* 2017) economists have tracked the cyclical elasticity of productivity changes. Okun's original stylized fact was that cyclical output changes were divided up one-third into changes in productivity, one-third into changes in the unemployment rate, and the remaining one-third divided between hours per employee and labor-force participation. For decades, Okun's one-third positive productivity response was roughly confirmed, but in the last two decades the research consensus shifted to the conclusion that the procyclical response vanished after 1985. More recent evidence further eroded support for procyclicality as productivity went in the opposite direction as the business cycle, when productivity growth was strongly positive during the recessions of 2008-09 and 2020.

Common practice in modern macroeconomic theory is to treat autonomous productivity shocks as a major source of output fluctuations. See, for instance, Acemoglu et al. (2012), Baquee and Farhi (2019), and Gabaix (2011).[4] These productivity shocks are assumed to move output in the same direction, requiring empirical support for a procyclical correlation between productivity and output changes. The empirical literature which finds that the procyclical correlation disappeared after 1985, and especially the strongly countercyclical behavior of productivity in 2009 and 2020, casts doubt on the relevance of the autonomous productivity shock paradigm.

This paper provides a unified explanation of slow productivity growth in 2010-19 and the apparent shift from pre-1985 procyclical behavior, to 1986-2006 acyclical behavior, back to

[1] "Recorded history" here goes back to 1889 in the data presented in Gordon, 2016, chapter 16. The slowest decade prior to 2010-19 back to 1889 was 1980-89 at 1.7 percent per year.

[2] 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 Table 1 below and http://www.johnfernald.net/TFP.

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

[4] Acemoglu et al. (2012) states that "microeconomic idiosyncratic shocks may lead to aggregate fluctuations." Baqure and Farhi (2019) study the "macroeconomic impact of microeconomic productivity shocks." Gabaix (2011) argues that "idiosyncratic firm-level shocks explain a large part of aggregate shocks."

procyclical behavior since 2010, punctuated by unique countercyclical responses in 2009 and 2020. Our approach centers on the definition that the change in productivity is a residual, equal to the change in output minus the change in hours of work. The fundamental dynamic driving productivity fluctuations is not a set of autonomous shocks to productivity itself, but rather demand-driven shocks to output combined with lags in the adjustment of hours of work to those output fluctuations. Costs of hiring and firing mean that the hours response to a given output change is spread out over time, with a current-quarter elasticity well below unity followed by further positive responses to a current output change occurring in subsequent quarters. The residual productivity change thus exhibits overshooting, with a positive response to an output change in the initial quarter followed by a negative response in subsequent quarters. If the cumulative sum of these responses is significantly positive, productivity changes are said to be procyclical.

This positive-negative sequence of current and lagged productivity responses to output changes contrasts with the positive-positive correlation implied by the autonomous productivity shock literature. What is treated here as exogenous is not the productivity changes themselves but rather the sequence of output changes, which are assumed to result from quarter-to-quarter variations in the demand for consumer spending, fixed investment, inventory changes, government spending, and net exports. Quarter-to-quarter changes in these output components can be quite volatile not only in recessions but also during expansions. For instance, the annualized quarterly changes of output during the four quarters of 2016 were 2.7, -0.6, 3.2, and 2.5, respectively. The microeconomic idiosyncratic productivity shocks at the industry level posited by the macro theory paradigm would be too small to cause such large quarter-to-quarter fluctuations in the aggregate economy. To make a difference at the aggregate level, microeconomic productivity shocks would need to be correlated across industries and over time and would show up as a gradual upward or downward movement in aggregate productivity changes, such as occurred in the pervasive multi-industry "dot.com" growth revival of 1996-2004.

This approach based on the gradual adjustment of labor hours is sometimes described as "labor hoarding" (see Biddle, 2014), but that is a misnomer because it refers only to the retention of labor when the demand for output decreases. Instead gradual adjustment of hours is symmetric, restraining the amplitude of changes in labor hours both when output decreases but also when it increases. Both hiring and firing are costly – firms are rational when they wait to see if a change in demand is transitory or permanent. Hours lag positive output changes because of the costs of recruiting, hiring, and training labor. Hours lag negative output movements because of costs imposed by contractual agreements, severance pay, and the loss of human capital when skilled workers lose their jobs.

When output changes are volatile or have a low serial correlation, they are viewed as partly transitory, and the costly adjustment of hours is incomplete, leaving the residual productivity changes to partially mimic the output changes. In contrast when output changes are less volatile or have a high serial correlation, firms are more likely to interpret output changes as permanent and are able more completely to adjust hours to reflect the output changes, leaving little or no residual positive correlation between output and productivity changes. We show that the shift of the productivity-output correlation from positive before 1985 to zero during 1986-2006 was caused by the Great Moderation in output volatility, and the return to a positive correlation after 2010 was caused by a drop to zero in the positive serial correlation of quarter-to-quarter output changes.

Using this framework of gradual hours adjustment to exogenous output fluctuations, we explain why productivity change was countercyclical in the Great Recession of 2008-09 and the Pandemic Recession of 2020. Our novelty is to allow the elasticity of hours to output growth to increase during these two recessions — capturing the "excess layoffs" created by firms as they responded to the severity of the negative demand shocks. In our interpretation, business firms overreacted to the sudden collapse of demand in the fall of 2008 by laying off far more employees in 2009 than in a normal recession. Once the recession was over and the ensuing expansion began, we show that these extra laid-off employees were rehired only gradually in what we call the "recovery effect." This extra rehiring beyond the normal response of hours to output growth caused *pari passu* sub-normal productivity growth after 2009. When estimated for business sector data, these reversals allow our model to explain the soaring 6.6 percent rate of productivity growth in 2009 and 5.6 percent in 2020, the slow 1.1 percent average productivity growth rate of 2010-19, and the -0.5 percent negative growth rate for the eight quarters of 2021-22.

To determine which industries contributed to these patterns of aggregate productivity growth, we develop a new quarterly data file of productivity for 17 industries using BEA and BLS data covering 2006-2023. We show how the excess layoffs in 2009 were concentrated in three industries that were hardest hit by declining demand during the recession – manufacturing, construction, and finance. We also show that the quarterly pattern of aggregate productivity growth in 2020 was distorted by disproportionate output reductions in low-productivity service industries. We create a fixed-weight productivity index that avoids this measurement issue and also use the industry data to shed light on those industry groups that have exhibited particularly strong and weak productivity growth since the pandemic.

Part 2 provides a brief review of the related literature on the cyclicality of productivity changes. Part 3 quantifies postwar productivity growth for selected intervals and develops statistically estimated trends. Part 4 analyzes deviations from trend, or "gap changes," for hours and productivity with particular attention to 2007-19, as well as the industry composition of the 2009 countercyclical upsurge in productivity growth. Part 5 presents our regression analysis of gap changes for both hours and productivity and conducts post-sample simulations to interpret the growth revival of 2017-2019. Part 6 examines the effect of changing industry weights on productivity performance in 2020-23. Part 7 provides a post-sample simulation analysis to explain aggregate productivity behavior in 2020-23. Part 8 examines 2020-23 productivity growth for three industry groups, highlighting the role of work-from-home industries. Part 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. This literature has not so far commented on the return to a productivity response after 2009. Fernald and Wang (2016) use correlations to argue that labor productivity turned countercyclical and total factor productivity (TFP) acyclical after the mid-1980s. 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) utilize a VAR framework to show a weakened response of productivity and heightened response of hours to non-technological shocks. Barnichon (2010) uses a neo-Keynesian search and matching model to attribute productivity's weakening cyclicality to lower labor frictions beginning in the 1990s. Gordon (2010) documents the disappearance of the procyclical productivity response in the context of an increased cyclical response of hours, which he attributes to heightened managerial emphasis on maximizing shareholder value.

Papers supporting a procyclical productivity response tend to have been written earlier than those finding no effect, but several were written after 2000, by which time 15 years of evidence had accumulated covering years during which the procyclical effect appeared to have vanished. These include Basu and Fernald (2001), a paper in the real business cycle tradition by Wen (2004), and a plant-level data study by Baily *et al.* (2001).

While most studies of the cyclicality of productivity changes focus on the relationship between productivity and output, some concern the relationship between productivity and employment. Hagedorn and Manovskii (2011) report that the procyclicality of productivity, measured by its correlation with fluctuations in employment, 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 contradicted the tight correlations predicted by a Mortensen-Pissarides (1994) search and matching model.

Most recent literature supports the reduction or disappearance of the procyclical response of productivity since the 1980s. Daly *et al.* (2013) use a "labor-market" model to divide hours growth into hours per employee and employment, as well as a "capital" model to decompose productivity into total factor productivity, capital deepening, labor quality, and utilization. While their "capital" model finds that the acyclicality of productivity is driven by a decrease in procyclical utilization relative to countercyclical capital deepening and labor quality, their "labor market" model shows that a procyclical shift emerges from an increased response of the employment rate to the business cycle. Biddle (2014) also argues that reductions in hiring frictions decrease labor hoarding, once thought to be one of the drivers of procyclical productivity responses. 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 acyclical services sector, as well as an increased sensitivity of TFP to persistent technological shocks that are negatively correlated with inputs.

More recently, Galí and Van Rens (2021) propose a model where reductions in hiring frictions increase employment flexibility, decreasing the procyclicality of productivity. In a different approach, Stamegna (2024) finds that the procyclical correlation between productivity and output has vanished since the mid-1980s and attributes this to a lessened incentive to invest in labor-saving innovations due "missing wage growth in the upturn of the business cycle." Fernald and Li (2022) document the countercyclical behavior of productivity growth in the 2008-09 and 2020 recessions by highlighting the positive correlation of productivity growth and the unemployment rate in those years.[5]

3. Trends of the Growth of Labor Productivity and TFP

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 letters for growth rates.

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

Table 1 documents labor productivity *(Y/H)* growth and total factor productivity (TFP) growth from 1950 to 2023. The first two columns provide annual growth rates of labor productivity for both the total economy and business sector. In both columns total output is measured by the geometric average of GDP and gross domestic income (GDI), following Nalewaik (2011), who showed that the average of GDP and GDI is more accurate than either one examined separately. The third column shows TFP, also based on the average of GDP and GDI, as calculated regularly at John Fernald's San Francisco Fed web site.

The first row displays the rapid growth of 1950:Q1-1972:Q4, followed by the slowdown of 1973:Q1-1995:Q4 that received so much attention during the 1970s and 1980s.[6] 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

[5] The explanation of countercyclical productivity growth in 2008-09 and 2020 by Fernald and Li (2022) is complementary to that in the current paper, the first draft of which (NBER WP 30267, July 2022) was released before the Fernald-Li paper was first presented at the August 2022 Jackson Hole conference. The current paper goes further than their analysis by quantifying the symmetry of the post-recession rehiring effect as unwinding the recession "excess layoffs" effect and showing that it largely explains the slow productivity growth of 2010-16 and 2021-22.

[6] 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), Perloff and Wachter (1980) and a more recent article by Vandenbroucke (2017)).

and the impact on TFP of personal computers, the internet, and search engines (see 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:Q1-2023:Q4

	Labor Productivity		TFP
Time Period	**Total Economy**	**Business**	**Business**
1950:Q1-1972:Q4	2.83	3.21	2.20
1973:Q1-1995:Q4	1.26	1.51	0.52
1996:Q1-2004:Q4	2.61	3.30	1.80
2005:Q1-2009:Q4	1.85	2.13	0.15
2010:Q1-2016:Q4	0.66	0.86	0.53
2017:Q1-2019:Q4	1.33	1.84	1.03
2020:Q1-2023:Q4	1.22	1.31	0.27

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, updated July 1, 2024), where output data are geometric averages of income and production sides of the business sector.

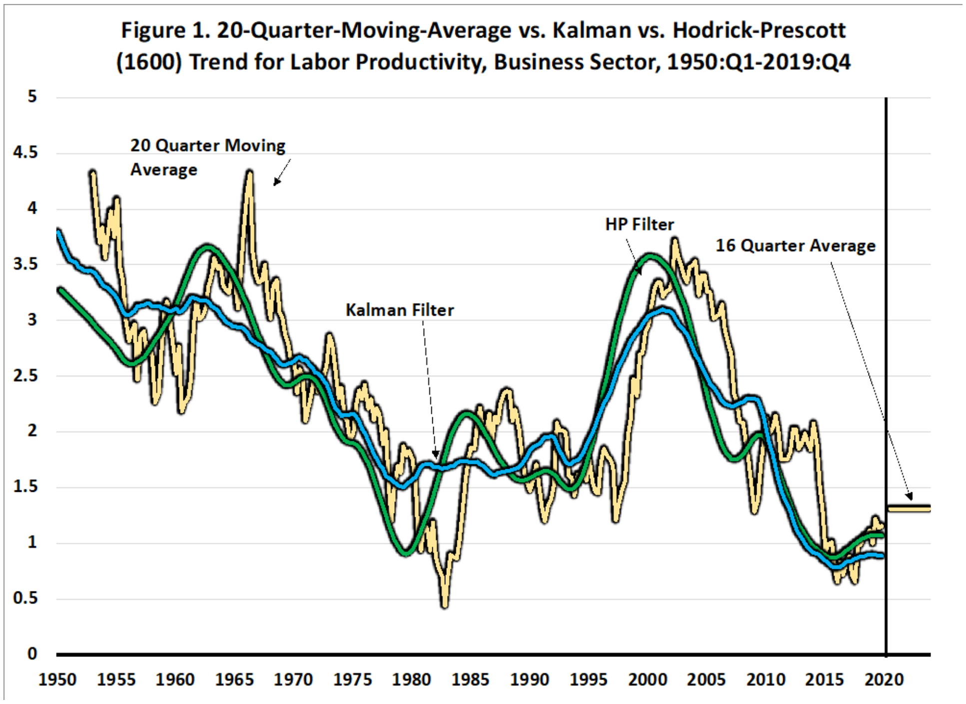
The post-2004 interval is divided into four sub-periods. The first, 2005:Q1-2009:Q4, includes the last stages of the 2001-07 economic expansion, the 2008-09 recession, and the first two recovery quarters after the end of that recession. We treat 2010:Q1-2016:Q4 as a distinct sub-period marked by unusually slow productivity growth and then break out the 12 quarters of 2017-19 that show a noticeable revival. The last line of Table 1 includes the 16 pandemic and post-pandemic quarters 2020:Q1-2023:Q4.

Growth in the business sector is always more rapid than in the total economy due to relatively slow measured productivity growth in non-business sectors like government and nonprofits. The 1996-2004 to 2010-19 slowdown was substantially greater for the business sector than the total economy. Productivity growth in the total economy, not just the business sector, matters for the growth of potential output and real output per capita, i.e., the standard of living. Productivity growth in the final 2020-23 interval was about 0.3 points faster than the 2010-19 average for the total economy and about 0.2 points faster for the private business sector.

The TFP growth rates in the third column are always slower than those of labor productivity for the business sector in the second column, differing by the normally positive contributions of capital deepening and labor quality. The TFP growth shortfall was about 1.0 perentage point in 1950-95 but rose to 1.50 points in 1996-2004, reflecting the marked rise in the growth rate of investment (capital deepening) in the dot.com era. Surprisingly, the TFP shortfall rose to an even larger 1.98 percent in 2005-2009 before dropping to 0.32 percent in 2010-16, 0.81 in 2017-19, and an even higher 1.04 in 2020-23. We return in Section 5 to a detailed decomposition of the difference between business-sector labor productivity and TFP growth in 2010-16, 2017-19, and 2020-23.

An alternative to displaying productivity growth over selected intervals as in Table 1 is to estimate statistical growth trends. Our preferred method is the Kalman filter, which removes correlations between 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 during that recession. 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, meaning it still exhibits substantial fluctuations at business cycle frequencies.

Our examination of trends in this section terminates the data in 2019 and leaves the interpretation of 2020-23 for Section 7. Figure 1 contrasts our Kalman filter for business sector productivity growth, shown in blue with a 20-quarter moving average of one-quarter annualized changes (yellow) and the H-P filtered series with parameter 1600 (green). Note that the H-P filter retains considerable cyclical sensitivity and appears to be a smoothed replica of the 20-quarter moving average. The right side of Figure 1 displays a horizontal line to the right of the black vertical bar indicating the average annual growth rate of business-sector productivity for the 16 quarters between 2020:Q1 and 2023:Q4, which is 0.42 points above the the calculated 0.89 percent growth rate of the Kalman filter in 2019:Q4.



The H-P filter by comparison exaggerates the trend upsurge of productivity growth in the business cycle expansions of the 1960s and late 1990s, erroneously depicting an acceleration of the trend from the 1950s to the 1960s while the Kalman trend indicates a relatively steady decline in trend growth from the early 1950s through the early 1980s. 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 spurious cycles than 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 official CBO NAIRU series to measure the unemployment gap. First, in 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 through 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 set equal to the CBO value for all quarters from 2007:Q4 back to 1950. The second adjustment is that, since the relationship between the output gap and hours gap changed after 1985 (see below), we conduct the Kalman detrending separately for 1950-85 and 1986-2019 and blend the two series together during 1984-87.[9]

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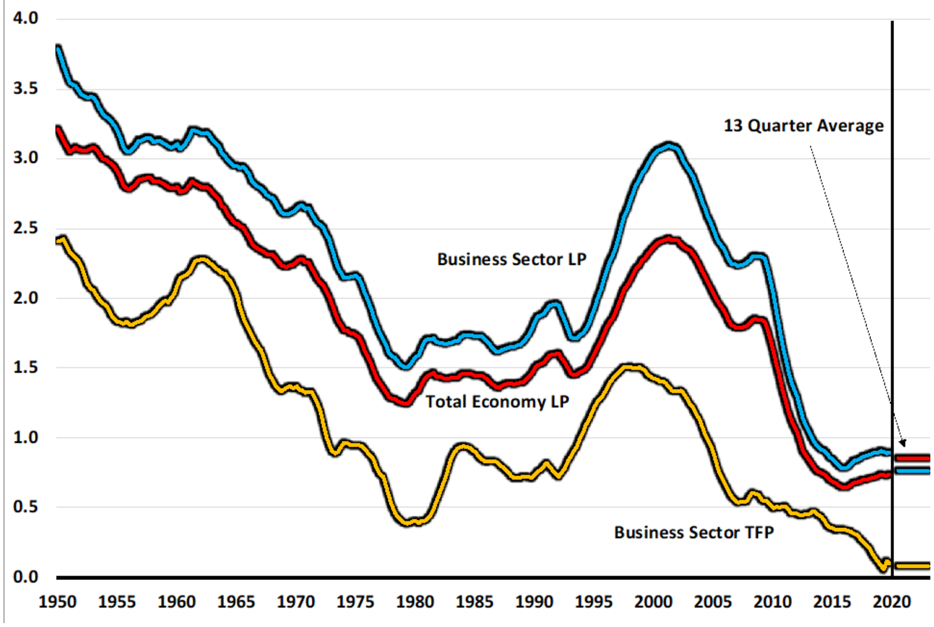
[7] The CBO NAIRU as listed on FRED declines from 4.84 percent in 2010:Q1 to 4.54 percent in 2019:Q1.
[8] The Fed indicated after its meeting of June 19, 2019, that it had lowered its projected range for the NAIRU to between 3.6 and 4.5 percent, i.e., an average of 4.05 percent. See the ranges shown 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.

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 business sector TFP in yellow. 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 difference between the TFP and labor productivity 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. As in Figure 1, the colored horizontal lines to the right show the actual growth rate of productivity in the three sectors for 2020-23. In each case, these actual average growth rates are modestly above the estimated value of the Kalman trend in 2019:Q4.

Figure 2. Kalman Trends for Labor Productivity Growth: Total Economy, Business Sector, Manufacturing Sector, 1950:Q1-2019:Q4



4. Behavior of the Productivity and Hours Gaps through 2019

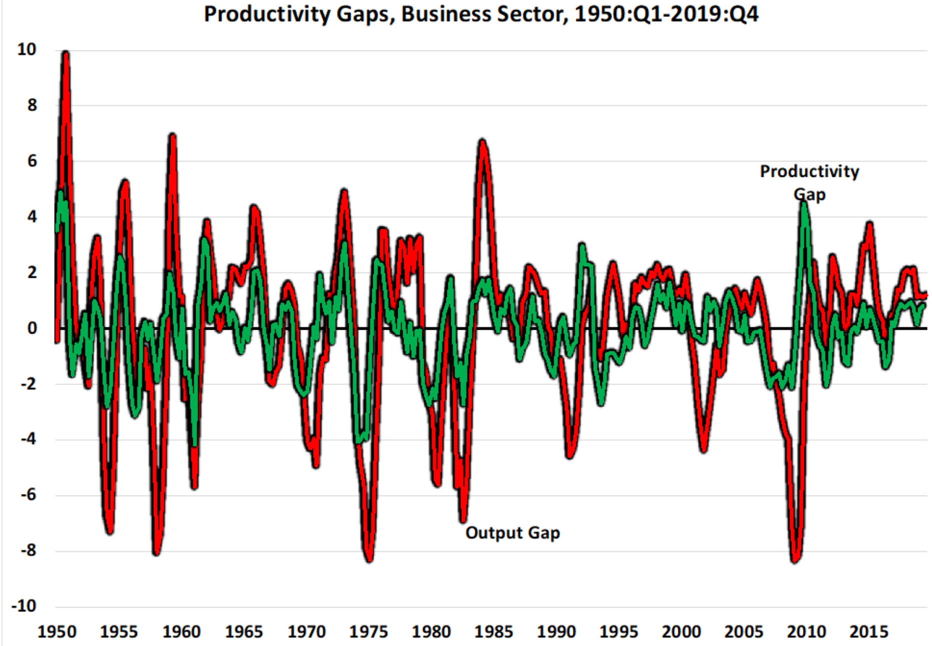
In this section we develop a framework that analyzes the cyclical relationship between deviations from trend, or "gaps," for output, hours, and productivity growth. Our approach characterizes the adjustment mechanism as a gradual response of changes in the hours gap to changes in the output gap. We then show that the observed cyclical behavior of changes in the gap in productivity, or output per hour, is 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.

Thus, we interpret what are often called "productivity shocks" in the macroeconomics literature not as autonomous shocks to productivity itself but rather as the mechanical byproduct of incomplete hours adjustment to quarterly output movements that reflect short-run changes in the dynamics of consumption, inventory change, or other components of real 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 describe the productivity gap change as acyclical. Using the notation * for trends and ʹ 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:

$$\mathrm{Y}' \equiv LN\left(\frac{\mathrm{Y}}{\mathrm{Y}^*}\right) \text{ and } \mathrm{y}' \equiv y - y^* \tag{2}$$

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 3a. When the displayed change meets the horizontal black line at zero, 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 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 not accompanied by a productivity gap response, appears to be the only exception to this regular procyclical behavior prior to the mid-1980s.

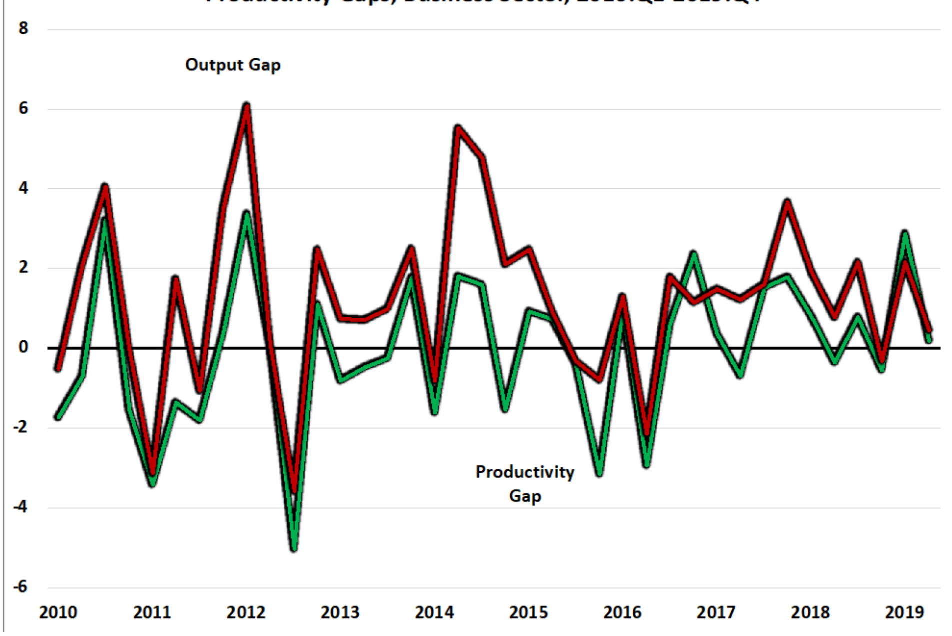
Figure 3a. Four-Quarter-Moving-Average Change in Kalman Output and Productivity Gaps, Business Sector, 1950:Q1-2019:Q4



Between 1986 and 2007, 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 the negative 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 3b, which displays *one-quarter* changes in output and productivity gaps for 2010-19. 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 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). Subseuqently we interpret the return of procyclicality in 2010-19 to the disappearance of positive serial correlation in the output series.

Figure 3b. One-quarter Annualized Change in Kalman Output and Productivity Gaps, Business Sector, 2010:Q1-2019:Q4



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, by definition equal to output less hours gap changes. 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 followed by subsequent further positive reactions. This implies that the productivity change exhibits overshooting, responding with a sharp positive response in the current quarter followed by negative reactions 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 evident in Figure 3b.

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:

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

The constant term 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 the output trend. 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:

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

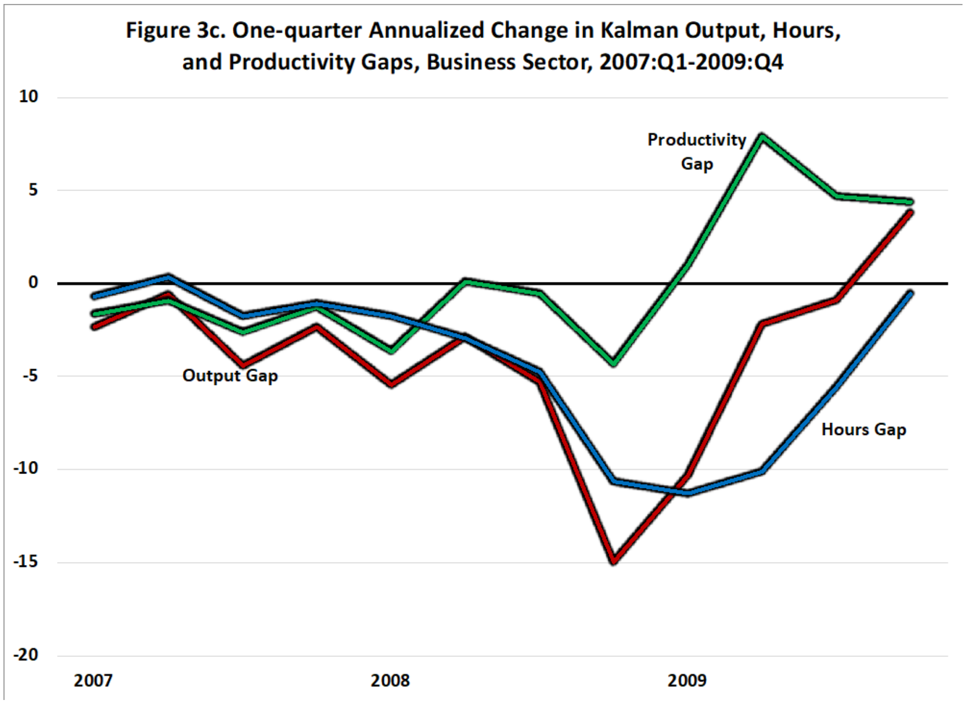
The responses of each dependent variable, hours or productivity, to current and lagged values of the output gap changes are given by the α_i coefficients. The coefficients on current output gap changes across the hours and productivity equations must sum to unity, while the coefficients across the two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

While the model in (3) and (4) captures the dynamics of hours and productivity before 2007, it misses an important extra component of behavior that occurred in the recession of 2008-09. Figure 3c displays one-quarter changes in the output, hours, and productivity gaps for 2007:Q1-2009:Q4. Note that the output gap change turned negative prior to the NBER-dated business cycle peak month in December 2007 because actual output growth was well below the Kalman trend of output change during all four quarters of 2007.[10]

The one-quarter changes in Figure 3c show that the hours gap responded very differently relative to the output gap in 2009 as compared to 2007-08. In the eight quarters of 2007-08, the hours gap (blue) declined somewhat less than the output gap (red), -3.0 percent compared to -4.8 percent, resulting in modest negative -1.8 percent decline of the productivity gap (green). Thus, the pattern of responses for 2007-08 in Figure 3c supports the view that

[10] Recall from Table 1 that our output concept is the average growth rate of real GDP and real GDI. While actual real GDP growth was positive in all four quarters of 2007, real GDI growth was a strongly negative -4.67 percent in 2007:Q3. The average growth rate of real GDI in the four quarters of 2007 was -0.89 percent, much lower than the 2.04 percent growth rate of real GDP.

productivity growth continued to be procyclical in 2007-08, conflicting with most of the literature reviewed above that productivity growth was acyclical after 1985.



Behavior was different in 2009. During the last two quarters of the NBER-dated recession (2009:Q1-Q2), the hours gap declined much more than the output gap, at an annual rate of -10.2 percent vs. -6.3 percent, resulting in a sharp 3.9 percent increase in the productivity gap. In the second half of 2009, the output gap began its recovery with an annualized growth rate of +1.4 percent while the hours gap continued to decline at a -3.2 percent annual rate, resulting in a further 4.6 percent increase in the productivity gap. For the four quarters of 2009 taken together, the productivity gap rose by 4.3 percent, equal to the -2.5 percent decline in the output gap minus the -6.7 percent decline in the hours gap. This opposing movement in the output and productivity gaps marks 2009 as displaying strongly countercyclical productivity behavior.

The collapse of the hours gap in 2009 mainly reflects the behavior of employment, not weekly hours of work.[11] Why did employment decline so much in 2009? Part of the weakness of employment in that year reflected the continuing influence of what Autor and co-authors (2021) call the "China shock," the effect of rising imports from China beginning in the early 2000s in closing plants and cutting employment in particular manufacturing industries linked to specific import categories. Acemoglu *et al.* (2016) also address this phenomenon with a specific comment on the low level of manufacturing employment in 2008-09:

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[11] Between 2007:Q4 and 2009:Q4 the percent log decline of total hours was -9.1 percent, of employment was -7.6 percent, and of weekly hours per employee was -1.5 percent. See https://data.bls.gov/PDQWeb/ce.

> U.S. manufacturing industries that were heavily exposed to Chinese import competition during the 1999-2007 period continued to see rapid, differential employment declines during 2007-2011. . . . One explanation for this long shadow is that US manufacturers recognized that the loss of comparative advantage in the sectors that Chinese imports had penetrated in the prior decade was largely permanent. . . . Thus, trade pressure appears to have contributed to the US employment sag not just before but also during the Great Recession (Acemoglu *et al.* 2016, p. S184).

The sharp contraction of employment in the Great Recession of 2008-09 did not just occur in manufacturing. Construction experienced the largest percentage drop, falling almost 30 percent from its peak in 2006:Q3 to the end of 2009, with most of the decline occurring after 2007. Much of the severity of the decline of overall employment during the recession was due to the combined effect of construction and manufacturing. Charles (2016) *et al.* point to a "masking" of the import-caused decline of manufacturing employment starting in the early 2000s by the employment-creating effects of the 2002-2006 housing boom. "The sharp decline of employment that occurred during the Great Recession was due not only to cyclical forces, but also to the fact that the massive housing bust, which coincided with the start of the recession, 'unmasked' the adverse employment effects of more than a decade of systematic manufacturing decline." (Charles *et al.*, 2016, p. 196).

The housing bust reduced employment in the broader economy beyond construction, reflected not only in a reduction in the activity of constructing new housing units. Crashes in house prices after the 2002-06 housing bubble meant many home values fell below owners' outstanding mortgage balances. In a cross-sectional study, Mian and Sufi (2014) show that "counties with larger declines in housing net worth experienced larger declines of employment in the non-tradable goods sector. These declines are not due to supply-side shocks like construction activity or credit availability" (Mian and Sufi, 2014, p. 2221).

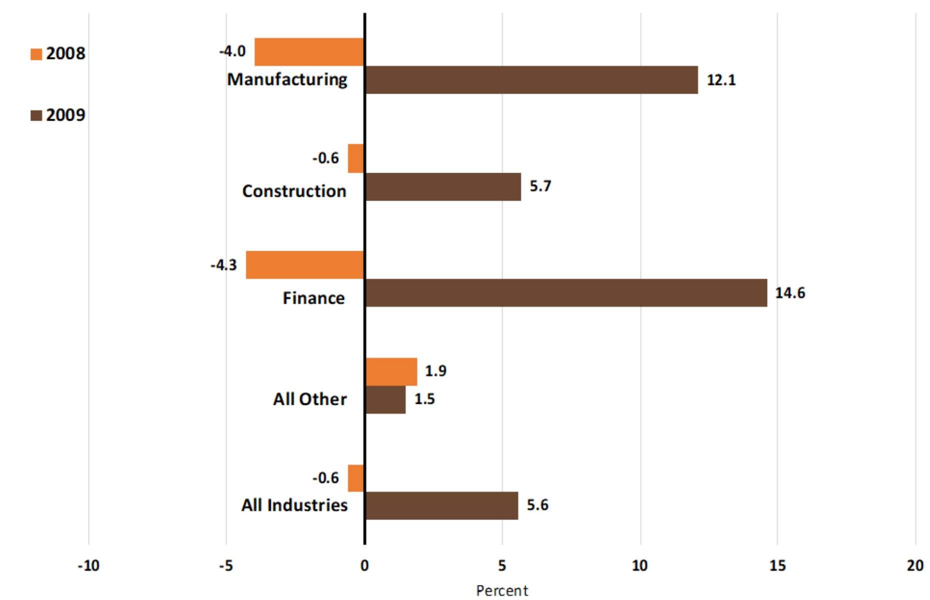
The Great Recession also caused a large dislocation in the finance industry, particularly after the failure of Lehman Brothers in September 2008. The timing of the Lehman failure helps us understand why, as shown in Figure 3c, the business-sector output gap declined in the 2008:Q4 by a massive -14.96 percent at an annual rate and the hours gap by -11.29 percent. The financial-sector implosion set off a panic throughout the economy. Business firms attempted to survive by cutting costs, particularly with excess layoffs that reduced hours more than output fell. Figure 3c shows that the hours gap fell slightly more than the output gap in 2009:Q1 and substantially more in 2009:Q2 and Q3, with negative growth of the hours gap despite positive output growth in 2009:Q4.[12] As a result, growth in the productivity gap was substantially positive in the last three quarters of 2009.

[12] The NBER-dated business cycle trough was in June, 2009. Our measure of the output gap declined in the subsequent quarter, 2009:Q3, even though it was the first quarter of the NBER-dated recovery, because the average of GDP and GDI growth was less than the growth in the Kalman output trend.

Labor hours were not the only component of the economy to exhibit unusually acute adjustment during 2009. Attanasio *et al.* (2022), show that U.S. household consumption and car purchase expenditures collapsed during the Great Recession at a larger rate than predicted by income changes. The collapse in auto sales was historic and proceeded at an annual rate of -61 percent between August 2008 and April 2009, resulting in the bankruptcy of two of the Big-Three auto manufacturers.[13] For the full year 2009, auto sales were 35 percent below the first half of 2008.

Our discussion suggests that this turnaround in the sign of productivity growth was concentrated in the manufacturing, construction, and finance industries. This evidence lines up with that shown in Figure 4 which displays (actual) productivity growth in those three industries separately for the four quarters of 2008 and 2009. The productivity growth turnaround from 2008 to 2009 was from -3.5 to +10.2 percent in manufacturing, from -0.5 to +10.2 percent in construction, and from -4.5 to a massive +14.6 percent in finance. In contrast there was no turnaround in the average of all other industries, which showed respective productivity growth of +1.9 and +1.5 percent in the two years. For all industries taken together, the turnaround was from -0.3 to +5.8 percent.[14]

Figure 4. Change in Productivity Growth in Selected Industries During the Four Quarters of 2008-09



[13] Source: https://fred.stlouisfed.org/series/TOTALSA

[14] These 2008-09 growth rates for all industries differ from those in Figure 3b for two reasons. First, they are actual growth rates of productivity, not the gaps that subtract the Kalman trend from the actual growth rates. Second, they come from our quarterly industry database described below where the numerator of productivity is real industry value added rather than the average of GDP and GDI.

5. Regression Analysis of the Recession and Recovery Effects

This section incorporates the unusual overshooting of the hours gap in the 2008-09 recession into the regression analysis introduced in equations (3) and (4). We define a separate set of current and lagged coefficients for the response of the hours gap to the output gap during the quarters of NBER-defined recessions. After discussing our initial results with this definition, we refine it subsequently to allow for a "recovery effect" in which the excess layoffs are gradually unwound by subsequent excess hiring.

For the recession effect, we modify the specification of our hours gap change equation:

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

"*recess*" is equal to 1 if quarter *t-i* is marked an NBER recession quarter and 0 otherwise. The α_i coefficients capture the normal 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 of the output and hours gap changes, equation (5) implies our productivity gap change $(y_t' - h_t')$ regression equation (6):

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

If there is a substantial positive sum of the recession β_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. Splitting up the regressions in equations (5) and (6) across different time periods will result in different estimates for the procyclicality of productivity (the sum of the α_is), for the additional recession effects (the sum of the β_is), along with different constant terms γ.

Our analyses of Figures 3a and 3b suggest 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. The second covering 1986-2006 witnesses a more muted and inconsistent procyclical response. The third from 2007 to 2019 combines the strong excess adjustment of hours during 2009 with the reappearance of a regular procyclical productivity response in 2007-08 and after 2009. After presenting estimated coefficients for the three time periods, we provide explanations for the shifts in the cyclical productivity response across time periods.

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. A current quarter change in the output gap creates a 0.46 to 0.54 division between 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 0.46+0.26 or 0.72, while that of productivity is 0.54-0.26 or 0.28. This long-run productivity response of 0.28 is highly significant and can be interpreted as a reflection of the incomplete adjustment of labor hours to output changes after five quarters are allowed for the adjustment process to take place. The 0.28 coefficient is similar to the one-third response of productivity that was a component of the original (1963) version of Okun's law. The overshooting embodied in the positive-negative sequence of the current and lagged productivity coefficients is consistent with our interpretation that productivity behavior is a residual, the definitional counterpart of the gradual adjustment of labor input to output fluctuations.

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	0.46**	0.54**	0.38**	0.62**	0.31**	0.69**		0.27**	0.73**
Effect of Output Lags 1-4	0.26**	-0.26**	0.41**	-0.41**	0.12	-0.12		-0.00	0.00
Total Effect of Output	**0.72****	**0.28****	**0.79****	**0.21**	**0.43****	**0.57****		**0.27***	**0.73****
Recession Effect of Current Output	0.11	-0.11	0.05	-0.05	0.15	-0.15		0.18	-0.18
Recession Effect of Output Lags 1-4	0.06	-0.06	0.34	-0.34	0.69**	-0.69**		0.76**	-0.76**
Total Recession Effect of Output	**0.17**	**-0.17**	**0.38**	**-0.38**	**0.84****	**-0.84****		**0.95****	**-0.95****
Constant	**0.25**	**-0.25**	**0.13**	**-0.13**	**0.59****	**-0.59****		**-0.07**	**0.07**
Adjusted R^2	**0.70**	**0.56**	**0.50**	**0.45**	**0.89**	**0.80**		**0.92**	**0.85**
RMSE	**2.12**	**2.12**	**1.58**	**1.61**	**1.07**	**1.07**		**0.93**	**0.93**

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

Results for the middle period 1986-2006 are displayed in the second pair of columns of Table 2. A current quarter change in the output gap is divided 0.38 and 0.62 between hours and productivity gap responses, indicating an initially greater productivity response and lower hours response than in 1950-85. However, the subsequent hours response over the following four quarters is a substantially greater 0.41, yielding a long-run response of hours of 0.79 while the long-run productivity response drops to 0.21 and is statistically insignificant. This set of results provides an important contrast to the previous literature. In going from 1950-85 to 1986-2006, the long-run productivity response declines not to zero but just from 0.28 to 0.21. Thus, it appears that the previous literature has exaggerated the difference in behavior of the pre-1986 and post-1986 intervals. After discussing 2007-19, we suggest two reasons why the productivity response was lower during 1986-2006 but then substantially higher during 2007-2019.

The next two columns of Table 2 show the results for 2007-19 and indicate that the current-quarter responses of hours and productivity are 0.31 and 0.69, respectively, close to the current-quarter responses in the middle 1986-2006 interval. But the subsequent adjustment in the next four quarters is a modest and insignificant 0.12 for hours and -0.12 for productivity. 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, doubling the 0.28 long-run response of productivity changes during the initial 1950-85 interval.

To understand the reasons for this shift in the productivity and hours gap responses after 2006, we need to focus on the second set of rows where the β_i recession coefficients are displayed. There for 2007-19 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 0.58 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 3c above.

As suggested above, a plausible interpretation of this episode is that business firms overreacted to 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 response took place 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 June 2009 NBER 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. Another measure of the severity of the Great Recession and slowness of the subsequent recovery is that the percent of the unemployed who were out of work for 26 weeks or more was above 30 percent continuously from June 2009 to February 2015, despite only briefly going above 20 percent in the entire previous postwar era. Farber emphasizes that one reason for the slow employment recovery was that the unemployed could not find new jobs by moving, because the downturn had been so widespread (Farber, 2012, p. 525).

The effect of the 2008-09 recession did not end in 2009. The employees who were victims of excess layoffs did not stay unemployed forever; they gradually found new jobs. The behavior of the employment-population ratio and long-duration unemployment confirms that this employment recovery took a long time. The highly significant constant terms in the 2007-2019 regressions shown in the third pair of columns in Table 2 indicate that on average hours grew faster than the output-response coefficients can explain. Our interpretation is that the downward overshooting of hours in 2009 was gradually reversed by a steady pace of rehiring and hours gap recovery that proceeded independently of changes in the output gap. The large positive constant term of 0.59 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. These results indicate that the observed procyclicality of productivity was the counterpart of relatively steady hours growth over the 2010-19 interval. Below we provide a complementary explanation based on the low serial correlation of output changes during the 2010-19 interval.

This gradual hours recovery persisted beyond 2010 through 2019. When we estimate the Table 2 regressions separately for 2010-14 and 2015-19, the constant term in the hours equation remains large, declining only from 1.01 to 0.63 between the two sub-periods, with both values at a high significance level. The tepid 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 3b, is characterized by a strong procyclical 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 in the constant term in Table 2, we model the recovery process explicitly as part of the recession effect, with the magnitude of the recession and recovery effects jointly 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 the output gap change 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 negatively sloped linear function of *t*. This linear function has the property that it is equal to 0 at time *t=M+N+1* and the sum of its values is equal to the *negative* of the cumulative recession values of y'_t. That is,

$$v'_t = -\xi(t - (M + N + 1)) \tag{7}$$

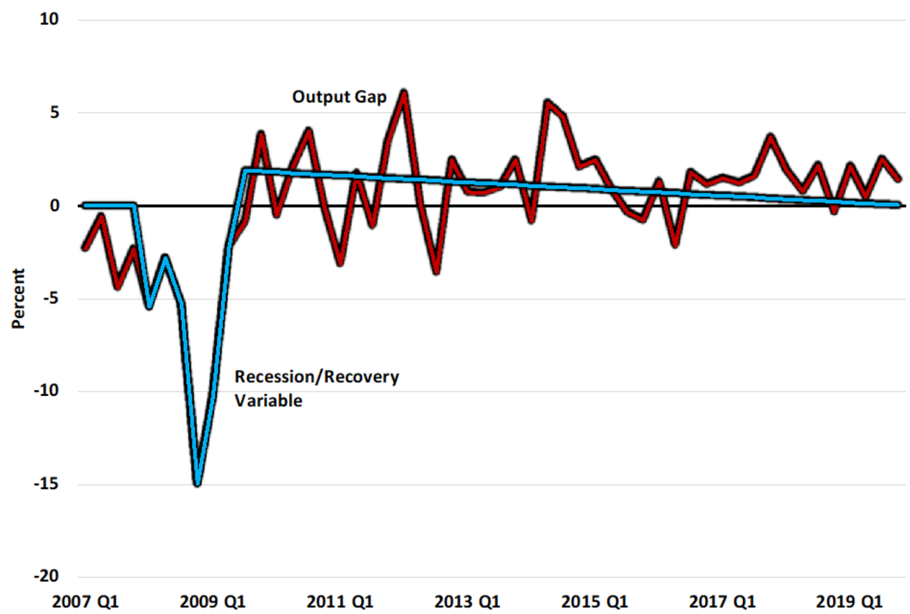
$$\sum_{t=M+1}^{M+N} v'_t = \sum_{t=1}^{M} y'_t \tag{8}$$

A brief calculation shows that $\xi = 2\frac{\sum_{t=1}^{M} y'_t}{N(N+1)}$. By definition, *Nv′* equals the negative of the summation term in (8), 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 $recov_t$ 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 (9):

$$h'_t = \gamma + \sum_{i=0}^{4} \alpha_i y'_{t-i} + \sum_{i=0}^{4} \beta_i * (recess_{t-i} * y'_{t-i} + recov_{t-i} * v'_t) + \eta_t \qquad (9)$$

The estimated β_i coefficients reflect the combined impact of the recession and subsequent recovery. The values of the recession/recovery variable for 2007-19 are shown in Figure 5a (blue), which also displays the quarterly change in the output gap (red). The blue line lies on top of the red in the six recession quarters of 2008:Q1 to 2009:Q2, reflecting the first term in the parenthesis in (9). After 2009:Q2 the blue line becomes a linearly declining segment extending from 2009:Q3 to 2019:Q2, i.e. the v'_t term in equation (9).

Figure 5a. Output Gap Change and Recession/Recovery Variable, Business Sector, 2007:Q1-2019:Q4



The choice of a linearly declining recovery variable extending for ten years is one of several possible alternatives, and so we have tested several other options including no recovery effect and different specifications for the timing of the recovery variable. The long-run coefficients and statistics of fit of seven alternatives are shown in Appendix Table A1, with root mean-squared errors declining across alternatives from 1.44 with no recession or recovery effect to 1.09 with our preferred treatment with the linearly declining recovery effect.[15] While ten

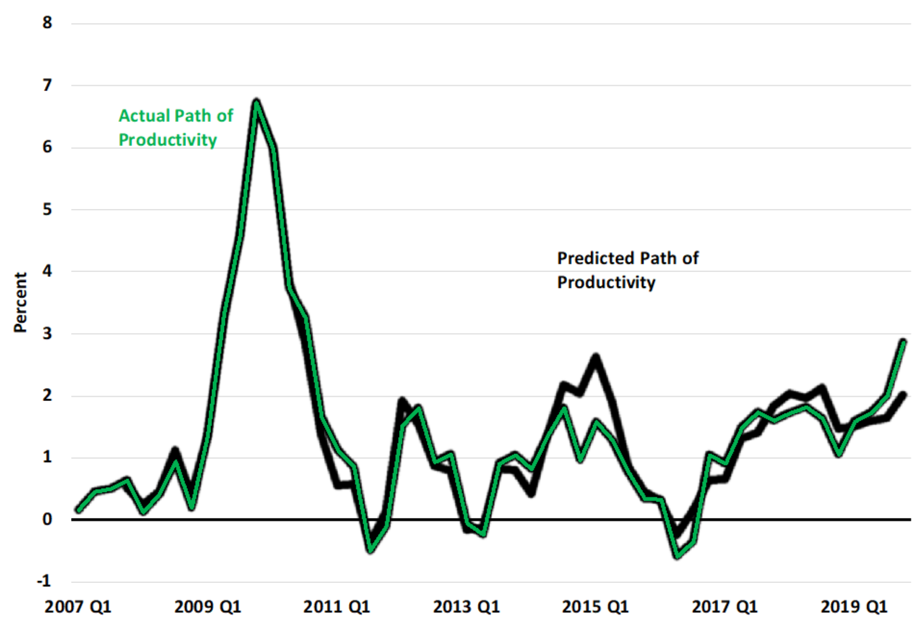
[15] . These include, in order from left to right in that table, (a) no recession or recovery effect with a constant, (b) recession effect and no constant or recovery effect, (c) recession effect and constant but no recovery effect, (d) recovery effect as a constant value for 2010-19, (e) a three-step recovery effect with a stepwise decline in v'_t in the three intervals of equal length between 2009:Q3 and 2019:Q2, (f) recovery effect as a constant value for 2010-16 and zero for 2017-19, and (g) the preferred version with a linearly declining recovery effect v'_t as in Figure 6a.

years may seem to be a long duration for the recovery effect, previous research has emphasized the slow and gradual recovery of the labor market from the 2008-09 trauma[16].

The two right-hand columns in Table 2 labeled "2007-2019 (Recovery)" report regressions identical to those in Table 2 labeled "(No Recovery)" except for the addition of the linearly declining v_t' recovery variable. In the two right-hand columns, the constant term drops from 0.59 to -0.07, indicating that our treatment of the recovery effect makes explicit the recovery pace of rehiring that is otherwise "hidden" in the large and significant constant term when the explicit recovery value is omitted. The long-run normal plus recession responses of hours gap changes to output gap changes is 1.22 with the recovery effect, similar to the 1.27 without the recovery effect.

Our preferred treatment of the 2007-2019 interval yields a remarkably precise set of fitted values of labor productivity gap changes, shown by the black line in Figure 5b. Predicted productivity growth soars in 2009, demonstrating the countercyclical response implied by excess layoffs. Following this countercyclical episode, the predicted productivity gap changes closely track actual changes throughout 2010-19.

Figure 5b. Actual vs. Fitted 4QMA of Labor Productivity Growth, Business Sector, 2007:Q1-2019:Q4



Two remaining questions about the Table 2 results concern the regular α_i (non-recession) long-run response coefficients of the productivity growth gap to output gap changes, declining from a significant 0.28 in 1950-85 to an insignificant 0.21 in 1986-2006 before jumping

[16] For instance, Yagan (2019) shows across local labor markets that "exposure to a severe local Great Recession caused working-age Americans to be substantially less likely to be employed in 2015." (Yagan, 2019, p. 2552)

up to a significant 0.73 in 2007-2019. What caused the lower response in 1986-2006 compared to 1950-85? One possible interpretation has been offered by Gordon (2010) and others: the lagged response of hours to output changes became more complete after 1985 as a result of greater management emphasis on maximizing shareholder value. The more complete adjustment of hours to output changes implies that the residual productivity changes residual exhibit a smaller response.

A complementary explanation is that the hours response to output changes was more complete during 1986-2006 due to the "Great Moderation"; the variance of output changes was much smaller than in the earlier 1950-85 interval. As shown in the left section of Table 3, the standard deviation of the quarterly output gap change was 2.50 for 1986-2006, less than half of the 5.47 standard deviation for 1950-85. Because the variance of output gap changes was smaller in 1986-2006 than before, labor input adjustment over the four lagged quarters could catch up more completely, that is, be a larger percent of the output gap change. Notice in Table 2 that the effect of output lags 1 to 4 is 0.41 in 1986-2006, substantially larger than the 0.26 in 1950-85. Because productivity growth is a residual, the larger percentage lagged response of the hours gap implies a smaller percentage lagged response of the productivity gap.

Table 3. Standard Deviation and Serial Correlation of Output, Hours, an Labor Productivity Growth Gaps, Selected Intervals, 1950:Q1-2019:Q4

	Output	Hours	Productivity
Time Period	**Standard Deviation**		
1950:Q1-1985:Q4	5.47	4.00	3.42
1986:Q1-2006:Q4	2.50	2.24	2.14
2007:Q1-2009:Q4	4.83	4.24	3.68
2010:Q1-2019:Q4	2.05	1.21	1.89
	Serial Correlation		
1950:Q1-1985:Q4	0.38	0.51	-0.01
1986:Q1-2006:Q4	0.37	0.52	0.03
2007:Q1-2009:Q4	0.46	0.77	0.56
2010:Q1-2019:Q4	0.00	0.17	-0.08

The second question is why the long-term productivity response jumped up to 0.73 after the Great Recession of 2008-09. Figure 3b plots the tight procyclical relation of the productivity gap change to the sharp up-and-down zig-zags of output gap change during 2010-19. Table 3 shows that the serial correlation of quarterly output gap changes declined from around 0.38 in 1950-2006 to exactly 0.00 during 2010-19. Because output gap changes were less persistent and kept jumping up and down, hours had insufficient time to catch up. The coefficient on lags 1 to 4 of the α_i hours gap response is 0.00 in 2007-2019, as shown in the right panel of Table 2, much smaller than the 0.26 in 1950-85 or the 0.41 in 1986-2006. Hence, productivity gap changes, the residual difference between erratic output gap changes and the incomplete hours gap responses, tended to mimic output gap changes, resulting in the long-run coefficient of 0.73.[17]

A robustness issue is the sensitivity of the Table 2 results to our particular form of data detrending based on the Kalman filter, as shown in Figures 1 and 2. To check on this sensitivity, Table 4 compares the results with and without detrending. The two left columns of Table 4 copy the previous results based on detrended data from the two right columns of Table 2. For comparison the two right columns of Table 4 show the same exact specification run on raw change data that have not been detrended. The results are similar without detrending and in fact the recession-recovery effect becomes larger. The normal long-run productivity response declines from 0.73 with detrending to 0.60 without detrending. The long-run recession-recovery productivity response rises from -0.95 to -1.44, indicating that the potency of this effect does not depend on our method of detrending the output, hours, and productivity data.

Table 4. Regression Response to Changes in Output for Labor Productivity and Hours, 2007:Q1-2019:Q4, Detrended vs. Non-Detrended Business Sector

	2007-2019 (Recovery, Detrended)			2007-2019 (Recovery, Non-Detrended)	
	Hours	**Prod.**		**Hours**	**Prod.**
Effect of Current Output	0.27**	0.73**		0.30**	0.70**
Effect of Output Lags 1-4	-0.00	0.00		0.10	-0.10
Total Effect of Output	**0.27***	**0.73****		**0.40***	**0.60****
Recession Effect of Current Output	0.18	-0.18		0.38**	-0.38**
Recession Effect of Output Lags 1-4	0.76**	-0.76**		1.06**	-1.06**
Total Recession Effect of Output	**0.95****	**-0.95****		**1.44****	**-1.44****
Constant	**-0.07**	**0.07**		**-0.25**	**0.25**
Adjusted R^2	**0.92**	**0.85**		**0.91**	**0.83**
RMSE	**0.93**	**0.93**		**0.98**	**0.98**

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

Has the cyclical behavior of TFP consistently echoed that of labor productivity? Table 5 repeats the productivity gap change regressions of Table 2 with changes in the TFP gap substituted as dependent variable. The main results of Table 2 are replicated for the same sample periods of 1950-85, 1986-2006, and 2007-2019, where the 2007-19 results repeat the recession-recovery treatment of the right side of Table 2. The long-run normal TFP gap response to a change in the output gap is strongly positive and consistent across the three time intervals— 0.50, 0.39, and 0.63. The pattern of normal response coefficients for TFP is again positive in the current quarter followed by negative in the subsequent four quarters, supporting our interpretation that productivity fluctuations are a residual, the result of gradual adjustment of labor hours. The long-run recession/recovery responses are insignificant in the first two

[17] While Table 3 and Figure 3b refer only to 2010-19 while the Table 2 regressions refer to 2007-19, we can see in Figure 3c that there was a substantial procyclical response of the productivity gap within in the year 2007, while movements in 2008-09 are captured by the separate regression-recovery β_i coefficients.

periods but a highly significant -0.50 in the third period. The constant terms for all three periods are insignificant and close to zero.

Thus, TFP growth is consistently procyclical throughout the postwar era. During the 2008-09 recession the normal effect is slightly larger than the recession-recovery effect, so that the sum of the two effects is 0.13, a small procyclical response. Why is this 2008-09 reaction slightly procyclical for TFP but strongly countercyclical for labor productivity? Leaving aside a small contribution of labor quality, TFP growth equals labor productivity growth minus capital's income share times the growth rate in the capital-labor ratio. Since capital growth exhibits little cyclical variation but labor input growth is strongly procyclical, particularly in 2008-09, as a result the capital-labor ratio is strongly countercyclical. Hence TFP growth would be expected to be more procyclical than labor productivity growth.

Table 5. Regression Response to Changes in Output Gap for Total Factor Productivity, 1950:Q1-2019:Q4, Business Sector

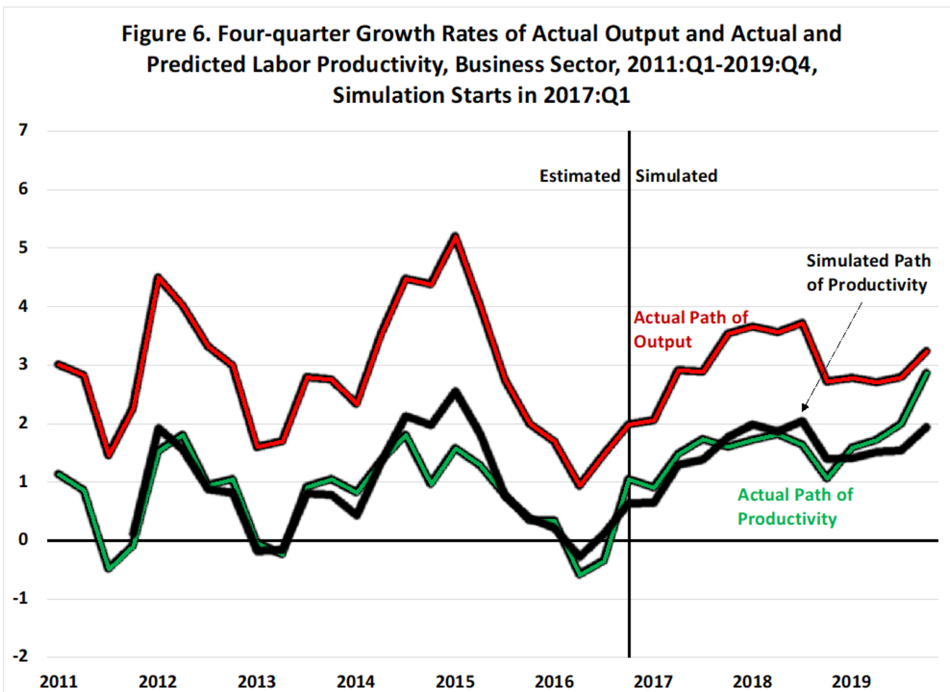
	1950-1985	1986-2006	2007-2019
	TFP	TFP	TFP
Effect of Current Output	0.71**	0.80**	0.87**
Effect of Output Lags 1-4	-0.21**	-0.41**	-0.24*
Total Effect of Output	**0.50****	**0.39***	**0.63****
Recession Effect of Current Output	-0.08	-0.12	-0.12
Recession Effect of Output Lags 1-4	-0.07	-0.27	-0.38**
Total Recession Effect of Output	**-0.15**	**-0.39**	**-0.50****
Constant	**-0.09**	**-0.13**	**-0.00**
Adjusted R^2	**0.83**	**0.64**	**0.88**
RMSE	**1.50**	**1.39**	**0.93**

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

So far, we have examined the behavior of the productivity gap growth for the 2010-19 decade as a whole. Another issue worth exploring is evident in Table 1 above – business sector productivity growth in 2017-19 was 1.84 percent per year, more than double the 0.86 percent growth rate of 2010-16. How much of this revival was due to the behavior of the recession/recovery effect? As shown in Figure 5b, the linearly declining positive pattern assumed for the recovery effect implies a much smaller recovery of hours growth in 2017-19 than in 2010-16. Since productivity growth is a residual, the recession/recovery effect implies that the *negative* impact on productivity growth in 2017-19 is much smaller than in 2010-16.

To test the ability of the model to capture the magnitude of the 2017-19 productivity growth revival, we run the equation again with the sample period shortened to 2007-16 instead of 2007-19. Then we calculate a post-sample simulation of the 2007-16 fitted coefficients that allows us to decompose the simulated 2017-19 values of productivity change into the respective contributions of the normal response to the change in the output gap, the separate recession/recovery effect, and the underlying trend used to calculate the gaps.

Figure 6 plots the simulated values of actual productivity change against the actual changes in output and productivity (that is, these are the actual changes in the data rather than the detrended gap changes). The graph covers 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 simulation to 2019:Q4 based on the regression's prediction of the productivity gap change. The black line plots the predicted gap change plus the Kalman trend values used to calculate the gaps from the raw productivity change data.



As in Figure 5b, the fitted values are accurate through 2016:Q4, tracking the ups and downs of productivity growth as it responds to changes in output growth. From 2017:Q1 to 2019:Q4, the predicted value of the productivity growth simulation does a good job on average, tracking the actual change accurately during 2017 and 2018 while modestly underpredicting it in 2019. On average, the predicted value for 2017-19 is 1.75 percent, slightly below the actual average of 1.84 percent. The fitted values of the regression equation for 2010-16 average 0.85 percent, so the equation accurately predicts that productivity growth doubled from 2010-16 to 2017-19.

How much does the recovery effect, which holds down productivity growth in 2010-16 due the post-recession rehiring, contribute to the predicted revival? Table 6 decomposes the contribution of the separate variables. Line 1 shows that an acceleration of the regular output ga; growth effect in 2017-19 explains 0.35 of the increase in productivity growth. Line 2 calculates a much larger contribution of 0.81 percent from the unwinding of the recovery hiring effect. Line 3 shows no contribution from the constant, and line 4 shows that the slowdown in the trend over the 2010 to 2016 interval subtracts -0.26 percent from thethe explanation of the 2017-19 productivity growth revival. We conclude that the main reason for the revival was that productivity growth had been held down in 2010-16 by the growth in hours due to the rehiring of workers after the excess layoffs of 2009, leaving only a minor role for an increase in output growth in 2017-19. This interpretation is important in assessing the potential role for President Trump's tax cuts and changes in regulation as possible causes of the 2017-19 productivity growth revival.

Table 6. Decomposition of Predicted Productivity Change vs. Actual Change, 2010-16 and 2017-19

	2010-2016	2017-2019	Change
(1) Contribution of Regular Output Gap Effect	0.81	1.16	0.35
(2) Contribution of Recession/Recovery Effect	-1.13	-0.32	0.81
(3) Constant Term	0.03	0.03	0.00
(4a) Contribution of Average Kalman Trend, 2010-16	1.14		
(4b) Contribution of Kalman Trend Value in 2016:Q4		0.88	-0.26
(5) Predicted Value (1+2+3+4)	0.85	1.75	0.90
(6) Actual Value	0.86	1.84	0.98
(7) Error (6-5)	0.00	0.08	0.08

We briefly assess the role of innovation — i.e. TFP growth — in driving the 2017-19 productivity growth revival. In simulation results based on the same technique as in Table 6 . we find that actual TFP growth in 2017-19 is almost precisely predicted by the Table 5 equation with its sample period shortened to 2007-16. The actual 2017-19 annual growth rate of TFP is 1.03 (see Table 1) while the predicted growth rate is 1.01, for an error of just 0.02 percentage points. This implies that, as for labor productivity growth, the revival in TFP growth was mainly due to the unwinding of the post-recession rehiring effect as captured by the estimated 2007-16 equation along with the assumed pattern of the rehiring effect. The underlying trend of TFP growth as shown in Figure 2 slowed from 1.35 percent per year in 1996-2004 to 0.61 percent in 2005-09 to 0.42 percent in 2010-16 to 0.18 percent in 2017-19.

Both labor productivity and TFP growth doubled between 2010-16 and 2017-19. Table 7 shows for 2010-16, 2017-19, and 2020-23 a decomposition of how TFP is calculated from data on growth in labor productivity, capital input, labor hours, and labor composition. The last two columns show the changes from one interval to the next. Between 2010-16 and 2017-19, productivity growth increased by 0.98 percentage points and capital by 0.50 points, while hours growth decreased by 0.69 points, implying a sharp acceleration of capital deepening (capital less hours growth) of 1.19 points. When multiplied by capital's income share of 0.38, the acceleration of the contribution of capital deepening accounts for 0.45 points of the 0.98 point revival of productivity growth. TFP growth increased by 0.50 points, with the extra 0.03 points of the labor productivity acceleration contributed by labor quality (totals do not exactly add due to rounding).

Table 7. Relationship Between Changes in Business Sector Labor Productivity and TFP, Selected Intervals, 2010-2024

	Annual Rate Changes Over Interval	2010-16	2017-19	2020-23	Change from 2010-16 to 2017-19	Change from 2017-19 to 2020-23
		[1]	[2]	[3]	[4]	[5]
1	Labor Productivity	0.86	1.84	1.31	0.98	-0.53
2	Capital Input	2.45	2.95	2.56	0.50	-0.39
3	Labor Hours	2.02	1.33	0.59	-0.69	-0.73
4	Capital Deepening (line 2-3)	0.43	1.63	1.97	1.19	0.34
5	Labor Quality	0.26	0.31	0.48	0.04	0.17
6	Contribution of Capital Deepening (line 4*9)	0.17	0.62	0.77	0.45	0.15
7	Contribution of Labor Quality (line 5*(1-9))	0.16	0.19	0.29	0.03	0.10
8	Total Factor Productivity (line 1-6-7)	0.53	1.03	0.24	0.50	-0.78
9	Memo: Capital Income Share	0.39	0.38	0.39		

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 21, 2023).

Subsequent sections of the paper examine the behavior of labor productivity growth during 2020-23, where our data extend through 2023:Q4. Here, our analysis is limited to the relative roles of capital deepening and TFP growth in contributing to pandemic-era productivity growth. Column [5] of Table 7 shows that TFP growth accounted for more than all of the sharp deceleration in labor productivity growth (-0.78/-0.53) when 2020-23 is compared to 2017-19. Notice in column [5] that capital deepening increased in 2020-23 despite slowing capital growth because hours decelerated even more rapidly. The contribution of added growth in capital deepening was supplemented by extra growth in the contribution of labor quality. Overall, TFP growth slowed more than labor productivity growth, by -0.78 percent to an abysmal 0.24 percent growth rate in 2020-23 from 1.03 percent in 2017-19.

6. Productivity Growth during and after the Pandemic: The Role of Changing Weights

We now examine productivity behavior in the 16 quarters from 2020:Q1 through 2023:Q4. This includes the sharp lockdown of the economy in 2020:Q2, the rapid but partial reopening in 2020:Q3, and the subsequent recovery of the following 13 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 15.1 percent in that quarter.

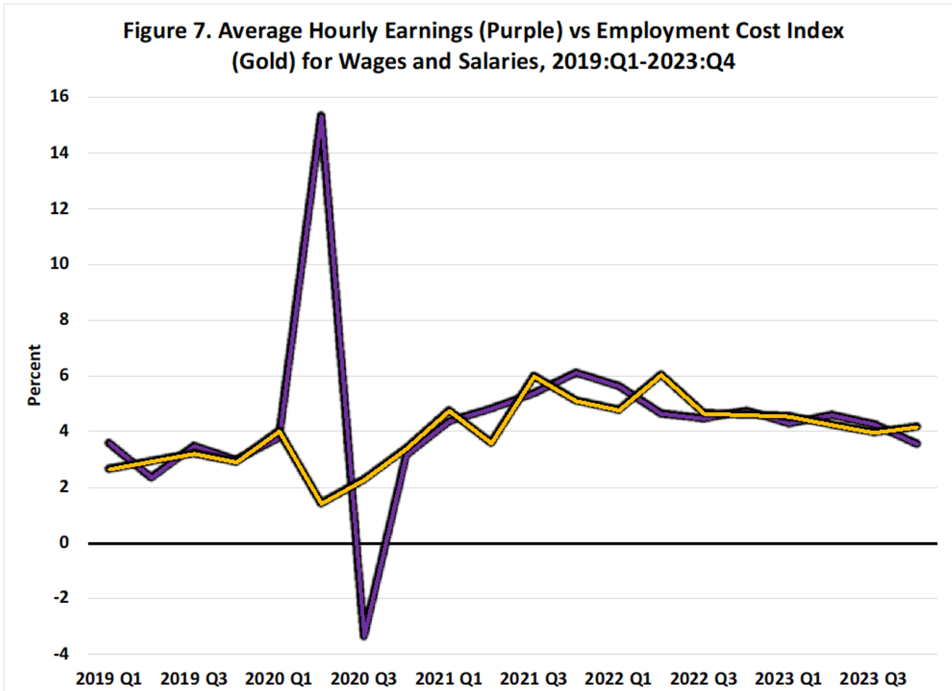
We show that the apparent countercyclical behavior of productivity in 2020:Q2 reflected not a sudden outburst of creative innovation but rather a shift in the mix of output and employment toward higher productivity sectors of the economy. While output and employment dropped everywhere, they declined much faster in sectors with a relatively low *level* of labor productivity and wages . 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 from 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 displayed below in Table 8.

Table 8. Industries Listed by Industry Group, Ranked by 2019:Q4 Real Value Added per Hour

Goods	Work-at-home Services	Contact Services
Mining (311.1)	Information (235.4)	Wholesale trade (92.9)
Utilities (246.1)	Finance, insurance, real estate, rental, and leasing (208.5)	Arts, entertainment, and recreation (70.0)
Nondurable goods (102.6)	Management of companies and enterprises (90.6)	Transportation and warehousing (49.7)
Durable goods (72.9)	Professional, scientific, and technical services (83.8)	Retail trade (45.9)
Construction (43.9)	Administrative and waste management services (35.1)	Educational services, health care, and social assistance (40.0)
		Other services, except government (37.8)
		Accommodation and food services (27.2)

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 15.3

percent in 2020:Q2 due to the disproportionate decline in hours of relatively low-paid employees, followed by a decrease of 3.3 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 both of these two quarters (1.4 and 2.3 percent annualized).



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 indices provide industry detail only in annual data. To address the mix issue for productivity in up-to-date quarterly data, we have constructed a quarterly database 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 hours as the product of industry employment and weekly hours (from the Current Population Survey).[18]

To avoid the weighting distortion that would occur if current weights (CW) were used, 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. We use the following to notate industry aggregate output:

$$Y_t^{agg} = \sum_i Y_{it}$$

[18] 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 listings of Table 8.

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

$$cw_t = y_{\boldsymbol{t}}^{agg} - h_t^{agg} \tag{10}$$

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

The FYW index represents 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 output share) times the labor productivity growth of that industry.

Table A2 in the appendix provides examples using two industries — information services and accommodation — that show intuitively why the CW growth index, as in published BLS productivity indexes, significantly distorts actual productivity changes at the industry level during the middle quarters of 2020. The quarter-to-quarter change during the lockdown quarter of 2020:Q2 followed by the partial reopening quarter of 2020:Q3 are drastically altered by the mix effect. In the Table A2 example, while information services had a productivity increase between 2019:Q4 and 2020:Q2 of 13.6 percent and accommodation had an annual decrease of -26.9 percent, 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.

Thus, the use of current values yields a heavily 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. Column (11) shows that the CW index for the subsequent quarter 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. The bottom panel of Table A2 repeats this exercise with the top and bottom quartile of the 17 industries when ranked by their 2019:Q4 level of productivity, and shows a similar effect.

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 17.6 percent compared to the 2.8 percent for the FYW index. The FYW index bounces back in the subsequent quarter 2020:Q3 when its annualized one-quarter change is 17.7 percent in contrast to 7.4 percent for the CW index. These large differences in growth rates across the two indexes apply only to the middle two quarters of 2020; Figure 8 shows that the two indexes record similar growth rates for the other quarters of 2020-23.[19]

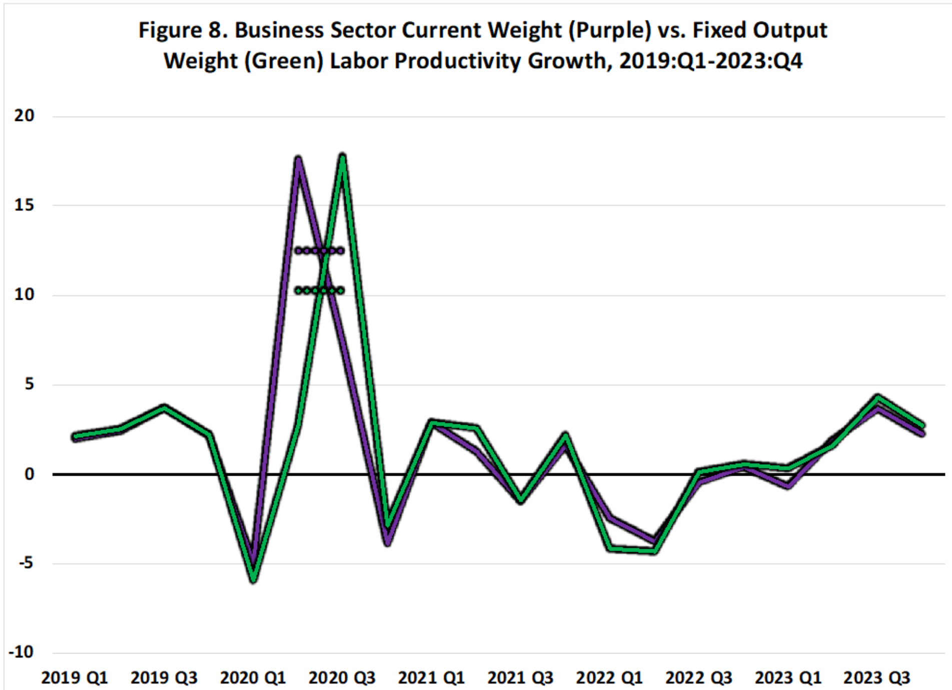


Figure 8 also shows that the difference between the CW and FYW indices in the middle two quarters of 2020 is reduced when plotting the average growth rates for these two quarters. . As shown by the horizontal dashed lines drawn for the two-quarters averaged together, the average CW growth rate of 12.5 percent is only modestly higher than the FYW growth rate of 10.2 percent. Thus, most of the shifting-weight phenomenon can be avoided by merging those two quarters together. Cumulative annual growth rates over the 16 quarters of 2020:Q1 to 2023:Q4 are almost the same: the CW and FYW indexes grow at similar rates of 1.33 and 1.20 percent respectively. The 1.33 percent CW index growth rate aggregated from our underlying industry data is virtually identical to the 2020-23 productivity growth rate for the aggregate business sector of 1.31 percent from the official aggregate BLS data (computed by the CW method) as recorded above in Table 1.[20]

[19] The difference between the two indexes exceeds an annualized 1.0 percent in only two quarters of the 13 quarters between 2020:Q4 and 2023:Q4.

[20] The aggregate growth rate of the industry data can be different than the growth rate of the business-sector data used in Table 1 and in the regression analysis in this paper, since the latter are based on the average of GDP and GDI rather than GDP alone as in the industry data.

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

In Figure 6 and Table 6, we used a simulation analysis to interpret the productivity growth revival in 2017-19 when compared to 2010-16. The same simulation approach can be applied to the 16 quarters of 2020-23, where we can calculate the predicted values of the productivity gap change based on the estimated coefficients from the 2007-19 regression equations. These are characterized not only by a procyclical response of productivity gap changes to output gap changes, but also by the recession/recovery effect in which the hours gap changes overreact to negative output gap changes during the 2008-09 recession, followed by a recovery interval in which the overreaction is gradually eliminated. In order to use the estimated 2007-19 Table 2 coefficients for the 2020-23 post-sample simulation, we employ the same business-sector productivity data used to estimate the regressions, but average the output change series for 2020:Q2 and Q3 to adjust for the output mix distortions discussed in the previous section.

We use the same estimated coefficients from the right column in Table 2, where the sum of the normal adjustment (α_i) coefficients in the productivity gap equation is 0.73 and the sum of the recession/recovery (β_i) coefficients is -0.95. 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 8 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.

Figure 9a shows the recession-recovery effect as the blue line, duplicating the format of Figure 5a. From 2020:Q1-Q3, it is superimposed over the red output growth line, and from 2020:Q4 to 2022:Q3 shows the recovery effect. Figure 9b shows the simulation results for 2020-23 together with the estimated values for 2014-19. All plotted values are four-quarter moving average changes, and calculated gaps have been added to the 2019:Q4 trend so that the values shown are data values, not gaps. The green line is the actual productivity change, measured by the fixed output-weight index (FYW) plotted in Figure 8, and the black line is the predicted productivity change. The black predicted line captures the volatile movements of the actual series remarkably well, with a sharp peak in late 2020 and early 2021, followed by several negative quarters in 2022. While the timing of the predicted 2020-21 productivity growth surge is one quarter late, the one-quarter changes of the predicted series are remarkably close to the one-quarter changes of the actual series for the four quarters of 2020 (2.87 vs. 2.93 percent), for the 12 quarters of 2021-23 (0.69 vs. 0.62 percent), and for the 16 quarters of 2020-23 together (1.24 vs. 1.20 percent).

Figure 9a. Four-Quarter Growth Rates of Actual Output with Recession/Recovery, Business Sector, 2014:Q1-2023:Q4, Simulation Starts in 2020:Q1

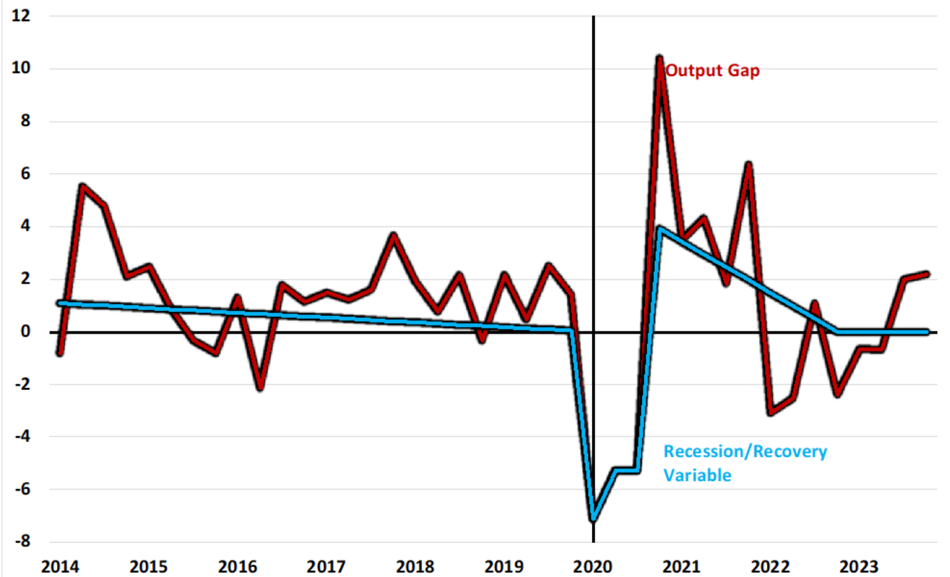
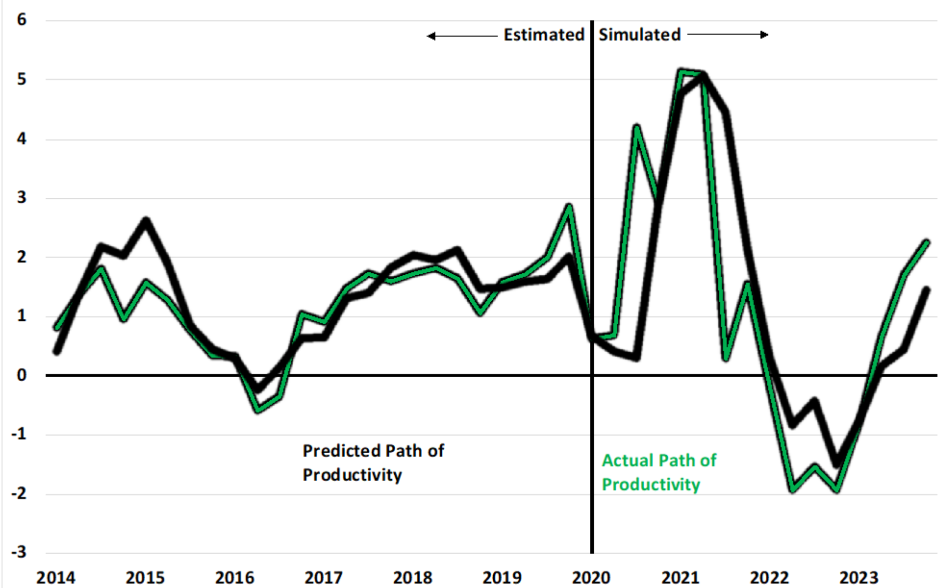


Figure 9b. Actual vs. Predicted 4QMA of Labor Productivity Growth, Business Sector, 2014:Q1-2024:Q1, Simulation Starts in 2020:Q1



Thus, the puzzle of soaring productivity growth during and after the recession of 2020 can be explained as a remarkably similar repeat of 2009. In both cases, an unexpected shock caused an overreaction by business firms, which cut hours more than normal. Why then did business sector productivity growth slow down sharply from a robust 4.8 percent in the first three quarters of 2020 to -0.6 percent in the subsequent eight quarters? The excess layoffs of

2020 were followed by the same recovery effect that occurred after 2009, but more rapidly. As business firms rehired employees to replace those who had been laid off and posted record-high vacancies, hours growth remained strong while productivity growth slumped. For the eight quarters following 2020:Q3 output growth averaged 3.6 percent, hours growth 4.3 percent, and productivity growth -0.6 percent.

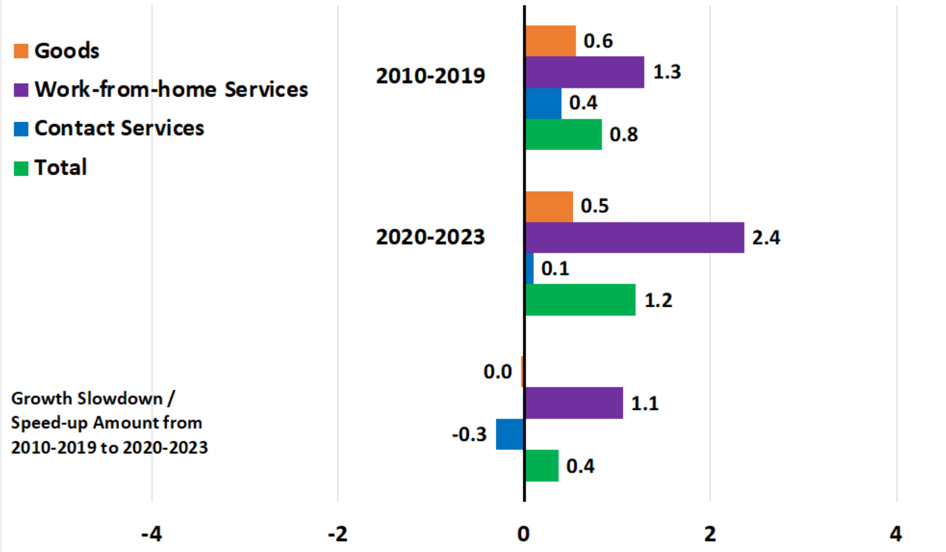
8. Post-2019 Productivity Change of Industry Groups and Individual Industries

This section addresses industry-level patterns in productivity growth during the pandemic era. Previously, we introduced the distinction between our current weight (CW) index and the fixed output-weight (FYW) index created from our industrial quarterly productivity database from 2006:Q2 to 2023:Q4. 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 can differ from the business-sector data previously used in the regression analysis.

To simplify the industry discussion, we combine the 17 industries into three groups, listed above in Table 8. The goods group includes manufacturing, mining, utilities, and construction. Services are divided into two groups. Industries where work can be done remotely at home are 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, 35 percent for WFH services, and 35 percent for contact services.

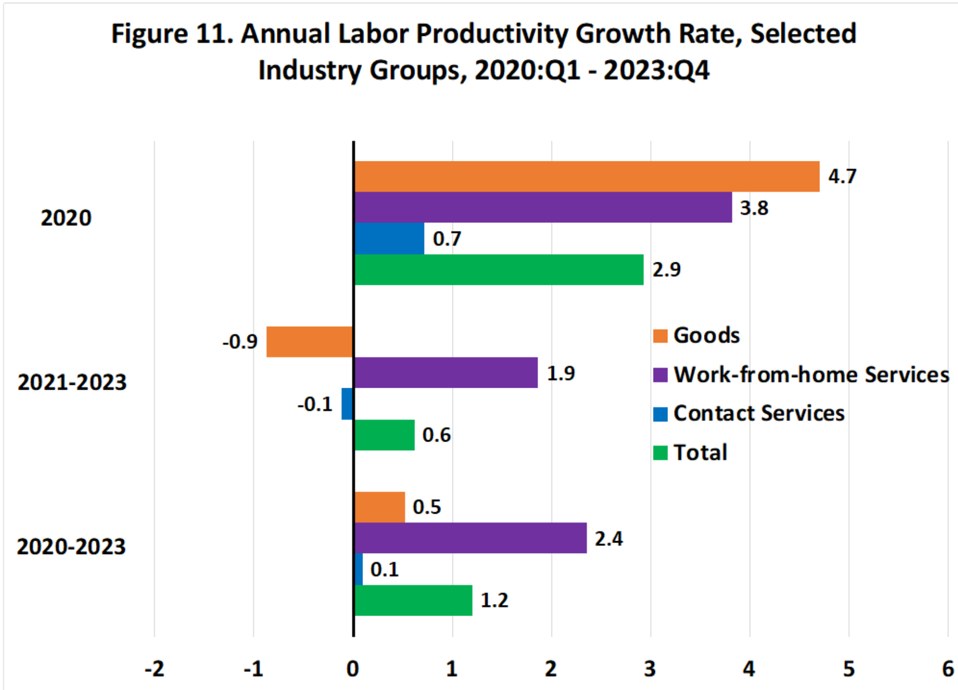
How do productivity changes in the three industry groups compare when the 16 quarters of 2020-23 are compared with the previous ten years, 2010-19? This comparison is based on fixed output-weight (FYW) indexes for each group and is shown in Figure 10. During 2010-19, average productivity growth was relatively similar across the three groups, with respective growth rates of 0.6, 1.3, and 0.4 percent, implying an average of 0.8 percent annual growth for the FYW index of all three groups taken together.

Figure 10. Annual Labor Productivity Growth Rate and Slowdown/Speed-up Amount, Selected Industry Groups, 2010:Q1 - 2023:Q4



The 2020-23 experience exhibits a divergence across the three groups. Productivity growth in the goods group fell slightly from 0.6 percent in 2010-19 to 0.5 percent in 2020-23. Productivity growth for WFH services almost doubled from 1.3 percent in 2010-19 to 2.4 percent in 2020-23. Contact services fell slightly from 0.4 to 0.1 percent. The stellar performance of the WFH sector boosted growth in the total economy from 0.8 percent in 2010-19 to 1.2 percent in 2020-23. Changes between the two intervals are plotted separately in the bottom section of Figure 10.

Figure 11 provides further insight into the industry composition of 2020-23 productivity growth behavior by splitting the 16-quarter 2020-23 interval into the four quarters of 2020 and the 12 quarters of 2021-23. Growth in the goods group declined from the exceedingly rapid rate of 4.7 percent in 2020 to -0.9 percent in 2021-23. Excess layoffs (boosting productivity growth) in 2020 followed by a recovery of hours (reducing productivity growth) in 2021-23 was concentrated in the goods group, mirroring the 2009 experience shown in Figure 4.



The buoyant performance of WFH services fell by half from 3.8 percent in 2020 to 1.9 percent in 2021-23 although remained relatively healthy compared to the other two sectors. Productivity growth in contact services fell from 0.7 in 2020 to -0.1 in 2021-23. The average for all industries decreased from 2.9 percent in 2020 to 0.6 percent in 2021-23.

Relatively high 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). Respondents reported that their WFH productivity was average 7.1 percent higher "than expected"[21]. 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, actual working hours increased relative to measured hours, which are assumed to remain unchanged. If so, this suggests that hours of WFH employees are understated in official data on hours per employee, implying an overstatement of productivity. In subsequent work Bloom (2024) concluded that on balance there was no net productivity impact so far from WFH, but that in the future WFH should raise productivity growth by opening up jobs to a greater range of talented applicants from distant locations than would apply if work had to be done locally in person.

In a complementary study, Eberly, Haskell, and Mizen (2022) point to another aspect of WFH, what they call an "unprecedented and spontaneous" deployment of "potential capital." This term refers to residential capital redeployed to work activities as well as investment in

[21] 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.

communication technology that allowed WFH activities to occur. They translate potential capital into a GDP equivalent and 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 2021-23 contrasts with the stagnant -0.1 percent 2021-23 growth experience of contact services. These industries were generally short of labor in 2021-23 when the overall economy posted a record number of vacancies. Short-staffed restaurants and retail stores may have been less productive than when they had normal staffing levels. The sharp turnaround of the goods sector from positive to negative productivity growth reflects the phenomenon of excess layoffs followed by a hiring recovery that had previously been evident in the 2009-09 recession and its aftermath.

Appendix Figure A1 provides the 2020-23 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. The experience of the 17 industries reveals a wide variance between the 6.6 percent average productivity growth of information services to the -2.8 percent growth of wholesale trade.

Our simulation exercise in Figure 9b computes a predicted path of productivity growth that soars in 2020 as a result of excess layoffs and then slumps in 2021-22 as a result of a gradual recovery in hours, mimicking 2009 and its aftermath. Our industry data show that this pattern is consistent with the behavior of the goods group. But the continued 2021-23 productivity performance of WFH services and the stagnation of contact services suggests that aggregate productivity performance reflects a more complex reality than summarized in the layoff/rebound paradigm.

9. Conclusion

This paper provides a unified explanation of puzzles regarding both the trend and cyclical behavior of U.S. postwar productivity growth. The first puzzle is about the trend – why was average productivity growth during the 2010-19 decade the slowest of any decade in U.S. history? The second puzzle is why the cyclical behavior of productivity growth, varied from procyclical during 1950-85 to acyclical during 1985-2006, back to even more strongly procyclical during 2007-19? Third, why was this transition interrupted by sharply *countercyclical* fluctuations during the recessions of 2008-09 and 2020?

These variations in the cyclicality of productivity are important to understand in themselves and also because they contradict the common approach in macroeconomic theory of modeling productivity changes as autonomous microeconomic shocks that are a major source of output fluctuations. If productivity shocks drive output changes, then they would always be procyclical instead of varying in the direction of cyclical correlation as observed in the postwar data.

Productivity growth is defined as output change minus the change in hours of work. The underlying source of productivity dynamics is that hours of work adjust gradually to exogenous changes in output due to costs of hiring and firing, leaving productivity changes as the residual, that is, the exogenous demand-driven change in output minus the gradual change in hours. Because the hours response to the change in output in the current quarter has a relatively small elasticity, the residual productivity elasticity is positive and relatively large. In subsequent quarters as the cumulative hours response becomes larger, the cumulative residual productivity response by definition becomes smaller. Hence the coefficients of productivity change in response to an output change are positive in the current quarter followed by negative in the subsequent quarters. If the sum of these responses is significantly positive, productivity growth is said to be procyclical.

The lagged adjustment of hours is the fundamental dynamic driving the cyclical behavior of productivity changes and is entirely rational in light of the costs of hiring and firing. But the elasticity of the lagged response is not uniform. When output changes are volatile, as in 1950-85 and 2007-19, the lagged hours response is incomplete, leaving room for a positive procyclical response of the productivity change residual. When output changes are less volatile, as in the Great Moderation of 1986-2006, hours can more completely catch up to output changes thus leaving little or no room for a positive response of the residual productivity change.

We concur with the previous literature that productivity growth was strongly procyclical during 1950-85. We further conclude that procyclicality did not disappear after 1985 as concluded by most of this literature. Our long-run sum of coefficients declines from a significant 0.28 for 1950-85 to an insignificant 0.20 for 1986-2006. We attribute the lower 0.20 response in the middle period to a decline by more than half in the standard deviation of output changes when 1986-2006 is compared to 1950-85. The high response in the third period reflects the zero serial correlation of output changes in 2010-19 that reduced the ability of hours changes to mimic these volatile short-run output movements, leaving changes in the productivity growth residual to echo output changes.

We distinguish the normal response of hours to output changes from an extra reaction to that has occurred during the two most recent recessions. During the 2008-09 recession, hours fell with a much higher than normal elasticity to the output decline, which we describe as "excess layoffs" due to the overreaction of business firms as output collapsed during and after the financial crisis of 2008. We link the sharp decline of hours during 2009 to the previous literature on sources of low employment in 2009, including the "China shock" that destroyed manufacturing jobs, the collapse of home building that cut construction employment, and the financial crisis following the Lehman failure. Since productivity change is a residual, it behaved counter-cyclically and rose in the four quarters of 2009 by a massive 6.6 percent, the amount by which hours growth fell below output growth. Our data on output by industry singles out three industries – manufacturing, construction, and finance – as entirely responsible for the upsurge of productivity growth in 2009.

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 that the cumulative extra rehiring addition of jobs in the post-2009 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 our regression analysis between 1950-85, 1986-2006, and 2007-19. The set of current and lagged coefficients on our combined recession-recovery variable is highly significant for the 2007-19 sample period.

Our novel recession/recovery treatment has five important implications that resolve several puzzles about the trend and cyclical behavior of U.S. productivity changes. 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 -0.5 percent instead of the actual 3.5 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 2010-19 had little to do with faltering innovation but rather resulted from the extra post-recession rehiring that offset the excess hours reduction that had previously occurred in the recession. Without that rehiring hours would have grown slower and productivity would have grown faster; the observed average annual 2010-19 productivity growth rate would have been 1.9 percent instead of 1.1 percent.[22] This suggests that the concern about "secular stagnation" that developed during that decade reflected a phenomenon that was inherently cyclical rather than secular.

Third, the appearance of a productivity growth revival from 2010-16 to 2017-19 is largely explained by the gradual unwinding 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. The return to procyclicality reflected the quarter-to-quarter volatility of output changes during this decade, which prevented slowly adjusting hours from catching up with output movements, leaving the residual productivity changes more closely to mimic output fluctuations.

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 2020-23. We find that our coefficients track the behavior of productivity growth during 2020-23 remarkably well. It tracks the upsurge in productivity growth in late 2020, albeit with a timing one quarter late, and it also captures the period of negative productivity growth in 2021-22. Overall the simulation errors are close to zero in matching the observed 5.6 percent rate of productivity growth in the year 2020 and the observed -0.1 percent average rate during the three years 2021-23. Once again the post-recession rehiring effect explains why productivity growth was so slow during 2021-23.

[22] Actual productivity growth was 2.1 percent in 2005-09 and 1.1 percent in 2010-19. Countrerfactual growth without the recession/recovery effect would have been 0.5 percent in 2005-09 and 1.9 percent in 2010-19.

Further insight into productivity behavior in 2020-23 is provided by our new quarterly data base of productivity levels and changes for 17 industries in the private business sector extending from 2006:Q2 to 2023:Q4. 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 a sharp shift in the industry mix away from low productivity industries like restaurants and hotels toward high productivity work-from-home industries like information and finance. We illustrate this distortion by creating an alternative aggregate of the 17-industry data that holds constant industry output weights at the 2019:Q4 level.

We combine these industries into three groups: goods, work-from-home (WFH) services, and contact services. The three groups behave very differently. For the 16 quarters of 2020-23 taken together, productivity growth is 0.5 percent in the goods group, 2.4 percent in WFH services, and 0.1 in contact services. The average across the three groups is 1.2 percent. Observed positive productivity growth in 2021-23 was entirely due to the performance of the WFH sector. We cite evidence showing that many WFH workers view themselves as more productive at home than expected, as well as a 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 underlying trend of productivity growth is better represented by averaging across sub-intervals within the 2005-19 interval, resulting in an average rate of productivity growth for those years of 1.5 percent. This is the same as the 1.5 percent achieved in the long "slowdown" period of 1973-95. The achieved rate of 1.3 percent in 2020-23 is close to this historical average. The brisk 3.3 percent growth rate of the 1996-2004 "dot.com" era is gradually becoming less relevant as it fades into the past.

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Table A1. Regression Response to Changes in Output Gap for Labor Productivity and Hours, 2007:Q1-2019:Q4, Business Sector							
	2007-2019 (No Recovery, No Recession)	2007-2019 (No Recovery, No Constant)	2007-2019 (No Recovery)	2007-2019 (Constant Recovery through 2019)	2007-2019 (Three Steps)	2007-2019 (Constant Recovery through 2016)	2007-2019 (Linear Descent)
	Hours	Hours	Hours	Hours	Hours	Hours	Hours
Total Effect of Output	1.05**	0.68**	0.43**	0.26	0.33*	0.35*	0.26
Total Recession Effect of Output	-	0.47**	0.85**	0.94**	0.94**	0.85**	0.97**
Constant	-0.01	-	0.62**	-0.05	0.43*	-0.07	-0.07
Adjusted R^2	0.80	0.84	0.86	0.86	0.87	0.88	0.89
RMSE	1.44	1.29	1.21	1.20	1.16	1.13	1.09

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

Table A2. Fixed-Weight Examples for Two Industries and Two Quartiles					
	Productivity ($/hour)			%Δ in Prod'y (Ann. Rate)	
	19:Q4	20:Q2	20:Q3	20:Q2	20:Q3
	(1)	(2)	(3)	(10)	(11)
Two Selected Industries					
Information Services	235.4	251.9	262.7	13.6	16.8
Accommodation and Food Services	27.2	23.8	27.1	-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
Top and Bottom Quartiles					
76-100 Quartile	252.3	263.2	264.7	8.5	2.3
1-25 Quartile	35.3	34.4	35.8	-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

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).

Figure A1. Average Productivity Growth Rate of 17 Industries, 2020:Q1-2023:Q4, in Descending Order of Productivity Growth