The Twin Puzzles of U.S. Productivity Growth Dynamics: A New Interpretation

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Abstract

This paper provides a unified framework that resolves recent puzzles in U.S. productivity growth that we show are interrelated. First, why was productivity growth in the 2010-19 decade the slowest of any decade in U.S. history? Second, why did the cyclicality of productivity growth change from procyclical in 1950-85 to acyclical in 1986-2006 and then back to procyclical in 2010-19? Third, why was productivity growth strongly *countercyclical* in the recessions of 2008-09 and 2020? The fundamental dynamic driving cyclical productivity fluctuations originates in the gradual adjustment of hours of work to demand-driven output fluctuations due to the costs of hiring and firing labor. Since productivity growth is a residual by definition, equal to output growth less hours growth, productivity growth immediately jumps in response to an upward output movement because hours are slow to respond and then falls back in subsequent quarters as hours complete their adjustment. We are able to explain the temporary 1986-2006 disappearance of procyclicality and its reappearance after 2009 as the result of changes in the standard deviation and serial correlation of output changes.

We explain countercyclical productivity surges in 2008-09 and 2020 by showing that business firms in those two episodes overreacted with "extra layoffs," cutting hours in response to the sharp output decline with a much higher elasticity than normal. By coupling these extra layoffs with a post-recession rehiring effect that boosted hours growth and depressed productivity growth for 2010-19, our regression analysis explains why productivity growth on average was so slow during that decade. If this recession/rehiring effect had not occurred, productivity growth in the 2010-19 decade would have been 2.1 percent per year instead of 1.2 percent, suggesting that concern about U.S. "secular stagnation" has been overstated.

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1. Introduction

The decade of the "teens" in the American economy witnessed the slowest labor 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 1.2 percent per year, only half of the average of 2.4 percent achieved 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], leading to the emergence of a large literature on "secular stagnation," beginning with Summers (2013, 2015).

The puzzle of what caused this decade-long growth slowdown is joined by a second puzzle about short-run productivity growth dynamics. Dating back to Okun's famous "law" (1963; see also Ball *et al.*, 2017), labor productivity growth has been presumed to be procyclical, that is, to exhibit a positive correlation with cyclical output movements. In Okun's original formulation, one-third of cyclical output movements was reflected in procyclical productivity fluctuations and the remaining two-thirds in procyclical changes in hours of work. Our second puzzle starts from the fact that the procyclicality of short-run productivity changes seems to have largely disappeared after the mid-1980s. But while this mid-1980s disappearance of the positive output-productivity correlation has long been recognized, there has been little notice to date that the procyclical correlation returned after 2006 and continued to 2024, with two notable interruptions: productivity growth was strongly *countercyclical* in the recessions of 2008-09 and 2020.

This paper provides an integrated explanation of why these cyclical shifts occurred that in turn unlocks the puzzle of slow 2010-19 trend growth. We utilize the perspective that changes in productivity growth originate in the gradual adjustment of hours to demand-driven output fluctuations. Quarter-to-quarter changes in labor productivity by definition equal changes in output minus changes in hours of work. This means that productivity changes can occur if output and labor markets operate independently, without any implications for underlying changes in worker efficiency. Short-run changes in GDP reflect the contribution of its underlying components of demand, such as consumer spending, fixed investment, and inventory changes. Hours of work may not perfectly mimic these changes in output, and hence short-run productivity changes can occur automatically, for two complementary sets of reasons. An older tradition dating back to Oi (1962) emphasizes adjustment costs that make labor into a "quasi-fixed factor" that does not perfectly mimic output changes. The more modern approach

[1] "Recorded history" here goes back to 1889, with pre-1947 data available in Gordon (2016), chapter 16. Decades here refer to each ten-year period beginning with year "0" and ending with year "9". The slowest decade prior to 2010-19 back to 1889 was 1980-89 at an average annual rate of 1.7 percent per year. For comparison the rate in the Great Depression decade of 1930-39 was 2.0 percent.

[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 from 2010:Q1 through 2019:Q4. For the 1930-39 decade the 2.0 percent number cited in footnote 1 is the log annual growth rate between the years of 1929 and 1939.

to labor market adjustment based on the Mortensen and Pissarides (1994) search and matching model focuses on workers' decisions between accepting job offers or continuing to search. Since changes in worker hours reflect the interplay between firm' hiring and layoff decisions with worker-chosen quits and job acceptances, the two approaches are complementary. Both imply that output changes are not duplicated by equiportionate changes in hours.[4]

The central insight that links our two puzzles is that employer behavior was different in the Great Recession of 2008-09 than in previous recessions. Instead of reducing labor hours with an elasticity of less than unity in response to the decline of output, as in past recessions or as implied by Okun's law, firms overreacted with what we call "extra layoffs," reducing hours with an elasticity well above unity. The cumulative decline in output during the 2008-09 recession was -3.4 percent but hours declined by -6.3 percent, resulting in a productivity change of +2.9 percent. For the year 2009 the difference was more extreme, with an output increase of +0.30 percent, an hours decline of -6.6 percent, and a productivity spike of +6.9 percent.

We estimate a regression model on data for 1950-2019 that captures the unusual reduction of hours in 2008-09 and thereby helps resolve the twin puzzles. The mystery of slow average 2010-19 productivity growth is resolved by recognizing that the extra layoffs of 2008-09 were gradually unwound in the following decade, as previously laid-off workers were gradually rehired. This extra growth of hiring beyond the normal response to output growth boosted hours growth and by definition reduced productivity growth. We show that this effect extended through 2019 and accounts for 0.9 percent annually of missing productivity growth, yielding a counterfactual average 2010-19 productivity growth rate of 2.1 instead of 1.2 percent.

The puzzle of countercyclical productivity growth in the 2020 recession is resolved by computing a dynamic post-sample simulation of our 2007-19 regression equation on data for 2020-24. The estimated pre-2020 coefficients quite accurately capture not only the +5.8 percent surge in productivity growth for 2020 but, as the rehiring effect took place, why productivity growth averaged a negative -0.3 percent for the two subsequent years 2021-22.

Our analysis distinguishes long-run trends in productivity growth from quarterly fluctuations in the difference between actual and trend growth, which we call "gap changes." We first estimate new trends for labor productivity and total factor productivity (TFP). We use these trends in our econometric analysis to resolve the first puzzle of slow 2010-19 trend growth by showing that it was an artifact of post-recession rehiring. We resolve the second puzzle by time period. The post-1985 shift from procyclical to acyclical short-run productivity changes is attributed to a sharp reduction in the standard deviation of output gap changes, i.e., the "Great Moderation." This allowed hours gap changes to more closely mimic muted output gap

[4] This 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 output demand decreases. Instead, the adjustment is symmetric, restraining the amplitude of changes in labor hours both when output decreases but also when it increases. 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.

changes, leaving little room for residual procyclical productivity gap changes. We attribute the post-2009 shift back to procyclicality on a reduction to zero in the previously positive serial correlation of output gap changes, leaving insufficient time for hours gap changes to react. By definition, these volatile quarter-to-quarter output gap changes spill over into positively correlated productivity gap changes. The steady stream of post-recession rehiring is a separate factor that also muted the hours reaction to volatile output gap changes during 2010-19. And the 2008-09 and 2020 episodes of countercyclical productivity gap behavior are attributed to the extra hours reduction followed by a reversal in the form of subsequent rehiring.

In addition to providing new estimates of productivity growth trends and gap changes, the econometric analysis explains changes in the hours gap as responding gradually to the current and four lagged output gap changes. Changes in productivity growth gaps are then a residual, with no life of their own. We display "dual" productivity gap equations that allow separate estimates of coefficient significance levels for productivity responses. The results are not dependent on our particular method of estimating trends, and are substantively unchanged when estimated on non-detrended data.

Another contribution is a new quarterly productivity database for 17 private-sector industries covering 2006-24. This allows us to identify the source of the 2008-09 extra layoffs as originating in three industries – manufacturing, construction, and finance. We cite literature on the China shock, housing bubble, and financial crisis to explain why the hours adjustment overreaction was centered in these three industries. We also show that the quarterly pattern of aggregate productivity growth in the 2020 recession was distorted by disproportionate output reductions in low-productivity service industries.

Our separation between growth trends and gap changes differs from standard practice in modern macroeconomics that treats "productivity shocks" as an important source of short-run output fluctuations. We view productivity shocks as events that occur at the level of millions of individual firms and workers. The impact of meaningful micro-level innovations is thus spread over many quarters and years and do not show up in volatile quarterly gap changes but rather in changes in long-run trends, such as the "dot.com" productivity trend growth revival of 1996-2004.

A large literature ignores this distinction between micro events and macro data, and between trends and gap changes. It treats autonomous productivity shocks as a major source of output fluctuations (see Acemoglu et al., 2012; Baqaee and Farhi, 2019; and Gabaix, 2011).[5] These productivity shocks are assumed to move output in the same direction, requiring empirical support for a procyclical correlation between output and productivity changes. Our analysis in Part 4 below provides three arguments that cast doubt on the relevance of quarter-

[5] Acemoglu et al. (2012) states that "microeconomic idiosyncratic shocks may lead to aggregate fluctuations." Baqaee 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."

to-quarter macro productivity shocks as independent causes of short-run macro output changes.

Part 2 reviews the cyclicality of productivity changes. Part 3 summarizes postwar productivity growth for selected intervals and estimates trend growth rates. Part 4 provides support for our approach viewing micro-level "productivity shocks" as influencing trends rather than short-run output changes. Part 5 documents deviations from trend, or "gap changes," for hours and productivity. Part 6 investigates the industry sources of the countercyclical behavior of productivity growth during the Great Recession and, consequently, provides support for the phenomenon of "extra layoffs." Part 7 presents our regression analysis of gap changes for both hours and productivity. Part 8 examines the effect of changing industry weights on productivity performance in 2020-24. Part 9 provides a post-sample simulation analysis to explain aggregate productivity behavior in 2020-24. Part 10 concludes.

2. Literature Review on Productivity Growth Dynamics

The first puzzle addressed in this paper is why the productivity growth trend was so slow during 2010-19. The second is why the cyclical correlation of productivity gap changes with output gap changes has evolved from positive (1950-85), to roughly zero (1986-2006), back to positive (2007-2024), with interruptions for a significant negative correlation during the recessions of 2008-09 and 2020. Our answer to the first puzzle emerges from our answer to the second and is unrelated to other previously proposed explanations of slow 2010-19 productivity growth.

Numerous papers have documented the mid-1980s decline or disappearance of procyclicality, as summarized by Fernald and Wang (2016) and documented in the modern macroeconomics literature by Galí and Gambetti (2009) and Galí and Van Rens (2021). Papers supporting a uniform procyclical productivity response over time tend to have been written earlier than those finding a shift after the mid-1980s. 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).

Our econometric results confirm that labor productivity was significantly procyclical during 1950-85 but not during 1986-2006. We attribute this shift in response to the reduced volatility of output during the 1986-2006 period that is frequently described as the "Great Moderation." Our interpretation supports Stiroh's (2009) findings at the aggregate and industry level and is complementary to other explanations, such as weaker labor frictions (Barnichon, 2010) and firms' heightened managerial emphasis on maximizing shareholder value (Gordon, 2010). Stamegna (2024) links the reduction of procyclicality to weaker incentives to invest in labor-saving innovations due to "missing wage growth in the upturn of the business cycle." Some papers provide industry or firm-level explanations for the reduction or disappearance of procyclicality. Wang (2014) shows that the economy's shift from commodities production towards the acyclical services sector, as well as an increased sensitivity of TFP to persistent

technological shocks, can partly explain the lessened correlation of productivity and output changes.

Our second contribution is to show — and explain why — productivity growth was strongly countercyclical in the recessions of 2008-09 and 2020. By definition productivity growth was positive in these episodes because hours of work fell more than the decline of output, i.e., an elasticity of the hours reduction to the output shrinkage of greater than unity. This elasticity was substantially less than unity in previous recessions. We label the added downward response of hours with the term "extra layoffs", which we attribute to the overreaction of firms to the unexpected severity of both the 2008-09 and 2020 recessions. This approach is consistent with the finding of Daly *et al.* (2018) that, after the 1980s, firms shifted from adjusting hours at the intensive margin to the extensive margin — plausibly driving countercyclicality in productivity growth — as well as Biddle's (2014) argument that reductions in hiring frictions decrease labor hoarding, a historical driver of procyclical productivity growth.

Our explanation of countercyclical productivity growth in 2008-09 and 2020 is complementary to that of Fernald and Li (2022), who highlight the positive correlation of productivity growth and the unemployment rate in those years. Foster et al. (2015) show that while labor was more likely to be reallocated from low to high productivity firms in past recessions via a "cleansing effect," cleansing was severely attenuated in the Great Recession. Van den Bosch and Vanormelingen (2023) use microdata from Belgium for 1997-2014 to find evidence of cleansing in manufacturing firms but not in services during 2008. This is consistent with our finding that the extra layoffs of 2008-09 were concentrated in manufacturing, as well as in construction and finance.

Our third contribution is linked to our second, which is to document a return to procyclical productivity changes for 2007-24, excluding the two recession years 2008-09 and single recession year 2020. This response emerges only after isolating the separate role of "extra layoffs" in 2008-09. Workers fired during the recession of 2008-09 were gradually hired back into the economy after 2009; thus, the source of the countercyclicality in 2008-09 also explains relatively steady growth of labor input after 2009. This allowed volatile quarter-to-quarter movements in output growth to be mirrored by similar fluctuations in productivity growth, supported by our evidence that the usual positive serial correlation of output movements disappeared during 2010-19. This finding that procyclicality returned after 2006 is at least in part consistent with the Daly *et al.* (2018) finding that labor productivity growth has had an even stronger procyclical response to monetary, credit, and oil-related shocks since the 1980s.

3. Trends in 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.

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

Table 1 documents the average growth rates of labor productivity *(Y/H)* and total factor productivity (TFP) over selected intervals from 1950 to 2024. 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. Data come from John Fernald's San Francisco Fed web site.

The first row displays the rapid growth of 1950-1972, followed by the slowdown of 1973-1995 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 and 2004, a revival usually attributed to the effects of high investment in the information technology revolution and the impact on TFP of personal computers, the internet, and search engines (see interpretations by Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000; and Jorgenson *et al.*, 2008). Labor productivity growth was slightly faster in 1996-2004 than in the previous rapid growth interval of 1950-72, whereas TFP growth was slower.

Table 1. Annual Growth Rates of Private Business Sector Labor Productivity and Total Factor Productivity, 1950:Q1-2024:Q4

Time Period	Labor Productivity	Total Factor Productivity
1950:Q1-1972:Q4	3.21	2.20
1973:Q1-1995:Q4	1.51	0.52
1996:Q1-2004:Q4	3.30	1.80
2005:Q1-2009:Q4	2.13	0.14
2010:Q1-2019:Q4	1.15	0.68
2020:Q1-2024:Q4	1.79	0.70

Business sector productivity and TFP data from John Fernald (http://www.johnfernald.net/TFP, updated February 12, 2025), where output data are geometric averages of income and production sides of the business sector.

The two decades from 2005 to 2024 are divided into three sub-periods. The first, 2005-2009, 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. Then follows the 2010-19 decade so notable for its slow average rate of productivity growth. The last line of Table 1 includes the 20 pandemic and post-pandemic quarters from 2020 to 2024. Productivity growth in the final 2020-24 interval was about 0.6 points faster than the 2010-19 decadal average.

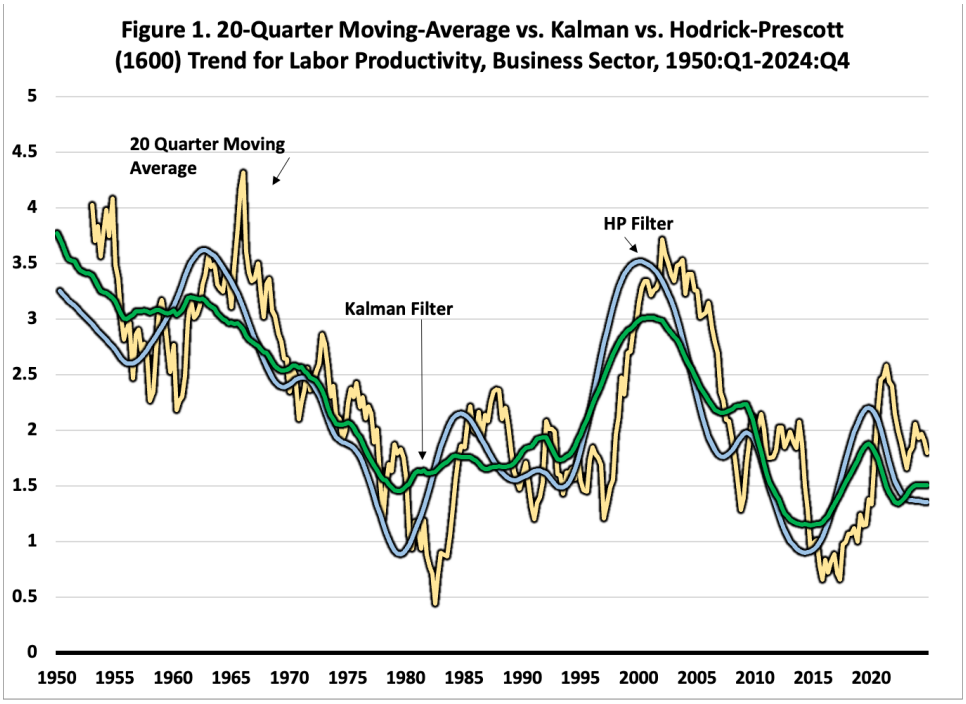
[6] The literature on the productivity growth slowdown of the 1970s and 1980s often pointed to the lower skills and experience of teenagers and women as an important cause of the slowdown (see Baily, 1981; Perry *et al.*, 1977; Perloff and Wachter, 1980; and a more recent article by Vandenbroucke, 2017).

The TFP growth rates are always slower than those of labor productivity, differing by the normally positive contributions of capital deepening and labor composition. The TFP growth shortfall was about 1.0 percentage 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. The TFP shortfall rose to an even larger 1.98 percent in 2005-2009 before dropping to 0.5 percent in 2010-19 and a greater 1.1 percent in 2020-24. Surprisingly, TFP growth was the same 0.7 percent throughout 2010-24 even though labor productivity growth was substantially faster in 2020-24 than in 2010-19. As previewed in the introduction, the interpretation of this paper explains that the slow labor productivity growth of 2010-19 was an artifact of business cycle timing rather than a sign of faltering innovation.

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 productivity growth and the unemployment gap, defined as the difference between the unemployment rate and the "long-run NAIRU" estimated by the Congressional Budget Office.[7] 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 displays a smooth evolution of the productivity growth trend. In contrast, the commonly used Hodrick-Prescott (H-P) filter is univariate and smooths a series using only information on deviations from average growth of the series itself, meaning it still exhibits substantial fluctuations at business cycle frequencies, at least during intervals when productivity growth is procyclical.

Figure 1 contrasts our Kalman filter for business sector productivity growth, shown in green, with a 20-quarter moving average of one-quarter annualized changes (yellow) and the H-P filtered series with the standard parameter of 1600 (light blue). Note that the H-P filter retains considerable cyclical sensitivity and appears to be a smoothed replica of the 20-quarter moving average. The green Kalman trend is less sensitive to the business cycle than the two other series, exhibiting rapid growth in the 1950s, a steady slowdown during the 1960s and 1970s to a plateau of around 1.5 percent in the 1980s, a marked revival between 1995 and 2005, and then another slowdown between 2005 and 2014. The series exhibits a temporary revival around the time of the 2020 pandemic and levels off in 2023-24 at a value of 1.5, roughly the same as in the 1980s.

[7] Details on Kalman trend estimation are provided in Gordon (2003).

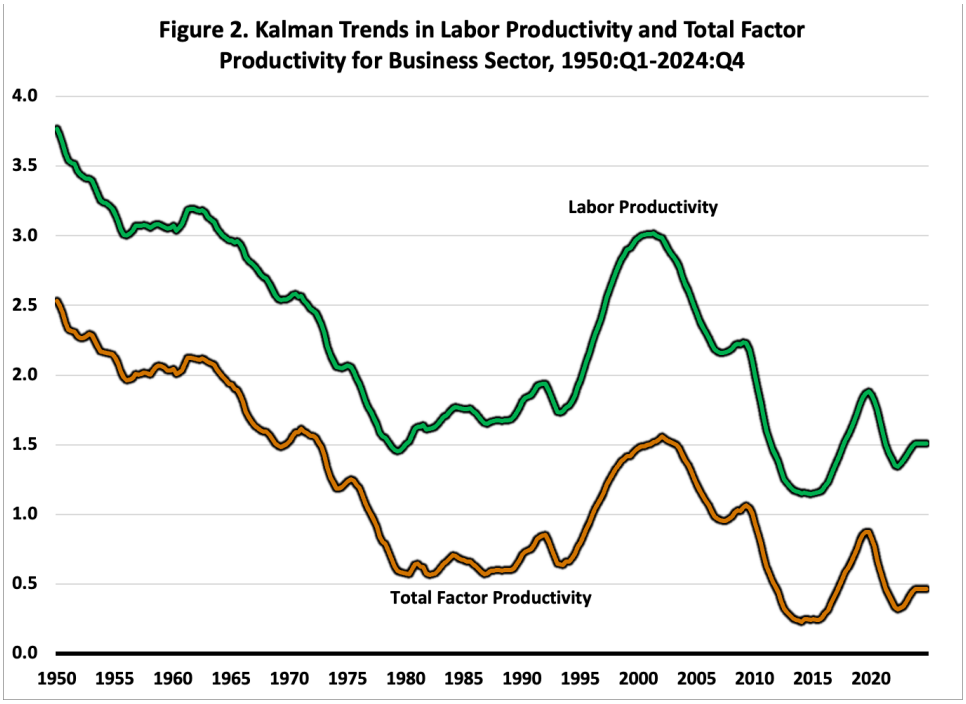


The H-P filter, by contrast, exaggerates the trend upsurge of productivity growth in the expansions of the 1960s and late 1990s, depicting accelerations when the Kalman trend indicates a steady decline in trend growth, while also showing declines in 1979-82 when the Kalman series indicates none. H-P 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 productivity growth rates are correspondingly understated.

In the absence of accelerating inflation in 2018-2019, we adjust the CBO NAIRU downward starting in the late 2000s to 4.0 percent in 2018:Q1. The NAIRU is assumed to decline in a straight line from its CBO value of 4.91 in 2007:Q4 to an assumed value of 4.0 in 2018:Q1, where it remains through 2024.[8] It is equal to the CBO value for all quarters from 2007:Q4 back to 1950. We note that the Federal Reserve has made a similar adjustment.[9]

Figure 2 copies the Kalman trend for productivity growth in green from Figure 1 and supplements it with the Kalman trend for TFP in brown. The difference between the TFP and labor productivity trends evolves as already noted in Table 1. The TFP trend declines more than labor productivity growth after 2010, ending up at a growth rate of only 0.5 percent in 2024, much lower than previous TFP trend peaks of 2.6 percent in 1950, 2.0 percent in 1959-60 and 1.6 percent in 2000-02.

[8] The CBO NAIRU as listed on FRED declines from 4.84 percent in 2010:Q1 to 4.54 percent in 2019:Q1.
[9] 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.



4. The Relationship Between Short-Run Output Changes and Demand

The econometric analysis below strips out the effect of the Kalman trends and explores the relationships among output, hours, and productivity of what we call "gap changes", that is, actual annualized quarterly changes in the data minus the Kalman trend growth rates. In particular, we regress gap changes for hours of work on current and lagged gap changes in output. Productivity changes are a definitional residual: exogenous output growth minus predicted hours growth. This may appear to reverse the order of causation implicit in the real business cycle (RBC) literature and numerous New-Keynesian analyses, where aggregate productivity shocks are treated as an important source of cyclical output fluctuations. In this section, we review the modern literature on productivity shocks and provide three reasons supporting our view that productivity shocks matter for trends like those depicted in Figures 1 and 2, but less for the quarter-to-quarter gap changes that are the focus of our econometric analysis.

The role of "productivity shocks" — measured as exogenous changes to TFP — in driving aggregate output fluctuations was pioneered in RBC models by Kydland and Prescott (1982), who argued that TFP variation could explain output changes in contemporaneous data. However, because TFP changes are measured by subtracting slower-moving changes in labor and capital inputs from output changes, a large fraction of volatile output changes is mechanically embedded in TFP changes. As a result, many modern analyses utilize techniques such as long-run restrictions (Galí, 1999), utilization adjustments to TFP series (Basu et al.,

2006)[10], or instruments such as stock market expectations (Beaudry and Portier, 2006) to more accurately identify the apparently exogenous effects of TFP fluctuations.

This line of research — including Francis and Ramey (2004), Christiano et al. (2005), Fisher (2006), and Smets and Wouters (2007) — finds that technological shocks explain at most a quarter of the variation in the business cycle at medium run frequencies.[11] Subsequent work favors the role of factors like investment and imperfect competition (Justiniano et al., 2010; Li, 2023). Ríos-Rull and Santaeulália-Llopis (2010) find an even weaker correlation between TFP and hours than between TFP and output, providing further evidence for our view of hours fluctuations as largely responding to changes in demand as opposed to TFP.[12] Relatedly, one of the key insights of our paper is to resolve the puzzle of abnormal responses of productivity growth in the recessions of 2008-09 and 2020. Galí and van Rens (2021) point to the countercyclical response of productivity growth in the Great Recession as itself evidence that technological shocks do not drive some of the key fluctuations this paper is concerned with, consistent with our subsequent explanation of countercyclical behavior in 2008-09.[13]

There are three substantive reasons to emphasize why productivity shocks may matter less for explaining short-run fluctuations in output. The first rests on a straightforward distinction between microeconomic agents and macroeconomic data. Because economywide productivity divides the output of millions of firms by billions of hours worked, summation across individual firms and workers smooths hourly and daily variations, making them invisible in aggregate data. Be they workers on assembly lines with the same hour-after-hour productivity or restaurant workers facing fluctuations throughout the day, these small changes are not large enough to show up in quarter-to-quarter changes in total GDP or economywide hours of work. At a conceptual level, our paper is thus most closely related to Rotemberg (2003), who shows quarterly fluctuations in GDP growth may emerge from transient forces, while the long-run level may still be affected by (stochastic) technical change.

Productivity changes at the firm level — such as new production methods introduced by innovation— are revealed gradually as incremental slow shifts in the underlying productivity trend rather than through sharp upward or downward jumps in the quarterly growth rate of productivity. The impact of innovation evolves as an S-curve, slow-fast-slow, as described by an expert on the evolution of technology (Potter 2025, pp. 47-48):

[10] The TFP series we use throughout from Fernald (2014) is adjusted for utilization.
[11] Tables 8 and 9 in Ramey (2016) provide an overview of exactly how much of output variation can be explained by these TFP fluctuations in both SVAR and DSGE models.
[12] Several papers more closely related to ours view business cycles as emerging from the demand side rather than productivity shocks. Lorenzoni (2009) interprets business cycles as resulting from consumers' (noisy) learning about the productivity capacity of the economy. Bai *et al.* (2024) consider a macroeconomy with search frictions, where larger demand translates into "more intense search." TFP growth is not taken as an exogenous variable, but is seen as the culmination of a search-related microfoundation.
[13] As an example of a very recent paper that treats anticipated productivity shocks as a source of business cycle fluctuations in output, see MacKowiak and Wiederholt (2025).

> Early on the technology works extremely poorly, if it works at all . . . As attention converges on the most promising avenues for advancement, performance improves more quickly. This often occurs as a series of small enhancements or tweaks to the technology that individually may not appear noteworthy but which collectively result in a significant performance boost. . . . Eventually, a technology's performance approaches some natural limit . . . gains in performance are harder and harder to achieve, and the rate of improvement slows.

The gradual nature of productivity acceleration is visible in Figures 1 and 2 with an increase in trend productivity growth from 1995-2002 in response to the ICT revolution and a gradual decrease from 2002 to 2015 as firms completed their adoption of new technology. If productivity shocks are important enough to matter for a majority of firms and workers, they show up in gradual changes in trend data, not in *quarter-to-quarter* gap changes. This view is complemented by Alexopoulos (2011), who utilizes a book-based measure of technological progress to show that technical change is far better at predicting output changes at nine-year than three-year horizons, where it explains at most 15% of output variation. At a three-year horizon, the response of labor hours to this measure of technology is close to zero, supporting our view that TFP fluctuations are less responsible for changes in hours fluctuations at *quarterly* frequencies.

Second, we view demand as the fundamental driver of output changes, based on historical data on fluctuations in the components of GDP as well as the nature of many past business cycle episodes. This is most obvious for the inventory change component of GDP, which reflects the difficulty of synchronizing firm and supplier production with changes in the demand of millions of customers. Such mismatching of the timing of supply and demand emerges from a host of factors that might be termed "demand shocks."[14] Our approach viewing TFP as an endogenous variable responding to demand shocks is thus conceptually related to Mayer et al. (2016), who modify the Smets and Wouters (2007) model to show how TFP endogenously responds to structural shocks.

A decades-old literature provides demand-based explanations of why some components of GDP are more volatile than others. The volatility of investment dates back at least to Samuelson's (1939) multiplier-accelerator model, while the relative stability of consumer spending is consistent with longstanding theories of consumer demand behavior based on permanent or life-cycle income, notably Friedman (1957) and Ando and Modigliani (1963). Kydland and Prescott (1982) explained the heightened volatility of investment and durables consumption by their "time-to-build" nature. More modern explanations of this regularity include credit markets (Bernanke et al., 1999), habit formation (Boldrin *et al.*, 2001), wage and price stickiness (Christiano et al., 2005), news (Jaimovich and Rebelo, 2009), and shocks to the marginal efficiency of investment (Justiniano et al., 2010). Indeed, some research argues that a

[14] The effect of tariffs and the termination of electric vehicle subsidies in 2025 on the timing of inventory accumulation provide two examples.

decrease in the magnitude of investment shocks drove the Great Moderation in output volatility, already cited above in Part 2 as an explanation for the reduced procyclicality of productivity after the mid-1980s (Justiniano and Primiceri, 2008).

Table 2 illustrates the higher variance of the investment in structures and durable goods, as well as the durable goods component of consumption, relative to spending on consumer nondurables and services. The left section displays the standard deviation of annualized quarterly changes in eight subcomponents of GDP for 2010-19 together with 2022-24, omitting the atypically volatile observations during the 2020-21 pandemic.[15] These demand components are arranged in order of decreasing volatility, with investment in structures at the top, followed by durable goods, nondurable goods, and services. Intellectual property investment is shown separately at the bottom. Investment in nonresidential structures is 11 times as volatile as consumer spending on services.

Table 2. Standard Deviations of Annualized One-Quarter Changes in Output by Demand Category and Labor Productivity by Related Industry, 2010:Q1-19:Q4 and 2022:Q1-24:Q4

Type of Product	GDP Demand Category	Output St. Dev.	Related Industry	Productivity St. Dev
Structures	Nonres. Structures Investment	12.0	Construction	5.7
	Residential Structures Investment	11.2		
Durable Goods	Producers Durable Equipment	8.6	Durable Manufacturing	4.7
	Consumer Durables	5.0		
Nondurable Goods	Consumer Nondurables	2.1	Nondurable Manufacturing	9.0
Services	Consumer Services	1.1	Retail Trade	6.9
			Transportation	5.0
			Accommodation, Food	4.2
			Arts, Entertainment	9.6
Information	Intellectual Property Investment	4.4	Information Services	7.1
	Exports of Services	6.0		

Source: Standard deviations for output categories come from NIPA Table 1.1.1. Standard deviations for productivity by industry come from Gordon-Sayed Quarterly Productivity Database.

Are investment and durable goods more volatile because the industries producing them have more volatile productivity changes? The right section of Table 2 answers this in the negative by showing the standard deviation of annualized quarterly changes in output per hour in the industries that produce the corresponding demand components; these data from our new industry productivity database are described in Part 8. There is no tendency for the most volatile spending components on the left side of Table 2 to be produced by industries having a

[15] Eight subcomponents of GDP are listed on the left side of Table 2, excluding six of the 14 subcomponents of NIPA Table 1.1.1 that lists quarter-to-quarter annualized changes in components of real GDP (the other rows of Table 1.1.1 are aggregates of the subcomponents, e.g., total consumer spending). The six components are excluded because they cannot be matched with the productivity change in the corresponding producing industries. For this reason three components of government spending are excluded because the productivity data refer only to the private sector. Two are excluded because they are imports, not produced in the domestic economy. The final excluded component is the export of goods, which cannot be matched to the separate productivity data in Table 2 that separate out durable from nondurable manufacturing.

high volatility of productivity changes. For instance, the two structures investment components are the most volatile, but construction productivity is not. Retail trade and arts/entertainment have more volatile productivity changes than construction, despite their low volatility as components of GDP. While investment in producer durables is four times more volatile than nondurables consumption, productivity changes in nondurable goods manufacturing are twice as volatile as in durable goods manufacturing.

Feedback from productivity shocks to output changes would predict a positive correlation between the two sides of Table 2. But the correlation is negative, a statistically significant -0.31. This evidence supports our previous conclusion based on the mismatch between microeconomic behavior and quarterly aggregate productivity changes, that there is only negligible feedback from quarterly gap changes in productivity to quarterly gap changes in real GDP.

The evidence in Table 2 that investment and durable goods spending are much more volatile than consumption of nondurables and services supports our interpretation that changes in the output gap largely emerge from changes in demand. Further support is provided by the inventory change component of real GDP, which is not included in Table 2 because the NIPA tables list its absolute dollar amount rather than its percentage change. For the same time interval as in Table 2, the average absolute quarterly difference in the inventory change component is $41 billion. The absolute quarterly difference for the sum of the four sub-components of fixed investment is $40 billion, while that for the three sub-components of consumer spending is a much lower $17 billion. Consistent with the literature surveyed above, the contribution of consumption to GDP volatility is only 40 percent of the fixed investment contribution, even though the real dollar *level* of consumption is four times higher than that of fixed investment. Inventory change, which makes up only 0.4 percent of the level of real GDP, contributes even more volatility than the sum of the four fixed investment categories. [16]

The gap changes that we analyze are equally positive and negative by definition, since they are defined as deviations from trends. For reverse feedback to occur from productivity shocks to output gap changes, shocks would have to be negative as often as they are positive. Yet productivity in the form of efficiency and technology moves forward, not backward. Could supply shocks — often cited as causes of recessions in 1973-75, 1980-82, and 2020 — plausibly explain why half of the productivity gap shocks must be negative? This brings us to a third reason to question the presence of productivity shocks as the predominant determinant of quarterly output gap changes. The first oil shock of 1973-75 — when OPEC nations hiked the price of oil from $2 to $12 per barrel — was not a productivity shock within the United States, since it originated in production changes in foreign nations. Instead, it was a "price shock'

[16] The inventory change component of GDP is not included in NIPA Table 1.1.1 nor in Table 2 here because it is not available as a percentage change. However it is possible to use data from NIPA Table 1.1.6 to calculate the absolute dollar difference between inventory change in successive quarters and compare that absolute change to the same change for the other subcomponents of real GDP. Since trend growth in real GDP would create positive absolute changes even if quarter-to-quarter volatility were absent, we calculate the growth rate of each real spending component between 2007 and 2024 and subtract the dollar change in each quarter attributable to trend growth.

which suddenly reduced disposable personal income and caused the demand for consumption and investment goods to decline through standard demand channels. The same "price shock" description applies to the second oil shock of 1979.

Thus, the most frequently cited "supply shocks" are really "price shocks," not domestic "productivity shocks." An increase in oil prices does not change productivity within the current quarter by reducing oil input relative to other inputs, because the energy efficiency of oil-using industries like transportation is embedded in the fixed-proportion specifications of the aircraft, truck, and rail engines in use at the time. Higher oil prices will lead to a gradual replacement by investment in more efficient equipment, altering the productivity growth trend rather than quarter-to-quarter productivity changes.[17]

What about agricultural shocks such as droughts or bird flu? These are also price shocks, not productivity shocks large enough to create more than a trivial change in aggregate output. The share of the entire agricultural sector in U.S. GDP in 2024 was only 1.0 percent, and the share of the farm sector was 0.7 percent. Even if a negative weather shock occurred that shut down the entire production of the U.S. farm sector for a year – no wheat, corn, soybeans, beef, milk, eggs, nor lettuce – U.S. GDP would decline by only 0.7 percent and productivity would decline by even less, because a substantial share of hired farm labor hours would decline as well. Of course, no historical agricultural shock has shut down the entire farm sector at once, instead affecting weather in a particular region or, like bird flu, for a particular product.

The pandemic shock of 2020 was primarily a demand shock: fearful consumers avoided personal contact by reducing their purchases of consumer services such as concerts, sporting events, and visits to retail stores. Demand quickly shifted to e-commerce and from services to goods such as exercise bikes and computers. This was combined with a supply shock as employees avoided coming to work and switched to working from home if possible. Thus, 2020 combined a demand shock, price shock, and productivity shock. However, if the recession of 2020 had been driven by a negative productivity shock alone, productivity growth would have been negative instead of the positive surge of 5.8 percent that actually occurred in the four quarters of 2020. We return to the countercyclical labor productivity change that occurred in 2020 in Part 9 by estimating post sample simulations of productivity growth for 2020-24, using coefficients estimated from pre-2020 data.

5. The Evolution from Procyclicality to Acyclicality and Back Again

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

[17] Higher oil prices could reduce transportation productivity even with fixed-proportions technology if firms respond by reducing transport speeds. Indeed this happened in January, 1974, when the President imposed a 55 MPH speed limit on American roads, almost simultaneously with the multi-stage increase in oil prices that extended from October, 1973 to March, 1974. Thus 1974:Q1 is a unique period in which causation runs both ways between output and productivity changes.

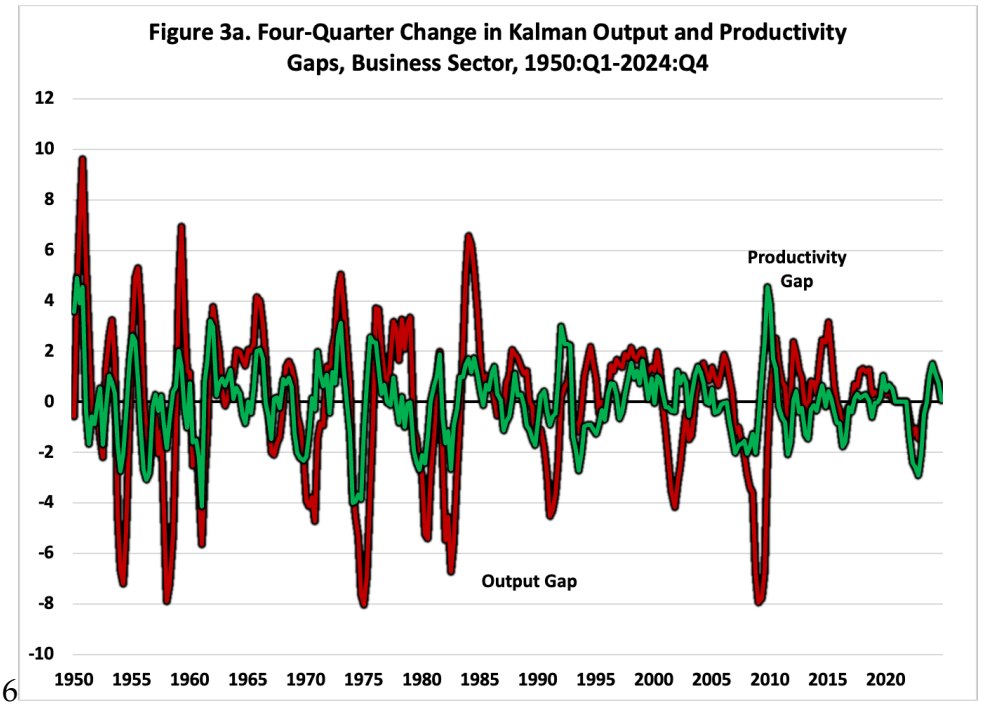
characterizes the adjustment mechanism as a gradual response of changes in the hours gap to changes in the output gap due to costs of hiring and firing. We then show that the observed cyclical behavior of changes in the productivity gap is a residual implied by the underlying hours adjustment mechanism. We allow this process to occur over the current and four lagged quarters, and we use the term "long run" to apply to the total response after the five-quarter process is complete.

Thus, we interpret what are often called "productivity shocks" 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 demand dynamics of consumption, investment, government spending, and foreign trade. When hours exhibit a 100 percent long-run response to output gap changes, there is no room left for a residual productivity response, and we describe the productivity gap change as acyclical.

Using the notation * for (Kalman) trends and ' for gaps, the percent level gap of a variable such as output can be written as the first term in equation (2) and the first difference of the gap as the second term:

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

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 four-quarter change was accompanied by a simultaneous movement of the productivity gap four-quarter change in the same direction with an elasticity of roughly 0.3. The time interval 1977-79, when positive output gap changes were not accompanied by a positive productivity gap change response, appears to be the only exception to this regular procyclical behavior prior to the mid-1980s.

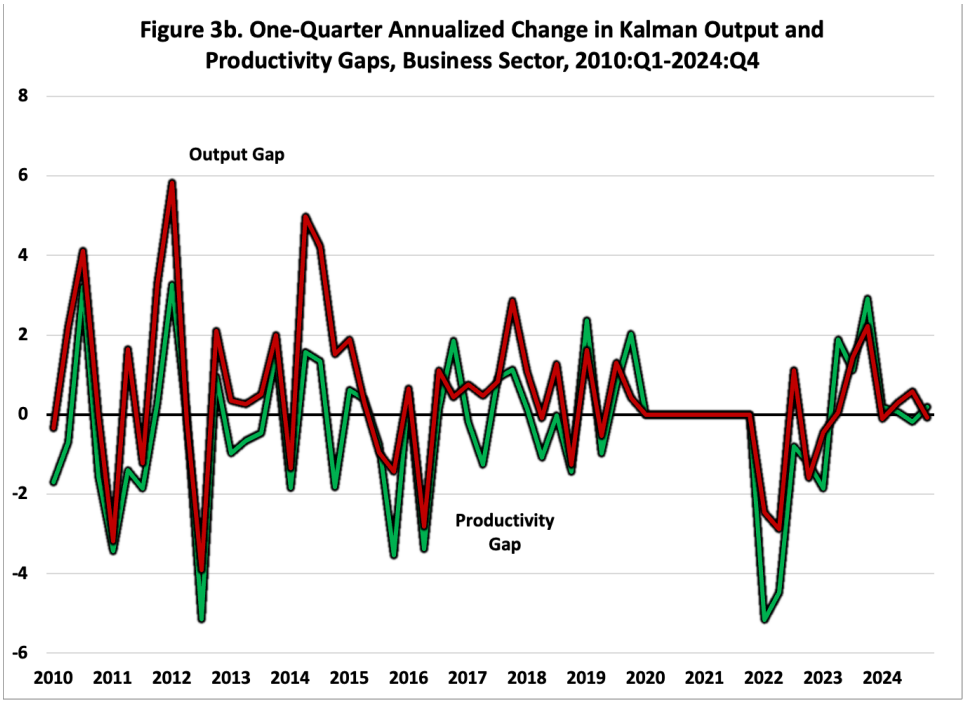


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Between 1986 and 2006, the previous procyclical relationship was muted or absent. There were no downward responses of the productivity gap changes in the recessions of 1990-91 nor 2001. There was one brief exception — a distinct procyclical response to the positive output gap change of 1999-2000.

We turn below on the unusual behavior during the Financial Crisis of 2008-09. Starting in 2010 the pattern changed again to a distinct procyclical response. This relatively tight procyclical relationship is more evident in Figure 3b, which displays *one-quarter* changes in output and productivity gaps for 2010-24, with the data for 2020-21 blanked out because of the enormous zig-zag output change reaction to the pandemic.[18] 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, implying that the hours gap response is muted. As we saw above in Table 2 for 2010-24 there is a *negative* correlation between the volatility of output components and productivity in the industries that produce those components.

[18] The annualized output gap change was -45 percent in 2020:Q2 and +33 percent in 2020:Q3. If included in Figure 3b these large changes would so distort the vertical scale that the procyclical pattern in the rest of the graph would be obscured.

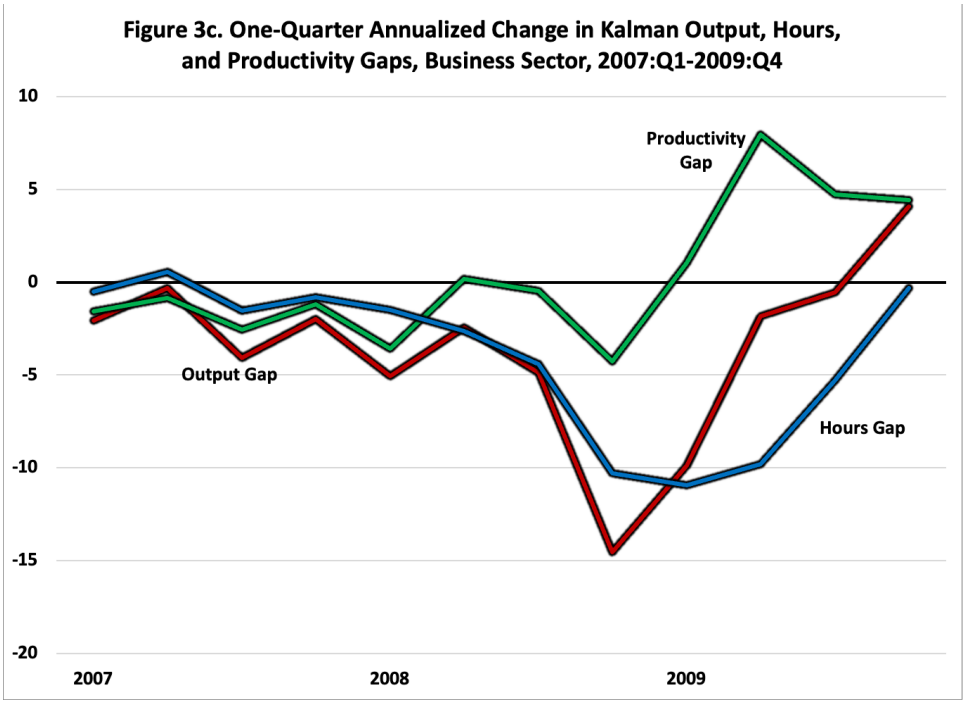


The reappearance of procyclical productivity behavior after 2009 — and the question of why it occurred — suggests that our subsequent regression analysis should split the postwar era into three intervals: 1950-85, 1986-2006, and 2007-19. We provide an explanation of the disappearance of the procyclical pattern during 1986-2006 and its reappearance after 2009. We reserve the 2020-24 data for post-sample simulations that help to shed light on the unusual behavior of productivity changes during the pandemic and post-pandemic interval.

6. Why the Great Financial Crisis Led to a Countercyclical Productivity Response in 2009

Figure 3c displays one-quarter changes in the output, hours, and productivity gaps for 2007-2009. Note that the output gap change turned negative prior to the NBER-dated business cycle peak month of December 2007, because actual output growth was well below the Kalman trend of output change during all four quarters of 2007.[19]

[19] Recall from Table 1 that our output concept is the average growth rate of real GDP and real GDI. 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.



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 a 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 productivity growth was 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 the year 2009 as displaying strongly countercyclical productivity behavior, forming part of the twin puzzles identified in the introduction.

The collapse of the hours gap in 2009 mainly reflects the behavior of employment, not weekly hours of work.[20] Why did employment decline so much in 2009? Part of the weakness of

[20] 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.

employment in that year reflected the continuing influence of what Autor and co-authors (2021) have called 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:

> 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 employment 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 *et al. (2016)* 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). Foster et al. (2015) also show that while past recessions experienced a mild increase in job creation and strong increase in job destruction, job creation uniquely plummeted during the Great Recession, accompanying an attenuation of the "cleansing effect" of recessions prior to 2008.

The housing bust reduced employment in the broader economy beyond the construction industry, 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).

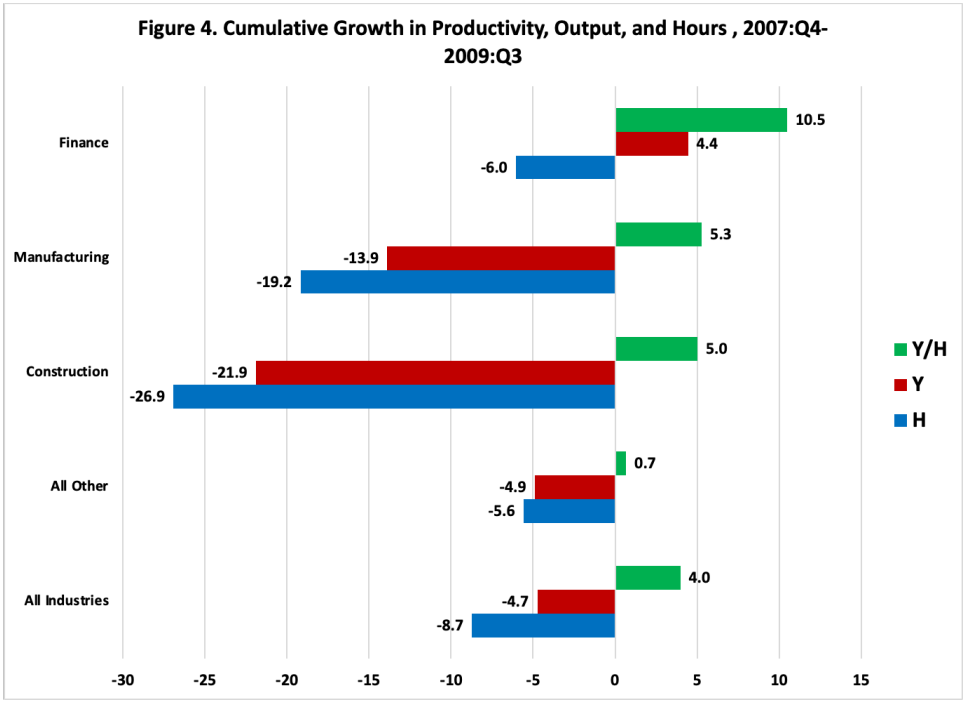
The Great Recession also caused a large dislocation in the finance industry, particularly after the failure of Lehman Brothers in September 2008. The timing of the Lehman failure helps us understand why, as shown in Figure 3c, the business-sector output gap declined in the 2008:Q4 by a massive -14.5 percent at an annual rate and the hours gap by -10.3 percent. The financial-sector implosion set off a panic throughout the economy. Business firms attempted to survive by cutting costs, particularly with extra 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.[21] As a result, growth in the productivity gap was substantially positive in the last three quarters of 2009.

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.[22] For the full year 2009, auto sales were 35 percent below the first half of 2008.

The observation that this turnaround in the sign of productivity growth was concentrated in the manufacturing, construction, and finance industries coincides with the changes displayed in Figure 4, which shows cumulative (non-detrended) growth in productivity, output, and hours between 2007:Q4 and 2009:Q3. Quarterly data are provided by our new quarterly data file, described below in Part 8. The three industries are displayed in order of their cumulative positive productivity change over the seven-quarter interval. The extra layoff interpretation is most convincing for the manufacturing and construction industries. Cumulative output change in manufacturing was -13.9 percent while extra layoffs reduced hours by -19.2 percent, resulting in the residual productivity change of +5.3 percent. Construction experienced an even larger output decline of -21.9 percent while extra layoffs reduced hours by -26.9 percent, leaving the residual cumulative productivity change of +5.0 percent.

[21] 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.
[22] Source: https://fred.stlouisfed.org/series/TOTALSA



The finance industry (including insurance and real estate) was somewhat different. Its cumulative output change was a positive 4.4 percent, differing from the large output declines in manufacturing and construction. Do "extra layoffs" describe an industry with a positive cumulative output change? It helps to split the year 2008 from the first three quarters of 2009. In the panic following the failure of Lehman Brothers in September 2008, output in the finance sector declined at an annual rate of 15.6 percent in 2008:Q4. The cumulative output decline in the year 2008 was -6.3 percent, and so the observed cumulative hours decline of -6.0 percent during the seven recession quarters can be interpreted as a lagged response to what happened in 2008.

Also shown in Figure 4 is that these three industries account for almost all of the +4.0 percent cumulative increase in productivity across all industries; the remaining 14 industries experienced cumulative growth in productivity of just 0.7 percent. The extra layoffs interpretation carries through to the total of all industries, with a cumulative output decline of -4.7 percent being exceeded by a cumulative hours decline of -8.7 percent.[23]

7. Regression Analysis of the Recession and Recovery Effects

This section introduces our baseline regression analysis that captures the dynamics of productivity and hours gap changes in response to changes in output gap changes. We define a

[23] 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.

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 "extra layoffs" are gradually unwound by subsequent extra hiring, and show how this can explain the countercyclical upsurge of productivity growth during 2008-09 as well as the historically slow average productivity growth rate of 2010-19.

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.

To capture differential responses during recessions, 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 designated as 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 usual identity, equation (5) implies our productivity gap change $(y'_t - h'_t)$ regression equation (6):

$$y'_t - h'_t = -\gamma + (1-\alpha_0)y'_t - \sum_{i=1}^{4}\alpha_i y'_{t-i} - \sum_{i=0}^{4}\beta_i * recess_{t-i}y'_{t-i} - \eta_t \qquad (6)$$

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), the additional recession effects (the sum of the β_is), and constant terms γ. The inclusion of lagged output terms in the recession response implies that the overshooting of hours can continue after the output change reverses from negative to positive at the end of the NBER-dated recession. This is the pattern for 2009 observed above in Figure 3c.

Figures 3a and 3b suggest there are three eras of cyclical productivity gap changes. The first extending from 1950 to 1985 features the regular procyclical response of roughly 0.3 visible in Figure 3a. The second covering 1986-2006 witnesses a more muted and inconsistent cyclical response. The third from 2007 to 2019 combines the strong extra adjustment of hours during 2009 with the reappearance of a regular procyclical productivity response in 2007-08 and after 2009. After estimating regressions for the three time periods, we provide explanations for the shifts in these cyclical productivity responses across time periods.

The left pair of columns in Table 3 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, the lagged hours response adds an additional 0.26, reducing the productivity response by the same amount definitionally. Thus the long-run response of hours is 0.46+0.26 or 0.73 after rounding, while that of productivity is 0.27. This long-run productivity response of 0.27 is statistically significant and reflects the incomplete adjustment of labor hours to output changes after five quarters. It is similar to the one-third response of productivity in Okun's original (1963) 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 demand-driven output fluctuations.

Table 3. 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**		0.26**	0.74**
Effect of Output Lags 1-4	0.26**	-0.26**	0.41*	-0.41*	0.18	-0.18		-0.00	0.00
Total Effect of Output	**0.73****	**0.27****	**0.79****	**0.21**	**0.49****	**0.51****		**0.26***	**0.74****
Recession Effect of Current Output	0.11	-0.11	0.06	-0.06	0.15	-0.15		0.18	-0.18
Recession Effect of Output Lags 1-4	0.05	-0.05	0.37	-0.37	0.65**	-0.65**		0.79**	-0.79**
Total Recession Effect of Output	**0.16**	**-0.16**	**0.43**	**-0.43**	**0.80****	**-0.80****		**0.97****	**-0.97****
Constant	**0.22**	**-0.22**	**0.13**	**-0.13**	**0.62****	**-0.62****		**-0.04**	**0.04**
Adjusted R^2	**0.70**	**0.56**	**0.49**	**0.46**	**0.89**	**0.81**		**0.91**	**0.85**
RMSE	**2.13**	**2.13**	**1.58**	**1.58**	**1.01**	**1.01**		**0.92**	**0.92**

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

Results for 1986-2006 are displayed in the second pair of columns of Table 3. 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 0.27 to 0.21. Nevertheless, that 0.21 is insignificant, and it is clear from Figure 3a above that the response of productivity gap changes to output gap changes is more muted and inconsistent during 1986-2006. Below we explain this decline in the long run productivity response as a byproduct of the Great Moderation in output volatility.

The next two columns of Table 3 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 0.18 for hours and -0.18 for productivity. This means the long-run response of productivity is a highly significant 0.51 during 2007-19, almost double the 0.27 long-run response during the initial 1950-85 interval. This return to procyclicality has neither been recognized nor explained in the previous literature.

The second set of rows, where the β_i recession coefficients are displayed, provides some insight into this shift. For 2007-19, we find a highly significant recession response of hours and productivity changes to output gap changes of 0.80 and -0.80, 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 0.49 and the extra recession response of

0.80, for a total hours gap response of 1.29. The corresponding productivity gap coefficients are 0.51 plus -0.80, for a total long-run response of -0.29. This countercyclical reaction of productivity gap changes is clearly visible for 2009 in Figure 3c.

As suggested above, a convincing 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 effect of the 2008-09 recession did not end in 2009. The highly significant constant terms in the 2007-2019 regressions shown in the third pair of columns in Table 3 indicate that, on average, hours grew faster than the output-response coefficients can explain.

Rather than leave the post-2009 recovery of hours hidden in the constant term in Table 3, 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 that are now constrained to apply equally to both the recession and recovery intervals. 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,

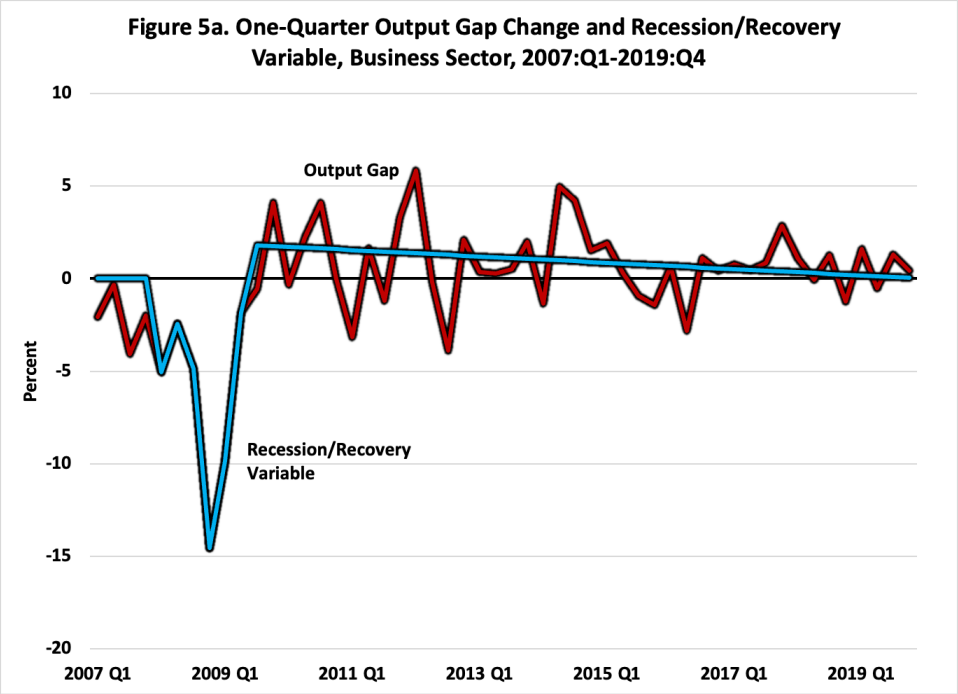
$$v'_t = -\xi(t - (M + N + 1)) \tag{7}$$

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

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 tied together by the fact that the β_i coefficients apply to both. 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):

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

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 blue in Figure 5a, which also displays the quarterly change in the output gap in red. The blue line lies on top of the red line for all 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).



The choice of a linearly declining recovery variable extending for ten years is one of several possible alternatives, and so we have tested other options including no recovery effect and different specifications for the timing of the recovery variable. The long-run coefficients and statistics of fit for 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 in Figure 5a.[24] While ten 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 after the 2008-09 trauma[25].

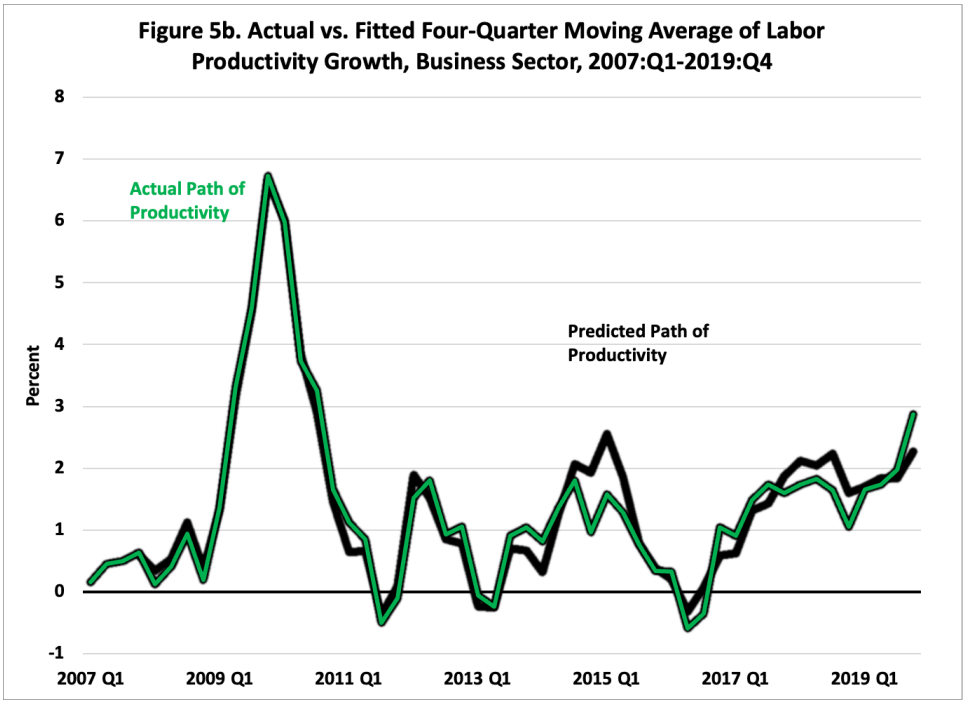
[24]These include, in order from left to right in that table, (a) no recession or recovery effect with a constant, (b) recession effect and no constant or recovery effect, (c) recession effect and constant but no recovery effect, (d) recovery effect as a constant value for 2010-19, (e) a three-step recovery 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.

[25] 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)

Several other indicators support the conclusion that the post-2009 hiring recovery was unusually slow. We have already noted that the trough of the employment-population ratio came two years after the trough of the NBER-dated output recession. Further, 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 slowness of the post-2009 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 (2012) provides one explanation: the unemployed could not find new jobs by moving because the downturn had been so widespread (p. 525).

The two right-hand columns in Table 3 labeled "2007-2019 (Recovery)" report regressions identical to those in Table 3 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 0.62 to -0.04, indicating that our treatment of the recovery effect makes explicit the extra pace of recovery rehiring that is otherwise "hidden" in the large and significant constant term. The long-run normal plus recession responses of hours gap changes to output gap changes is 1.23 with the recovery effect, similar to the 1.29 without the recovery effect.

Our preferred treatment of the 2007-2019 interval yields a remarkably precise set of fitted values of labor productivity changes, shown by the black line in Figure 5b, which adds back in the Kalman trend. Predicted productivity growth soars in 2009, demonstrating the countercyclical productivity response implied by extra layoffs. Following this countercyclical episode, the predicted productivity gap changes closely track actual changes throughout 2010-19. While the visibly precise fit for the six recession quarters of 2008-09 is to be expected due to the current and four lagged recession coefficients that closely track that interval, the predicted values of the equation are also highly accurate in capturing the volatile ups and downs of quarterly productivity growth in 2010-19.



One of the two motivating puzzles for this paper is the unusually slow 1.2 percent average growth of U.S. labor productivity during the 2010-19 decade. Our analysis shows that this sluggish pace was largely due to the post-recession rehiring effect which reversed the extra layoffs of 2008-09. Our regression coefficients for the recession effect imply that hours were reduced by a cumulative total of -9.1 percent between 2008:Q1 and 2009:Q4 in extra of the normal non-recession response. Spread over the 2010-19 decade, the reversal of this -9.1 percent response adds a cumulative +9.1 percent to hours, or +0.9 percent per year. Added to the actual recorded growth of 1.2 percent, the resulting counterfactual productivity growth rate for 2010-19 would have been 1.2+0.9, or 2.1 percent per year. Thus, the Financial Crisis not only decimated labor markets during and after the recession itself, but also explains indirectly what appears in the data to be secular stagnation and a slowing of innovation. Instead, historically slow productivity growth in the 2010-19 decade is a business-cycle phenomenon, the byproduct of the recession itself.

Two remaining questions about the Table 3 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 0.27 in 1950-85 to an insignificant 0.21 in 1986-2006 before jumping up to a significant 0.74 in 2007-2019. What caused the lower response in 1986-2006 compared to 1950-85? An explanation that appears in some of the previous literature reviewed above in Part 2 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 4, the standard deviation of the quarterly output gap change was 2.46 for 1986-2006, less than half of the 5.40 standard deviation for 1950-85.

Because the variance of output gap changes was so much smaller in 1986-2006 than before, labor input adjustment over the four lagged quarters could catch up more completely, that is, become a larger percent of the output gap change. The ratio of the standard deviation for hours relative to the standard deviation for output rose from 73 percent in 1950-85 to 90 percent in 1986-2006. Notice in Table 3 that the sum of coefficients in the hours equation 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 in 1986-2006 implies a smaller percentage negative lagged response of the productivity gap.

Table 4. 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	5.40	3.95	3.41
1986:Q1-2006:Q4	2.46	2.21	2.14
2007:Q1-2009:Q4	4.78	4.20	3.66
2010:Q1-2019:Q4	2.05	1.20	1.83
	Serial Correlation		
1950:Q1-1985:Q4	0.37	0.50	-0.01
1986:Q1-2006:Q4	0.35	0.51	0.03
2007:Q1-2009:Q4	0.45	0.76	0.56
2010:Q1-2019:Q4	0.00	0.14	-0.16

The second question is why the long-term productivity response jumped up to 0.74 after the Great Recession of 2008-09. Table 4 shows that the serial correlation of quarterly output gap changes declined from 0.35 in 1986-2006 to exactly 0.00 during 2010-19, consistent with the sharp up-and-down zig-zags of one-quarter output gap changes in Figure 3b. 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 3, 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 0.74. Procyclicality returned not because of any inherent change in the behavior of productivity itself, but because of a change in the time-series volatility of demand-driven output changes relative to the partial and lagged response of hours changes.

A robustness issue is the sensitivity of the Table 3 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, appendix table A2 compares the results for the 2007-19 interval with and without detrending. The results are similar without detrending and in fact the recession-recovery effect becomes stronger. The normal long-run productivity response declines from 0.74 with detrending to 0.61

without detrending. The long-run recession-recovery productivity response rises from -0.97 to -1.45, indicating that the potency of this effect does not depend on our method of detrending the output, hours, and productivity data.

Has the cyclical behavior of TFP consistently echoed that of labor productivity? Table 5 repeats the productivity gap change regressions of Table 3 with changes in the TFP gap substituted as dependent variable, where the 2007-19 results repeat the recession-recovery treatment of the right side of Table 3. The long-run normal TFP gap response to a change in the output gap is strongly positive and consistent across the three time intervals— 0.52, 0.44, and 0.74. 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 periods but a highly significant -0.54 in the third period.

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**	0.82**	0.91**
Effect of Output Lags 1-4	-0.19**	-0.37*	-0.17
Total Effect of Output	**0.52****	**0.44***	**0.74****
Recession Effect of Current Output	-0.07	-0.12	-0.14
Recession Effect of Output Lags 1-4	-0.07	-0.25	-0.40**
Total Recession Effect of Output	**-0.15**	**-0.37**	**-0.54****
Constant	**-0.20**	**-0.10**	**-0.37***
Adjusted R^2	**0.84**	**0.67**	**0.90**
RMSE	**1.49**	**1.32**	**0.84**

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

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 0.20, 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, the capital-labor ratio is strongly countercyclical. Hence, we would expect TFP growth to be substantially more procyclical than labor productivity growth.

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

We now examine productivity behavior in the 20 quarters from 2020:Q1 through 2024:Q4. This includes the sudden lockdown of the economy in 2020:Q2, the rapid but partial reopening in 2020:Q3, and the subsequent recovery of the following 17 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. While output collapsed in 2020:Q2, business-sector productivity growth was positive at an annual rate of 15.7 percent.

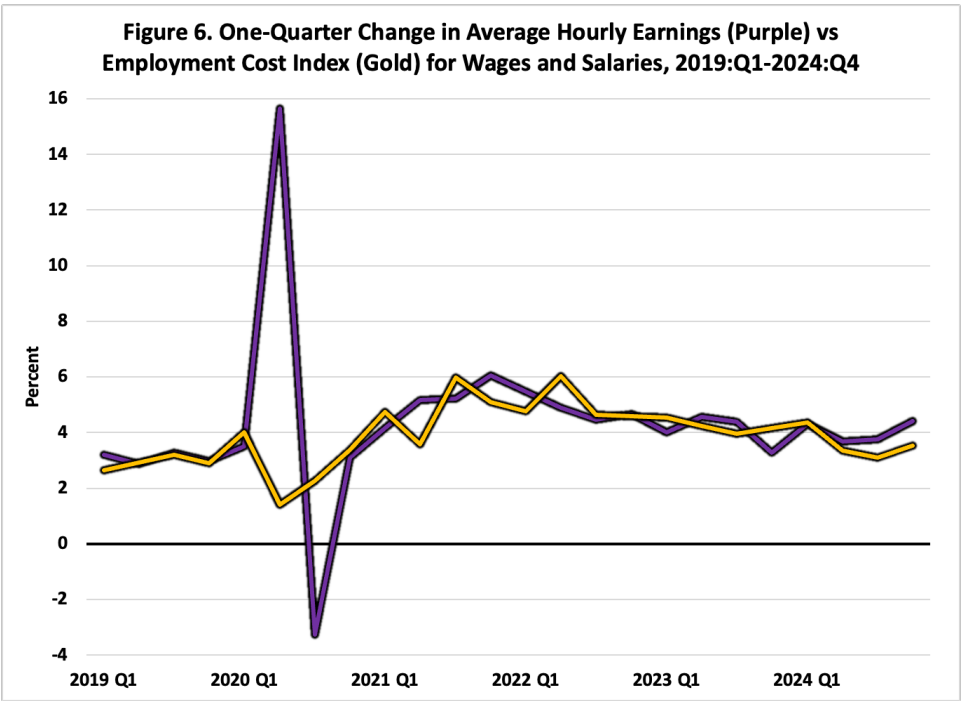
We show that the apparent countercyclical behavior of productivity in 2020:Q2 reflected not a sudden outburst of creative innovation but rather a shift in the mix of output and employment toward higher productivity sectors of the economy. While output and employment dropped everywhere, they declined much faster in sectors with relatively low *levels* 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 hospitality. In contrast, there was a relative increase in the employment of workers who could 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 6.

Table 6. 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 6, where we compare annualized quarterly changes of average hourly earnings (AHE) with the fixed-weight Employment Cost Index (ECI). The change in AHE, which divides total earnings by total hours, is jolted by a sharp annualized 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 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 for annual data. To address the mix issue for productivity in up-to-date quarterly data, as well as to assess the contribution of individual industries to productivity behavior in 2008-09 as in Figure 4 above, 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).[26]

To avoid the weighting distortion that would occur if current weights (CW) were used, we employ a fixed-weight (FW) growth measure that weights the output change for all 17 industries by their 2019:Q4 share of total real value added, and the hours change by the hours share of each industry in the same quarter. We denote industry aggregate output as

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

where *i* designates individual industries. Then, we compute the CW (equation 10) and FW (equation 11) productivity growth rates as:

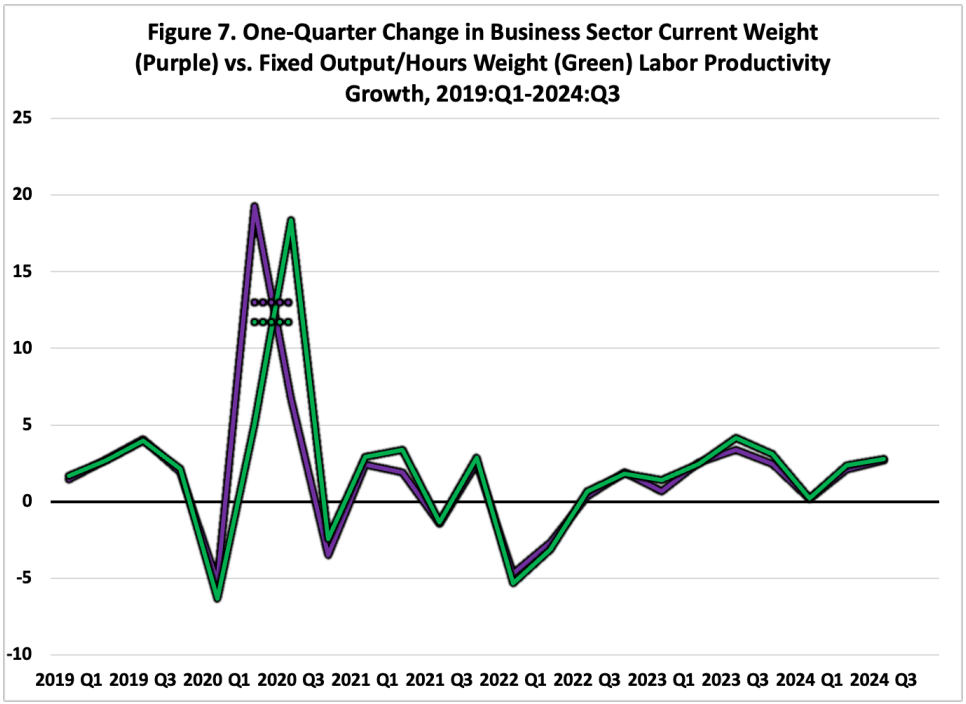
[26] Since real value added is at an annual rate, BLS hours are multiplied by 52 so that the level of output per hour is in the correct units of dollars per hour, as shown in the productivity listings of Table 6.

$$cw_t = y_t^{agg} - h_t^{agg} \tag{10}$$

$$fw_t = \ln\left(\sum_i \exp\left(\frac{y_{it}}{100} * \frac{Y_{i,2019:Q4}}{\sum_i Y_{i,2019:Q4}}\right)\right) - \ln\left(\sum_i \exp\left(\frac{h_{it}}{100} * \frac{H_{i,2019:Q4}}{\sum_i H_{i,2019:Q4}}\right)\right) \tag{11}$$

The FW index represents aggregate labor productivity growth as the difference between the fixed-weight growth rate of output minus the fixed-weight growth rate of hours.

How do growth rates of the alternative current-weight and fixed-weight indexes compare during the pandemic recession and recovery? Figure 7 shows that the annualized one-quarter change in 2020:Q2 for the CW index is a massive 19.3 percent, compared to 5.1 percent for the FW index. The FW index bounces back in the 2020:Q3 when its annualized one-quarter change is 18.3 percent in contrast to 6.7 percent for the CW index. These large differences in growth rates across the two indexes apply only to the middle two quarters of 2020; they record similar growth rates for the other quarters of 2020-24.[27]



[27] The difference between the two indexes exceeds an annualized 1.0 percent in only two quarters of the 13 quarters between 2020:Q4 and 2024:Q4.

Figure 7 also shows that the difference between the CW and FW indices in 2020:Q2 and Q3 is reduced when averaging their growth rates; the dotted lines indicate that the average CW growth rate of 13.0 percent is only slightly higher than the FW growth rate of 11.7 percent. Thus, most of the shifting-weight phenomenon can be avoided by averaging these two quarters. These changing weights have no effect on cumulative growth for 2020:Q1 to 2024:Q4 taken together, with identical average five-year annual growth rates of 1.7 percent for both indices. This is just below the rate of 1.8 percent for 2020-24 in Table 1.[28]

9. A Post-Sample Simulation for 2020-24 of the Productivity Gap Growth Equation

To what extent was the countercyclical surge of labor productivity growth in 2020 driven by the downward overshooting of labor hours in response to the decline in output, as in 2008-09? We utilize our regression equations from Table 3, which are estimated using data through 2019, to perform post-sample simulations during the pandemic recession and afterwards.

We employ the fixed-weight business-sector productivity data and average series for 2020:Q2 and Q3 to adjust for the output mix distortions discussed above, as well as the extreme volatility of the output changes (-42 percent at an annual rate in 2020:Q2 and +35 percent in 2020:Q3). We use the estimated coefficients from the right column in Table 3, where the sum of the normal adjustment (α_i) coefficients in the productivity gap equation is 0.74 and the sum of the recession/recovery (β_i) coefficients is -0.97. We calculate the recovery effect as the cumulative negative values of the output gap change in 2020:Q1 to Q3 with sign reversed, linearly declining over eight quarters starting in 2020:Q4.[29]

Figure 8a displays the recession-recovery effect in blue: it is equal to the red output growth line from 2020:Q1-Q3 and linearly declines from 2020:Q4 to 2022:Q3. Figure 8b compares actual productivity changes compared with the simulation results for 2020-24 together with the predicted values for 2014-19. All plotted values are four-quarter changes, and calculated gaps have been added to the Kalman Trend, so that the growth rates shown are actual and simulated growth rates, not growth gaps. The green line is the actual productivity change of the fixed weight index from Figure 7, and the black line is the simulated productivity change[30]. The black predicted line captures the volatile movements of the actual series remarkably well, even in the post-sample simulation period when the post-2019 data played no role in estimating the regression coefficients.

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[28] 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.

[29] Recall that we average changes in 2020:Q2 and Q3, so we treat the recession as extending from a peak of 2019:Q4 to a trough in 2020:Q3, not 2020:Q2.

[30] Through 2019:Q4, we utilize John Fernald's quarterly business sector data as-is to create parity with the exercise in Table 3. Beginning in 2020:Q1, we take Fernald's data and add to it the difference in the growth rates of the BLS FW and CW series to construct a corresponding "FW" series for Fernald's data.

Figure 8a. Actual One-Quarter Output Change with Recession/Recovery Variable, Business Sector, 2014:Q1-2024:Q4, Simulation Starts in 2020:Q1, Fixed-Weight Series

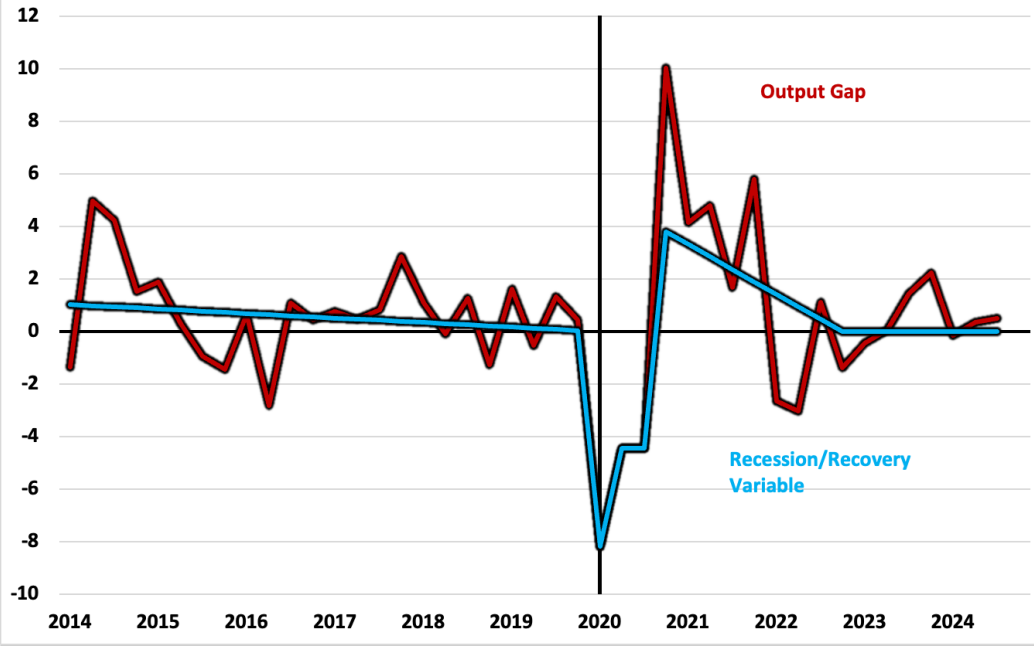
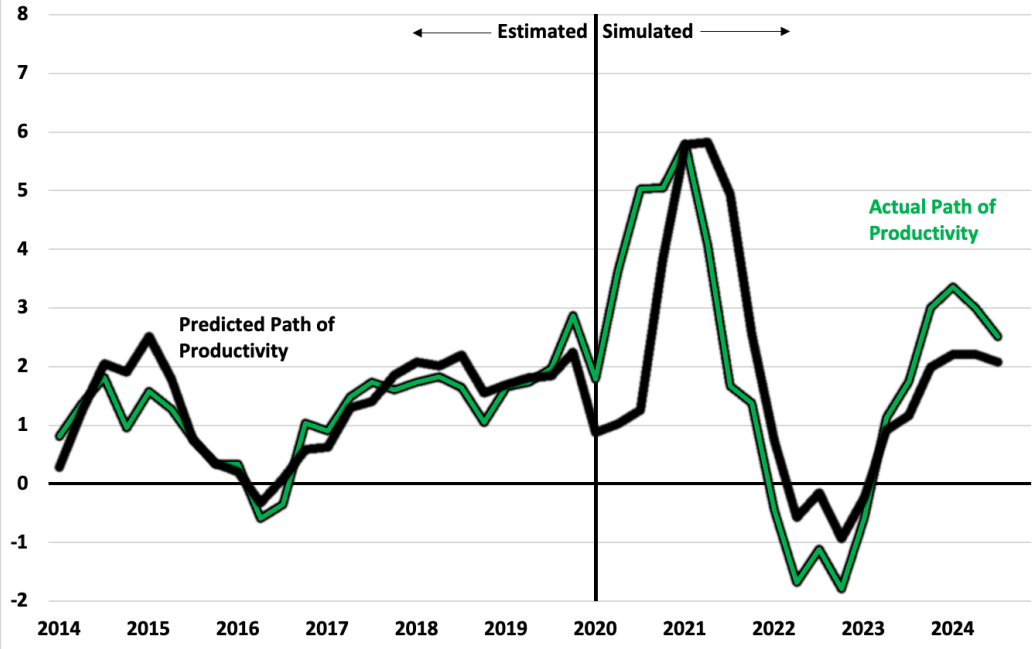


Figure 8b. Actual vs. Predicted 4QMA of Labor Productivity Growth, Business Sector, 2014:Q1-2024:Q4, Fixed-Weight Series Starting 2020:Q1



The simulation captures the sharp 2020 peak in the actual growth rate, albeit two quarters late, and accurately tracks a sharp decline to negative growth in 2022. The simulation

concludes by duplicating the 2023-24 recovery to relatively normal productivity growth. The average of the one-quarter annualized changes of the predicted series accurately capture the sharp swing in productivity growth from strongly positive to negative back to positive again.

As shown in Table 7, the simulated annualized growth rates underestimate actual productivity growth in 2020 (3.83 simulated vs. 5.04 percent actual), overestimate it during 2021-22 (0.81 vs. -0.20 percent), and slightly underestimate it for 2023-24 (1.82 vs. 2.34 percent). For the entirety of 2020-24, the average simulated value is 1.82 percent vs. the actual value of 1.86 percent. Thus the simulation accurately captures the volatile swing in productivity growth from a countercyclical bulge in 2020, to a negative hiring recovery in 2021-22, back to normal growth in 2023-24. Averaged over all 20 quarters, the simulation error is a notably small -0.04 percent.

Table 7. Actual Business Output, Hours, and Productivity Growth vs. Predicted Productivity Growth, Post-Sample Simulations 2020:Q1-2020:Q4, Fixed-Weight Series

	Output	Hours	Prod. (Actual)	Prod. (Predict.)	Error
2020:Q1-2020:Q4	0.64	-4.40	5.04	3.83	1.21
2021:Q1-2022:Q4	3.46	3.66	-0.20	0.81	-1.02
2023:Q1-2024:Q4	2.77	0.43	2.34	1.82	0.52
2020:Q1-2024:Q4	2.62	0.76	1.86	1.82	0.04

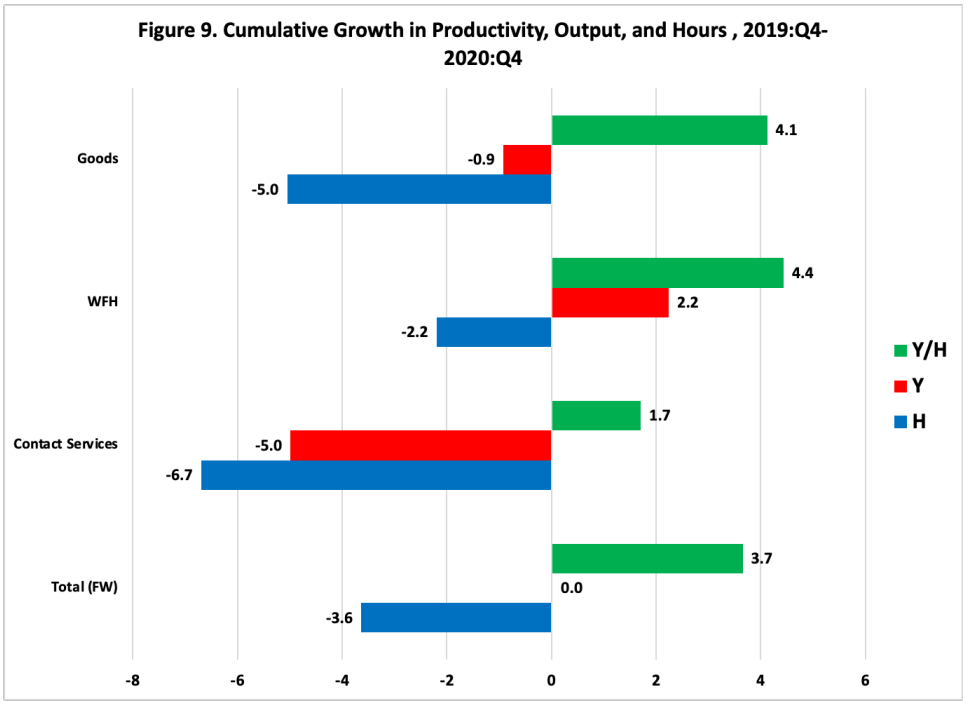
Thus, the puzzle of soaring productivity growth during and after the recession of 2020 can be explained as a remarkably similar repeat of 2008-09, despite the many differences in the causes and timing of those recessions. In both cases, an unexpected shock caused an overreaction by business firms, which cut hours more than normal, and with an elasticity of well above unity with respect to the decline in output. The next question is: why did business sector productivity growth slow down sharply from a robust 5.0 percent in the four quarters of 2020 to -0.2 percent in the eight quarters of 2021-22?

The extra layoffs of 2020 were followed by the same recovery effect that occurred after 2009, but much 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. Following the initial bounce-back in 2020:Q3, the strongest period for rehiring was in the four quarters ending in 2022:Q1, when hours grew at an annual rate of 5.3 percent (compared to average growth of just 0.5 percent for the full 2020-24 interval). The tightness of labor markets in spring 2022 is confirmed by the peak of the quit rate in March, 2022, and the peak of the ratio of vacancies to unemployment in April, 2022.[31]

[31] FRED data indicate that the monthly quit rate peaked at 3.0 percent in March, 2022, compared to 2.0 percent in the business cycle peak year of 2007 and 2.3 percent in 2019. The FRED ratio of vacancies to unemployment peaked at 2.3 in April, 2022, much higher than 0.7 in 2007 and 1.2 in 2019. The Fernald data shown in Table 1 indicate that productivity grew at an annual rate of -0.5 percent in the four quarters ending in 2022:Q1.

There remains the question of which industries contributed to the positive countercyclical productivity growth phenomenon of the year 2020. While we cite the role of three industries — manufacturing, construction, and finance — as leading the extra layoffs in 2008-09, the 2020 jump in productivity was more widely spread across industries. The lockdowns of the Covid pandemic created a distinction among the three groups of industries already listed above in Table 6 – goods, work from home (WFH) services, and contact services.

Figure 9 repeats the format of Figure 4 but includes all industries combined into these three groups. Our discussion above highlighted the fact that contact services group, with a relatively low level of productivity, was impacted most severely by the pandemic. This finding is borne out in Figure 9: output for contact services in 2020 declined by -5.0 percent and hours by a larger -6.7 percent, resulting in an increase in productivity of +1.7 percent.



The goods sector, dominated by manufacturing, had a smaller -0.9 percent output decline but a larger hours shortfall of -5.0 percent. This implied a productivity increase of 4.1 percent. The outlier was the WFH services industry group, which was unaffected by lockdowns as employees could work from home, and whose output increased by +2.2 percent during 2020. Hours declined by -2.2 percent, resulting in productivity growth of +4.4 percent. The WFH sector has been the most dynamic sector of the economy, registering much faster productivity growth on average during 2020-24 than the other two sectors, and the 2020 recession was not severe enough to interrupt its relatively steady growth of output.

For all industries taken together, Figure 9 shows that the cumulative decline of hours in 2020 of -3.6 percent contrasted with an unchanged level of output, yielding a +3.7 percent

countercyclical increase in productivity.[32] The total private-sector productivity change in 2020 of +3.7 percent was remarkably similar to the +4.0 change of 2008-09, even though the 2008-09 decline of output (-4.7 percent) and hours (-8.7 percent) were much more severe.

10. 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 of only 1.2 percent per year during the 2010-19 decade the slowest of any decade in U.S. history? The second puzzle is: why did productivity growth swing from procyclical during 1950-85 to acyclical during 1985-2006, back to even more procyclical during 2007-24? Part of the second puzzle is: why was this transition back to a procyclical productivity response interrupted by sharply *countercyclical* responses of productivity growth during the recessions of 2008-09 and 2020?

These variations in the cyclicality of productivity are important to understand in and of themselves and also because they contradict a common approach of modeling productivity changes as autonomous shocks that drive short-run output fluctuations. If productivity shocks were a consistent driver of output changes, they would always be procyclical instead of registering a variety of positive, zero, and negative correlations as observed in the postwar data.

Productivity growth is defined as output growth minus growth in hours of work. The gradual adjustment of hours to changes in output due to costs of hiring and firing drives changes in productivity growth as a definitional residual; that is, they emerge as the mechanical difference between exogenous demand-driven output and endogenous adjustments in hours. Because hours respond to output changes in the current quarter with 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 becomes smaller. 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 reflects 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 2007-24, the lagged hours response is incomplete, leaving room for productivity change to register a positive long-run response. 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 the productivity change residual to register a positive long-run response.

[32] As noted above, the productivity growth rates for the aggregate private business sector in our quarterly data set differ from those in the Fernald data used to construct Table 1 and the data used in the econometric analysis, since the quarterly industry data measure output by real value added, while the Fernald data measure output as the average growth rates of GDP and GDI.

We concur with the previous literature that productivity growth was strongly procyclical during 1950-85. We depart from this literature by finding that procyclicality did not disappear after 1985. Our long-run sum of coefficients declines from a significant 0.27 for 1950-85 to an insignificant 0.21, rather than to zero, for 1986-2006. We attribute this lower response to a decline by more than half in the standard deviation of output changes when 1986-2006 is compared to 1950-85. Hours could adjust more completely to output shocks when output is less volatile. The large procyclical 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 these volatile quarterly output changes. The hours response was also muted after 2009 by the slow but steady rehiring of the many workers who lost their jobs in the 2008-09 recession.

We distinguish the normal response of hours to output changes from an extra reaction during the two most recent recessions. During the 2008-09 recession, hours fell with a much higher than normal elasticity in response to the sharp decline in output. We describe this phenomenon as "extra layoffs" due to the overreaction of business firms as output collapsed during 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 after the housing bubble, and the financial crisis following the 2008 Lehman failure.

Since productivity change is a residual, and hours declined much more than output fell, productivity registered an increase of 5.1 percent between 2007:Q4 and 2009:Q3. By definition this is 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 almost entirely responsible for this cumulative 2008-09 upsurge of productivity growth.

The extra layoffs of 2008-09 did not occur in isolation; the lost jobs returned as workers were rehired over the ensuing years. 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 extra reduction of jobs during the recession. The extra growth of hours during the drawn-out rehiring phase explains why hours growth was high and residual productivity growth low during the 2010s, resolving the first puzzle about trend productivity growth raised in this paper.

Our novel recession/recovery treatment has four important implications that resolve several puzzles about the trend and cyclical behavior of U.S. productivity changes. First, our estimated recession/recovery coefficients imply that a major explanation for slow productivity growth in the 2010-19 decade resulted from the extra post-recession rehiring that offset the extra hours reduction that had previously occurred in the recession. In the absence of this effect, hours would have grown slower and productivity faster, and the observed average annual

2010-19 productivity growth rate would have been 2.1 percent instead of 1.2 percent.[33] This suggests that the concern about "secular stagnation" that developed during that decade was based on a misunderstanding of the underlying sources of productivity growth dynamics.

Second, 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 high quarter-to-quarter volatility of output changes during this decade which prevented hours from catching up with output movements, leaving the residual productivity changes to more closely mimic volatile quarter-to-quarter output changes. The relative lack of response of hours to short-run output changes also reflected the slow but steady pace of post-recession rehiring which persisted for most of the decade.

Regarding the pandemic era, our third conclusion emerges when our estimated 2007-19 regression coefficients are applied in a post-sample simulation to actual data for 2020-24. We find that our coefficients reproduce the behavior of productivity growth during 2020-24 remarkably well. The simulation tracks the upsurge in productivity growth in late 2020, and it also captures the period of negative productivity growth in 2021-22 followed by the return to positive growth in 2023-24. Once again, the post-recession rehiring effect explains why productivity growth was negative during part of 2021-22. Overall the simulation errors are relatively small in matching the observed 5.8 percent rate of productivity growth in the year 2020 and the observed 1.1 percent average rate during the four years 2021-24.

Where does this leave our assessment of the long-run trend in productivity growth? The paper has suggested that productivity growth was distorted by extra layoffs in 2008-09, shifting some productivity growth into that two-year period and moving it away from the 2010-19 decade when rehiring cancelled the effects of the extra layoffs. The underlying trend of productivity growth is better represented by averaging across sub-intervals within the 2005-24 interval, resulting in an average rate of productivity growth for those 20 years of 1.6 percent. This is close to the 1.5 percent achieved in the long "slowdown" period of 1973-95. The achieved rate of 1.8 percent in 2020-24 suggests that long-run growth has ticked up a bit, but it is still a long way from the brisk 3.3 percent growth rate of the 1996-2004 "dot.com" era.

[33] Actual productivity growth was 2.13 percent in 2005-09 and 1.15 percent in 2010-19. Counterfactual growth without the recession/recovery effect would have been 0.33 percent in 2005-09 and 2.05 percent in /

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Table A1. Regression Response of Hours to Changes in Output Gap, Alternative Treatments of Recession/Recovery Effect, 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	1.12**	0.74**	0.49**	0.36*	0.39*	0.39**	0.26*
Total Recession Effect of Output	-	0.42*	0.80**	0.83**	0.90**	0.82**	0.97**
Constant	0.20	-	0.62**	0.01	0.42**	0.00	-0.04
Adjusted R^2	0.83	0.86	0.89	0.89	0.90	0.90	0.91
RMSE	1.29	1.14	1.01	1.01	0.97	0.97	0.92

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

Table A2. 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	0.26**	0.74**		0.29**	0.71**
Effect of Output Lags 1-4	-0.00	0.00		0.10	-0.10
Total Effect of Output	0.26*	0.74**		0.39*	0.61**
Recession Effect of Current Output	0.18	-0.18		0.39**	-0.39**
Recession Effect of Output Lags 1-4	0.79**	-0.79**		1.06**	-1.06**
Total Recession Effect of Output	0.97**	-0.97**		1.45**	-1.45**
Constant	-0.04	0.04		-0.24	0.24
Adjusted R^2	0.91	0.85		0.91	0.83
RMSE	0.92	0.92		0.99	0.99

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