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Productivity and Potential Output Before, During, and After the Great Recession

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Abstract

U.S. labor and total-factor productivity growth slowed after the early- to mid-2000s in aggregate, industry, and regional data. The broad-based nature of the slowdown, and its timing, rules out simple stories related to housing and finance before the recession, or to effects of the recession itself, but is consistent with some models of the effects of information technology. A calibrated growth model suggests trend productivity growth is only slightly faster than its 1973-1995 pace. One implication is that about $\frac{3}{4}$ of the shortfall of actual output from pre-recession estimates of trend reflects a reduction in the level of potential.

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1. Introduction

Disappointing productivity growth...must be added to the list of reasons that economic growth has been slower than hoped...The reasons for weak productivity growth are not entirely clear: It may be a result of the severity of the financial crisis...or it may simply reflect slow growth in sales, which have led firms to use capital and labor less intensively, or even mismeasurement...Yet another possibility is weak productivity growth reflects longer-term trends largely unrelated to the recession. Obviously, the resolution of the productivity puzzle will be important in shaping our expectations for longer-term growth.

Federal Reserve Chairman Ben Bernanke (2014).

“Variations in productivity growth have proved to be one of the most durable puzzles in macroeconomics....”

William Nordhaus, BPEA 2002

This paper addresses the behavior and implications of U.S. productivity before, during, and since the Great Recession. As the two quotations above suggest, productivity performance is an enduring puzzle. Its performance shapes our views about potential output and, as Chairman Bernanke’s quotation suggests, matters for both welfare and policy. In the longer term, productivity and potential output are central in determining living standards. In the near term, assessments of potential output play a key role in policy discussions. For example, policymakers and others regularly debate the degree of “slack” in the economy. One benchmark measure of slack is the gap between actual output and an estimate of potential, such as the one provided by the Congressional Budget Office (e.g., CBO 2014).¹

In the mid-1990s, productivity accelerated markedly. A key finding of this paper is that, several years before the Great Recession, productivity growth receded from its exceptional, but apparently temporary, mid-1990s/early 2000s pace. Figure 1 shows the mid-1990s speedup, when labor productivity growth surged relative to its pace over the preceding quarter century. It then shows the slowdown over the decade that ended in 2013:Q4, broken into the four years prior to the Great Recession and the six years since. Growth in labor productivity (and underlying total-factor-productivity, TFP) has been reasonably similar over these sub-periods, and much more similar to the pre-1995 period than the late 1990s/early 2000s period. (Data sources for the figure are in the Appendix, and I define and discuss the growth-accounting decomposition in Section 2.)

This mid-2000s retreat from exceptional growth is apparent in aggregate, industry, and regional data. The aggregate data on labor and total-factor productivity include data that adjust for variations in factor

¹ See, for example, the blog discussion at <http://economistsview.typepad.com/economistsview/2012/02/potential-output-measuring-the-gap.html>; or the summary of policymaker views <http://www.federalreserve.gov/monetarypolicy/fomcminutes20120125.htm>, where “participants expressed a range of views on the current extent of slack in the labor market.”

utilization. The slowdown in the mid-2000s occurred at a time when the economy was booming, so cyclical mismeasurement associated with capital and labor utilization is not a factor. During the recession, empirical measures of utilization plunged but, by late 2010 or early 2011 were back close to pre-recession levels. Industry TFP data show that the pre-Great Recession slowdown was broad-based. In particular, it is not limited to sectors that were “unusual” in the mid-2000s, such as construction and finance. Regional labor-productivity data show that the slowdown is geographically widespread, with 44 out of 51 U.S. states (include Washington, D.C.) seeing slower growth in the run-up to the Great Recession (2004-2007) compared with the fast-growth 1995-2004 period.

That the slowdown predated the Great Recession suggests that it primarily reflects longer-term trends, rather than disruptions or measurement problems associated with the recession itself. Indeed, Figure 1 suggests no evidence that productivity was slower (or much faster) from 2007-2013 than in the several years before that. There are a number of channels through which one might expect a financial crisis and deep recession to affect productivity trends, at least for a while.² But the timing suggests that the recession was not the primary reason for the slowdown.

Early in the recession and recovery, informal commentary often highlighted apparently exceptional productivity performance. I document how data revisions since 2004 have changed our views on trend growth and on seemingly strong recession performance. Relative to real-time releases, data revisions have systematically pushed productivity down both before, and during, the recession. As a result, the pre-recession slowdown in productivity is more apparent in revised than in real-time data. And productivity performance during the Great Recession appears in line with previous deep recessions. In particular, using quarterly growth-accounting data from Fernald (2012), TFP declined 4 percent peak-to-trough during the downturn—the sharpest TFP downturn in the post-war period. Consistent with traditional stories of labor and capital hoarding, measures of utilization also fell sharply. Since the trough, utilization recovered strongly and quickly. TFP appeared back on its mid-2000s trend by the late 2010 or 2011 (check/refine).

Consistent with my results, Gali, Smets, and Wouters (2012) also argue that productivity performance after the 2007-9 recession was fairly typical. As a result, they argue this recovery, like the ones that followed the 1990-91 and 2001 recessions, should be described as “slow” rather than “jobless.” In the results here, a rebound in factor utilization explains much of the early-recovery surge in labor and total factor productivity—a surge that reversed the earlier plunge.

² Basu and Fernald (2009) discuss some of the possible channels, such as reduced reallocation from credit frictions or reduced investment in R&D and other intangible investments. Fatas (20xx) provides a broader review of literature of effects of business cycles on long-run growth. Petrosky-Nadeu (2013) argues that a financial crisis might truncate low-productivity firms, raising productivity for a time. [Other references, more recent and across countries].

Economists' understanding of why productivity trends vary over time is, of course, imperfect, as the Bill Nordhaus quote suggests. I focus on industry data to look for clues. As noted above, the slowdown in productivity appears broad-based across industries. [Discuss what I find]

Circumstantial evidence suggests the slowdown marks a pause (if not end) of the pace of unusual productivity growth associated with information technology (ICT). In particular, IT has arguably had a broad-based and pervasive effect on measured total factor productivity (TFP) through its role as a general purpose technology (GPT) that fostered complementary innovations, including business reorganization. The GPT story is essentially one of a drawn-out level effect on productivity—and it appears that, at least for now, the rapid growth effects may have ceased. That is, the low-hanging fruit may have been plucked.

I then turn to two implications of the mid-2000s slowdown in productivity growth. The first involves long-run growth. With reasonable estimates of underlying technology trends, a multi-sector neoclassical growth model implies steady-state business-sector labor-productivity growth of about 1.9 percent, as shown in Figure 1. Capital deepening in the model depends on capital's share of income as well as investment-sector technology. Capital's share of income was relatively constant from 1947 until the early 2000s. Since 2001, however, that share increased steadily from 31 percent to above 38 percent. My benchmark uses a share that is the average from 2001-2007 and, hence, assumes some reversal. If I instead use the most-recent estimate, that would raise the projection by about 2/10ths per year. Prior to the Great Recession, more typical estimates of trend growth were in the range of xx percent per year. Incorporating demographic estimates from the Congressional Budget Office (2014), my benchmark estimate for productivity performance implies longer-term growth in GDP about 2.2 percent.

A second implication is that by 2013, the output gap, defined as the difference between actual and potential output, is likely smaller than currently estimated by the CBO (2014). I use the CBO definition of potential, which is essentially a production-function definition.³ Conceptually, I decompose the CBO gap into a "labor gap" and a "utilization gap," where the latter reflects cyclical measurement of total factor productivity. CBO (2014) estimates that both gaps remain sizeable as of 2013, whereas my empirical estimates suggest that this gap is small.

Figure 2 shows my alternative estimate of the path of potential output, based on an alternative estimate of the utilization gap but using the CBO labor gap. My alternative estimate of potential output is notably lower than CBO (2014) which, in turn, is notably lower than the pre-recession CBO trend.

The key difference between my estimate and the CBOs is that the CBO assumes a relatively smooth underlying pace of technology, with relatively infrequent adjustments in its level or growth rate. In contrast, empirical estimates imply a much more variable rate of technological progress. This variability appears is

³ Basu and Fernald (2009) and Kiley (2010) discuss alternative definitions of potential output and output gaps.

apparent in “cleansed” Solow residuals (as in Basu, Fernald, and Kimball, 2006, and Fernald, 2012) as well as in the empirical estimates of modern DSGE models that allow for variations in utilization. Although my estimates of long-run trends going forward are not much different than the CBOs, my analysis of the recent period differs noticeably, in that I have a much less persistent utilization gap. In my own estimates, about $\frac{3}{4}$ of the shortfall of actual output from the pre-crisis trend reflects a decline in potential output.

It is worth emphasizing, however, that much of the shortfall of potential relative to its pre-recession trend reflects a shortfall in capacity growth. The weak economy has led to weak investment growth, leading capital input to growth at the slowest pace since World War II. This slow growth in productive capacity immediately implies slower growth in the full-employment level of output. Of course, to the extent that capital formation has been low for cyclical reasons, potential output should rebound as the economy recovers.

Section 2 discusses “facts” about the slowdown in measured labor and total-factor productivity, and compares the experience during and since the Great Recession to previous recessions and recoveries, finding that productivity experience was comparable. Section 3 uses industry data and assesses explanations for the productivity slowdown, including the GPT hypothesis. Section 4 uses a multi-sector growth model to project medium- to long-run potential output growth. Section 5 then draws on the preceding analysis to discuss current potential output and slack, in the context of the general methodology followed by the Congressional Budget Office.

2. Productivity Growth before the Great Recession

Trend productivity growth appeared to slow several years *before* the Great Recession.

2.1. The mid-2000s Slowdown in Labor Productivity Growth

shows the log-level of labor productivity for the business sector starting after the well-known slowdown in 1973.⁴ The speedup in growth during the mid-1990s is clear.⁵ Considerable literature has highlighted the role of information and communications (ICT) in explaining the mid-1990s acceleration.⁶

The striking feature of Figure 1 is that the mid-1990s acceleration in labor productivity ended in the early- to mid-2000s. The vertical bars show the dates chosen from a Bai-Perron test for multiple structural

⁴ See the appendix for a discussion of the data used in this section and the rest of the paper. The measure of output used in this paper combines the expenditure and income sides of the accounts, so that labor productivity differs slightly from the BLS productivity and cost release (which uses expenditure-side data). None of the results in the paper appear particularly sensitive to combining the two measures.

⁵ Fernald (2007) discusses the statistical evidence as of the mid-2000s for the speedup.

⁶ For example, Oliner and Sichel (2000) and Jorgenson (2000) emphasize the accumulation of ICT capital; Basu, Fernald, Oulton, and Srinivasan (2003) emphasize intangible investments in organizational capital related to ICT. Oliner, Sichel, and Stiroh (2006) review this literature.

change in mean growth rates for the period since 1973. The dates chosen for the new regimes are 1997:Q2, and 2003:Q4. The breaks are statistically significant.⁷ From 2003:Q3 through 2013:Q4,⁸ labor productivity in the business sector has grown at only 1.6 percent per year, down from a rate of 3.6 percent from 1997:1-2003:3. Indeed, the recent pace is comparable to the 1.5 percent average growth in labor productivity from 1973:2 through 1997:1.

The Bai-Perron results that show a slowdown in the early to mid-2000s are reinforced by the findings of Kahn and Rich (2011, 2013). They estimate a regime-switching model, using data on labor productivity, labor compensation, and consumption. They find that productivity switched from a high-growth to a low-growth regime around 2004.

Of course, labor productivity has a considerable element that is endogenous to the business cycle. To gain more perspective on the forces underpinning the slowdown, I turn to growth accounting.

2.2. Growth Accounting Identities

Growth accounting provides a perspective on the forces explaining the slower pace of productivity growth. In order to provide definitions of variables and concepts used later, suppose there is a constant returns aggregate production function for output, Y :

$$Y = A \cdot F(W \cdot K(K_1, K_2, \dots), E \cdot L(H_1, H_2, \dots)) \quad (1)$$

A is technology. K and L are observed capital and labor input. W is the workweek of capital and E is effort. W and E thus represent unobserved variation in the utilization of capital and labor. K_i is input of a particular type of capital—computers, for example, or office buildings. Similarly, H_i is hours of work by a particular type of worker, differentiated by skills, education, age, and so forth. Time subscripts are omitted for notational simplicity.

The first-order conditions from cost-minimization imply that output elasticities for a given type of input are proportional to shares in cost. Let α be total payments to capital as a share in total costs and c_i^j , $j \in K, L$, be the shares in the total costs of capital and labor, so that $\sum_i c_i^j = 1$, $j \in K, L$. Then, for example, the output elasticity for a given type of capital is αc_i^K . Differentiating logarithmically (with hats

⁷ The test assumes growth rates are stationary, and tests whether mean growth (the drift term for a random walk series) has breaks. For the sample from 1973:Q1 through 2012:Q2, the Bai-Perron WDmax test of the null of no breaks against an alternative of an unknown number of breaks rejects the null at the 1 percent level. The UDmax version of the same test rejects the null at the 2.5 percent level. The highest significance level is for the null of no breaks against the alternative of 2 breaks, which is significant at the 1 percent level. In the full sample from 1947:Q1 on, there appears to be an additional break at 1973:Q2, as expected.

⁸ “From 2003:Q3” means average (logarithmic) growth rates starting in 2003:Q4. All percent changes in this paper are calculated as 100 times the change in natural logs.

representing log-changes in a variable), imposing the first-order conditions, and omitting time subscripts yields:⁹

$$\begin{aligned}\hat{Y} &= \alpha \hat{K} + (1 - \alpha)(\hat{H} + \widehat{LQ}) + \widehat{Util} + \hat{A} \\ &= \alpha \hat{K} + (1 - \alpha)\hat{L} + \widehat{Util} + \hat{A}\end{aligned}\quad (2)$$

where various input aggregates on the right-hand-side are defined as :

$$\begin{aligned}\hat{K} &\equiv c_1^K \widehat{K}_1 + c_2^K \widehat{K}_2 + \dots, \\ \hat{L} &\equiv c_1^L \hat{H}_1 + c_2^L \hat{H}_2 + \dots \\ \hat{H} &\equiv \hat{H}_1 + \hat{H}_2 + \dots \\ \widehat{LQ} &\equiv \hat{L} - \hat{H} \\ \widehat{Util} &\equiv \alpha \hat{W} + (1 - \alpha)\hat{E}\end{aligned}\quad (3)$$

Growth in capital services, $\hat{K}$, is share-weighted growth in the different types of capital goods; growth in labor services, $\hat{L}$, is share-weighted hours growth by different types of workers. Total hours growth, $\hat{H}$, is the simple sum of hours worked by all types of labor. Labor quality growth, $\widehat{LQ}$, captures the productive benefits of changes in composition of hours worked and is defined so that growth in labor input is the sum of growth in hours and growth in labor quality. Finally, $\widehat{Util}$ represents variations in capital's workweek and labor effort.

Observed total factor productivity (TFP) growth, the Solow residual, is output growth not explained by growth in observed inputs:

$$\begin{aligned}\widehat{TFP} &\equiv \hat{Y} - \alpha \hat{K} - (1 - \alpha)\hat{L} \\ &= \widehat{Util} + \hat{A}\end{aligned}\quad (4)$$

The second line follows from equation (2). A large literature discusses why short-term fluctuations in measured TFP might reflect factors other than technology.¹⁰ Over the business cycle, a key reason, reflected in $\widehat{Util}$, is unobserved variations in the intensity with which factors are used. For example, such variations might reflect incentives to hoard labor in a downturn. Basu, Fernald, and Kimball (BFK, 2006) and Basu, Fernald, Fisher, and Kimball (2013) implement a theoretically based measure of utilization. In practice, their

⁹ See, for example, Basu and Fernald (2002) for derivations and discussion of how to interpret measured TFP when constant returns, perfect competition, and the assumed existence of an aggregate production function do not apply. With a first-order approximation (which is exact, if the aggregate production function is Cobb-Douglas), the shares are constant over time. A Tornquist approximation to equation (1)—which uses log-growth rates of all quantities, and where shares are time-varying averages in periods t and $t-1$ —is exact for the translog functional form, which provides a second-order approximation to any general production function (see Diewert, 1976).

¹⁰ See Basu and Fernald (2002) for extensive discussion and references.

method essentially involves rescaling variations in detrended hours per worker. I return to this measure below.

From (2) and (4), labor productivity growth, defined as growth in output per hour, is then:

$$\begin{aligned}\hat{Y} - \hat{H} &= \alpha(\hat{K} - \hat{H} - \widehat{LQ}) + \widehat{LQ} + \widehat{Util} + \hat{A} \\ &= \alpha(\hat{K} - \hat{H} - \widehat{LQ}) + \widehat{LQ} + \widehat{TFP}\end{aligned}\tag{5}$$

Loosely speaking, labor productivity rises in the long run if workers have more capital to work with; if their quality improves; or if innovation raises technology. In the short run, cyclical variations in utilization also affect labor productivity.

2.3. Aggregate Data and Growth-Accounting Results

This section implements the decomposition in equation (5) using a quarterly growth-accounting dataset described in Fernald (2012), and briefly described in the appendix. These data provide quarterly business-sector growth accounting components, and are available about 1-1/2 months after the end of the quarter. The data show that slower growth in both TFP and capital deepening contributed to the mid-2000s slowdown in labor productivity growth.

Figure 2 shows the components. All are measured in log-levels (i.e., cumulated changes in logs), which makes it easier to see trends. The utilization measure follows BFK as applied to quarterly data. BFK consider a more general framework than in Section I.B to allow for non-constant returns, imperfect competition, and cyclical reallocation effects on productivity measures. Because of data limitations in quarterly data, however, the Fernald measure used here controls only for utilization change. For this reason, Fernald refers to the empirical counterpart to $\hat{A}$ as utilization-adjusted TFP.

In a growth accounting sense, the figure shows a slowdown in both TFP and capital deepening around the time of the mid-2000s slowdown in labor productivity growth. Panel A shows TFP and utilization-adjusted TFP. The eye clearly identifies a slowdown in the early to mid-2000s, and a Bai-Perron test confirms its significance.¹¹ Panel B shows capital-deepening, $K / (H \cdot LQ)$. In the early 2000s, capital deepening leveled out and, hence, also contributes to the slower growth in labor productivity. Panel C shows labor quality, which has risen steadily and, indeed, accelerated in the Great Recession. Finally, Panel D shows utilization itself. This series is clearly highly cyclical. By 2012:Q2, this measure suggests that

¹¹ The UDMax and WDMax tests for the null of no breaks against the null of an unknown number of breaks is significant at about the 5 percent level.

utilization has rebounded to a level close to its pre-recession peaks—indeed, somewhat above its longer-run mean.¹²

I look more closely at the experience during and since the Great Recession in Section x. But it is worth noting that in Figure 1 (for labor productivity) or Figure 2.A (for TFP), productivity as of mid-2012 appears to lie more or less on the slow trend line from the mid-2000s.

2.4. Productivity Growth during the Great Recession

This section turns to the more recent productivity experience. Specifically, how unusual was the behavior of productivity during the Great Recession? This section argues that during and immediately after the Great Recession, the behavior of productivity has been in line with previous deep recessions. In particular, TFP and utilization fell very sharply during the recession, and recovered strongly once the recession ended.

[Rewrite as needed]

Labor productivity has evolved similarly to previous deep recessions. This conclusion contrasts with many informal discussions, which suggest that labor productivity was surprisingly strong during and immediately after the Great Recession.

Figures 4 and 5 show “spider charts” comparing the Great Recession to the nine previous recessions (1953-2001). In each panel, the horizontal axis shows the number of quarters from the peak. In the Great Recession, for example, quarter 0 corresponds to 2007:Q4. Panel A of Figure 4 shows that the experience of labor productivity is quite similar to previous deep recessions in 1973-75 and 1981-82. Notably, labor productivity is at the bottom of the historical experience. Of course, output fell far more than in previous downturns (Panel B). And hours worked fell by an exceptional amount (Panel C).

In contrast to what these figures show, many commentators have suggested that productivity was, in fact, surprisingly strong during the recession and recovery. For example, because of extraordinary fear and concern in late 2008 and early 2009, firms may have cut workers more sharply and earlier, relative to previous deep recessions. If this were the case, then they might not have hoarded labor in the usual way—so intensity margins (observed, such as hours per worker, or unobserved utilization) should not have been used as much. It is true that labor fell by an exceptional amount. But firms also made substantial use of the intensity margin: The BFK measure of utilization in Figure 5.D, which is a mapping from observed hours per worker, fell more than in any previous post-war recession and then recovered very sharply during the recovery.

¹² The level at the end point is a bit uncertain because the measure comes from industry hours per worker, which need to be detrended. This measure uses a biweight filter, but any filtering method suffers inherent uncertainty at end points.

TFP provides a complementary perspective on the intensity story that does not depend on a specific measure of factor utilization. Specifically, if labor productivity behaved unusually because firms didn't hoard labor, then TFP should not have fallen as much as in previous recessions. But Figure 4.D shows that TFP did, in fact, fall by more than in any previous recession. When the recovery took hold, TFP then bounced back.

From a growth-accounting perspective, why was the TFP decline even more pronounced than the labor productivity decline, relative to previous downturns? Consistent with equation (5), both capital deepening and labor quality were strongly positive. Panel A of Figure 5 shows that capital input growth has been extraordinarily weak. Indeed, in the depth of the recession, capital stopped growing entirely (for the first time in the post-war period). But of course, labor also fell very sharply, and Panel B shows that the capital-labor ratio rose very sharply. This supported labor productivity relative to TFP. Panel C shows that labor quality also rose more quickly than in previous downturns, as low skilled/low education workers disproportionately lost jobs. This also supported output per hour relative to TFP. The capital-deepening and labor-quality effects partially offset the sharp decline in utilization shown in panel D.

Gali, Smets, and Wouters (2012) focus on the recovery and, as I do, argue that, following the Great Recession, productivity performance was in line with historical experience. Specifically, they look at the experience in the three so-called "jobless recoveries" following the recessions of 1990-91, 2001, and 2007-9. They argue that these recoveries are not jobless, per se, in that the relationship between employment and GDP has been fairly stable. Rather, these recoveries should be characterized as "slow."

Their finding is consistent with the pattern in Figure 4. But to focus more specifically on recoveries alone, Figure 6 indexes to the trough rather than to the peak. Figure 6 shows clearly that, in the first five or so quarters of the recovery, labor productivity and TFP performed similarly to previous recoveries. The anomaly, rather, is the "flat spot" in productivity that begins in the end of 2010, roughly six quarters into the recovery. TFP is at the bottom of the band of historical experience, whereas labor productivity is slightly below historical experience (in part reflecting that capital-deepening, panel E, has fallen below historical experience).

Unfortunately, the flat spot does not appear to be an anomaly, or "payback" from unusual experience early in the recession. Rather, looking back at Figure 1, TFP growth paused in the mid-2000s. From the broader perspective, the "flat spot" appears to reflect the slow underlying trend. Indeed, the experience is reminiscent of the experience in the 1970s, when utilization-adjusted TFP in 1983 was only at its 1975 level; standard TFP shows a similar pattern. (Reassuringly, TFP growth subsequently picked up again in the 1980s—it did not permanently stagnate. Nevertheless, the entire 1973-97 period was disappointing.)

Did the Great Recession itself affect TFP growth? For example, it could have affected reallocation of capital towards higher productivity firms. Informational and contractual frictions, including financing

constraints, are important in reallocating capital efficiently (see, for example, Eisfelt and Rampini, 2006). In the past few years, some businesses have certainly faced financing constraints. In addition, firms may have cut back on research and development and other investments in innovations that did not offer rapid payback. From 2003:3-2007:4, utilization-adjusted TFP growth averaged only a 0.2 percent pace; since then, it has averaged a 0.4 percent pace. There is little evidence in these figures that there was a further influence of the Great Recession on underlying TFP growth, as opposed to there simply being an anemic underlying pace of growth.

Finally, real-time data obscured the slowdown in trend, and overstated productivity's strength early in the Great Recession. Figure 7 shows that almost every revision since 2005 has lowered the path of labor productivity. The real-time data obscured the weakness in labor productivity growth after 2003. In addition, the real-time data also overstated the strength of labor productivity growth early on in the recession. Thus, data revisions help explain some of the disconnect between perceptions of recent productivity performance and the disappointing reality.

3. Where and Why Did TFP Growth Productivity Slow?

[Summary of what I find]

3.1. Industry data

I now consider BLS data on TFP by industry that might shed further light on the sources of the mid-2000s productivity slowdown. The dataset includes industry gross output, intermediate inputs, capital input, and hours worked for 60 manufacturing and non-manufacturing industries.¹³ Conceptually, the industry data allow a similar representation to TFP in equation (4), except that the data do not control for labor quality, LQ . I deal with the first issue by expressing everything in value-added terms, so it is conceptually similar and, except where necessary, ignore the second. There are also differences of data vintage, in that the BLS industry data predate the benchmark NIPA revisions in 2013.

¹³ The BLS refers to their indices as multi-factor productivity (MFP), which is a synonym for TFP. The industry data do not control for labor quality and are done from the bottom up rather than from the top down (as in the Fernald data, or the BLS data on aggregate private-business MFP by sector). I present industry statistics in terms of value-added TFP by taking industry gross-output TFP and “rescaling” by dividing by one minus the intermediate-input share. This is equivalent to computing industry value-added as a Tornquist index and then calculating TFP as in equation (4). Aggregating over industries, the correlation of year-to-year changes in business TFP with the Fernald TFP index is about 0.84. For more discussion of the data, see <http://www.bls.gov/opub/mlr/2010/06/art2full.pdf>. For the methodology used in estimating KLEMS multifactor productivity measures, see Michael J. Harper, Bhavani Khandrika, Randal Kinoshita, and Steven Rosenthal in “Nonmanufacturing industry contributions to multifactor productivity, 1987-2006,” *Monthly Labor Review*, June 2010, pp. 16-31 (see <http://www.bls.gov/opub/mlr/2010/06/art2full.pdf>) and William Gullickson “Measurement of Productivity Growth in U.S. Manufacturing,” *Monthly Labor Review*, July 1995, pp. 13-27 (see <http://www.bls.gov/mfp/mprgul95.pdf>).

[The top line of Table ?? (to be added) shows Fernald TFP growth by subperiod. Line 2 shows Fernald TFP excluding the effects of labor quality. Line 3 shows the aggregated BLS industry data. All three of these measures shows that TFP growth sped up in the late 1990s and sped up further in the early 2000s; but, after 2004, growth slowed markedly. In the industry data, for example, growth slowed from 2.19 percent per year from 2000-2004 to 0.63 percent from 2004-2007. The slowdown over the entire 2004-2011 period is similar. From 2007-2011, BLS industry TFP growth then picked up further, to 0.90 percent. Some of this apparent pickup reflects the omission of labor quality, which spiked during the Great Recession.]

The mid-2000s had several unusual features, including the housing boom, the rise of finance (and unusual financial instruments), and sharp increases in oil and other commodity prices. The fourth line shows that TFP in the corresponding industries was modestly negative (-0.28 percent per year) from 2000-2004 and then more substantially negative (-1.38 percent) from 2004-2007. The next few lines show that natural resources and construction decelerated sharply, whereas real estate and finance actually showed a TFP acceleration in the runup to the Great Recession.

In thinking about the future, we probably do not want to draw substantive macroeconomic conclusions from past TFP growth in this grouping. Both agriculture and mining are highly volatile and idiosyncratic, with year-to-year standard deviations of TFP growth of nearly 10 percent. In construction, the swings may reflect short-run decreasing returns or mismeasurement of hedonics, the effects of which could have been exacerbated by the housing boom. (For example, construction prices might improperly incorporate some land price movements.) And the financial industry has undergone substantial upheaval since 2007, so previous trends might not be relevant. In any case, this set of industries showed a pickup in productivity growth after 2007, unlike the rest of the economy.

Outside of these unusual industries, line xxx shows that the remainder of the economy—the narrow business sector, defined to exclude excluding natural resources, construction, and FIRE. This narrower business sector, which is about $\frac{3}{4}$ of overall business, had a slowdown after 2004 of comparable magnitude to the slowdown in overall business. Thus, the slowdown was not merely a direct reflection of the unusual features of commodities, housing, and finance. In this broader economy, there was a further slowdown after 2007. This further slowdown could reflect lingering cyclical effects from the Great Recession and weak recovery—such as incomplete reversal of utilization effects—and so I focus predominately on the 2004-2007 period in what follows.

The lines below show additional summary “cuts” of the narrow business sector that illustrate the broadbased nature of the slowdown.¹⁴ These cuts of the data give an indication of the broadbased nature of the slowdown.

IT-producing sectors—computers and semiconductors; publishing (which includes software); and computer system design and related services—saw rapid TFP growth in the late 1990s of more than 16 percent per year. That rate slowed to under 12 percent in the 2000-04 period but then slowed modestly further prior to the Great Recession, to a rate not much different from its pre-1995 pace. Non-IT-producing industries—which is the vast share of the economy—saw a pickup from the late-1990s to the early 2000s. That group of industries slowed sharply in the 2004-07 period, again to a rate modestly below its pre-1995 pace.

A second cut of the data, highlighted by Griliches (1994) and Nordhaus (2002), is well measured versus poorly measured.¹⁵ Well-measured industries are predominately manufacturing and utilities (in addition to natural resources, which I exclude from this measure), whereas poorly measured industries are predominately services. Griliches (1994) points out that much of the productivity slowdown was in poorly measured industries. As the table shows, both well-measured (line xx) and poorly-measured (line yy) industries sped up in the late 1990s, sped up further in the early 2000s, and then slowed markedly (by more than 1-1/2 percentage points) after 2004.

Some industry results are of note. Computers v other equipment...Add more detail].

As a third cut of the data, I look at finance-intensive versus non-finance-intensive industries.¹⁶
[Describe].

One plausible candidate is information technology. There is a direct effect of IT production. But that doesn't explain all of the speedup in the mid-1990s, nor does it explain all of the slowdown. But stories of information technology as a general purpose technology suggest that the effects are more subtle.

¹⁴ Qualitative conclusions in what follow do not appear sensitive to the exclusion of natural resources, construction, and finance.

¹⁵ Griliches (1994) imagines “a ‘degrees of measurability’ scale, with wheat production at one end and lawyer services at the other. One can draw a rough dividing line on this scale between what I shall call ‘reasonably measurable’ sectors and the rest...”, Griliches and Nordhaus draw the dividing line slightly differently. For Table xx, I largely follow Nordhaus, except that I exclude (well-measured) agriculture and mining and (poorly measured) construction and FIRE. Well-measured thus comprises manufacturing, utilities, transportation, trade, as well as selected services (broadcasting and telecommunications, accommodations, and food services). Switching trade and the selected services from well-measured to poorly-measured would make the slowdown in well-measured a bit less pronounced. Nevertheless, both well-measured and poorly-measured show a deceleration of more than a percentage point after 2004, so the main takeaway is unaffected by this choice.

¹⁶ Calculated from the BLS input-output tables, available at xx. Industries were aggregated from 169 private business input-output industries to 60 BLS MFP industries according to NAICS codes. Finance usage was nominal purchases of various financial services as a share of industry gross output. “Finance intensive” is the half of all industries with the highest shares.

Industries that invested heavily in the past should see a large service flow from intangible capital; but industries investing heavily today should see a negative effect on measured productivity.

BFOS consider how to measure the indirect effects.

3.2. Explaining the Slowdown in Trend Labor Productivity

Why did productivity growth slow in the mid-2000s? A large literature explains the earlier productivity acceleration of the late 1990s in terms of the direct and indirect effects of information and communications technology (ICT). This section emphasizes the converse: If the rapid pace of ICT gains came to an end, then it would naturally show up in both TFP and capital-deepening. Specifically, the aggregate and industry data are consistent with the view that productivity slowed in the 2000s because of the waning of the exceptional growth effects of information technology as a general purpose technology (GPT).

To understand this hypothesis, it is worth thinking about why productivity growth sped up in the mid-1990s and, further, in the early 2000s. ICT was the obvious suspect, as computers and the Internet became increasingly pervasive. As Jorgenson (2000) and others emphasized, in a neoclassical framework, technological progress in the production of a capital good like ICT has two effects on labor productivity. First, to the extent that ICT goods are domestically produced, it increases directly. Second, it lowers the user cost of capital, and induces greater capital-deepening in ICT-using sectors.

Both factors are apparent in the industry data. But they aren't the whole story, since measured TFP growth increased broadly—in ICT-using, as well as ICT-producing, sectors (see, for example, Basu, Fernald, Oulton, and Srinivasan, BFOS, 2003). Stories of ICT as a GPT provide an explanation. As emphasized by Greenwood and Yorokoglu (1997), Brynjolfsson and Hitt (2000), and BFOS, faster ICT and (starting in the 1990s) the Internet induced firms to invest in intangible, complementary organizational capital to take advantage of faster informational processing. BFOS discuss how to map GPT stories into conventional growth accounting. The story is one of intangible investment. When firms are investing in intangible organizational or other capital, measured productivity declines as firms divert resources to unobserved investment. With a lag, firms get the benefits of the accumulated intangible capital and measured productivity rises.

BFOS derive an observable proxy for intangible investment associated with ICT: Growth in ICT capital, weighted by share of payments to ICT capital in total production cost. The intuition is straightforward. First, the link from unobserved intangible organization investment to observed ICT growth comes from the evidence that expansions of ICT capital are associated with a increases in complementary reorganizations to take advantage of the information processing (see Brynjolfsson and Hitt, 2000). Second, the share weight comes from the fact that we need to account for the scale or magnitude of the intangible

investments. For example, suppose firms don't use much ICT capital, as reflected in a small share. Then, for any given growth rate of ICT capital, unobserved IT-related reorganizations are less likely to a quantitatively important source of mismeasurement of productivity than if the firm uses a lot of ICT capital.

Figure 3 shows the aggregate value of this proxy. It peaks around 2000 and then falls off. In the BFOS/intangibles story, true productivity growth was even faster than measured in the late 1990s as firms diverted resources to reorganization. In the early 2000s, ICT investment plunged—but, as noted earlier, measured productivity growth remained strong (or even rose). This is consistent with firms no longer diverting resources to intangible investment, which temporarily boosts measured productivity. With a lag, however, productivity growth in this story would end. As Oliner, Sichel, and Stiroh (2007) note:

...intangible investment has been quite sluggish since 2000, coinciding with the soft path for IT capital spending. All else equal, this pattern could be a negative for labor productivity growth in the future to the extent that these investments are seed corn for future productivity gains.

Fundamentally, the rapid pace of GPT benefits of information technology on growth had to end sometime. It was just hard to know *ex ante* when the slowdown would take place. It is plausible that the low-hanging fruit was plucked by the mid-2000s.

4. Implications for Medium and Long-Run Growth

The analysis so far indicates that underlying productivity growth slowed prior to the Great Recession, for reasons that appear likely to have some persistence. In this section, I consider the implication of slower productivity growth for projections of potential output growth in the medium and longer run.

In the long run, output depends on supply-side factors: What the economy can produce using actual capital input (at normal, or steady-state, utilization); with labor input at its steady-state level; and with available technology. Following typical conventions (e.g., CBO, 2001), I will refer to this measure as potential output. Rearranging equation (5), growth in potential output can be decomposed into growth in labor productivity and labor input:

$$\hat{Y}^* = \underbrace{\left[\alpha \left(\hat{K} - \hat{H}^* - \widehat{LQ}^* \right) + \hat{A}^* \right]}_{\text{potential labor productivity growth}} + \underbrace{\left[\hat{H}^* + \widehat{LQ}^* \right]}_{\text{quality-adjusted hours growth}} \quad (6)$$

Stars (*) denote potential or steady-state values. The term $\left(\hat{K} - \hat{H}^* - \widehat{LQ}^* \right)$ represents steady-state capital deepening.

What follows generally assumes constant returns and perfect competition and that utilization has a zero steady-state growth rate. Hence, steady-state growth in technology and measured TFP are equal:

$$\hat{A}^* = \widehat{TFP}^*.$$

4.1. Multi-Sector Projections of Labor Productivity Growth

I use a neoclassical growth model to project business-sector labor productivity. As is well known, capital-deepening in the one-sector neo-classical growth model (e.g., the Solow model) depends on exogenous TFP growth. In the steady state of that model, the capital-output ratio is constant. In U.S. data, however, the capital-output ratio has an upward trend. For example, business-sector capital input grew about $\frac{3}{4}$ pp per year faster than output from 1973 through 2007.

Multi-sector models, where one (or more) sector produces investment goods and other sectors do not naturally generate a trend in the capital-output ratio. In such models, capital deepening depends solely on TFP in the investment sector (see the appendix, or Basu and Fernald 2009). Assuming all capital goods are reproducible, potential labor productivity in equation (6) can then be expressed as:

$$\hat{Y}^* - \hat{H}^* - \widehat{LQ}^* = \widehat{TFP} + \alpha \cdot \widehat{TFP}_I / (1 - \alpha). \quad (7)$$

In practice, not all capital goods are reproducible: land, T (for **T**erra), is also an important input: In the post-war period, land's share of capital payments, c_T , averages about 14 percent. Adding exogenous (non-reproducible) land to the model attenuates the capital-deepening effect (the weight on reproducible $\widehat{TFP}_I$), since the weight depends on the share of reproducible capital in output, i.e., omitting payments to land. If $\alpha^R = \alpha(1 - c_T)$ is the reproducible capital share in output, and if land use grows at the same rate as labor, the equation becomes:¹⁷

$$\hat{Y}^* - \hat{H}^* - \widehat{LQ}^* = \widehat{TFP} + \alpha^R \cdot \widehat{TFP}_I / (1 - \alpha^R) \quad (8)$$

To implement this equation, I draw on the following theoretical and empirical observations:

- Theory tells us that investment TFP determines capital-deepening
- Investment itself is heterogeneous. Most notably, the price of equipment, especially but not solely information-technology related, has fallen rapidly relative to the prices of other goods. In contrast, the relative price of structures has risen modestly but steadily over time.
- Land is a sizeable non-reproduced capital input that can be pulled into the business sector from other uses. I take it as exogenous.

¹⁷ As the appendix shows, equation omits (8) an “excess” land-growth term: $\alpha^T \cdot (\hat{T}^* - \hat{H}^* - \widehat{LQ}^*) / (1 - \alpha^T)$, where $\alpha^T = \alpha c_T$ is the share of land in total cost. Historically, that term is minimal, adding about 2 basis points over the entire sample period and 0 basis points from 1995 through 2007, and I henceforth ignore it.

- Inventories' share of capital payments averages 9 percent since 1947—also sizeable. Inventories are goods, not services, so I assume that inventories are produced by the durable sector. (The majority of non-durable consumption is services.)

To implement this steady-state decomposition, I assume there are three final-use sectors that use capital and labor (which grows exogenously) to produce output:

$$\begin{aligned} D &= (K_D)^\alpha (AN_E)^{1-\alpha} \\ B &= Q_B (K_B)^\alpha (AN_B)^{1-\alpha} \\ C &= Q_C (K_C)^\alpha (AN_C)^{1-\alpha} \end{aligned} \quad (9)$$

The **Durable** goods sector produces equipment, consumer durables, and inventories. The **Building** sector produces structures. The **Consumption** sector produces non-durables and services for households and government. The production functions are identical apart from building-specific and consumption-specific technology shocks, Q_B and Q_C .

Some durable goods, D , are invested and become equipment capital; some are used as inventories (a form of capital input). All new buildings become structures. Both equipment and structures accumulate according to the standard perpetual inventory formula. Land grows exogenously. All three sectors use the same capital aggregate, which uses equipment E , structures S , inventories V , and land T .

$$K = E^{c_E} S^{1-c_E-c_V-c_T} V^{c_V} T^{c_T} = K_D + K_B + K_C$$

The appendix discusses the general properties of this model.

To identify sectoral technology growth, I use relative prices from the NIPAs. The output price in each sector is a markup, μ , over marginal cost, MC . So the relative price of, say, consumption to durable equipment is:

$$\widehat{P}_C - \widehat{P}_D = (\widehat{\mu}_C + \widehat{MC}_C) - (\widehat{\mu}_D + \widehat{MC}_D) \quad (10)$$

With identical production functions and factor prices, marginal cost depends solely on relative technologies. With perfect competition, the markups both equal one and, hence:

$$\widehat{P}_C - \widehat{P}_D = \widehat{A}^D - \widehat{A}^C = -\widehat{Q}_C \quad (11)$$

This approach follows the literature on investment-specific technical change (e.g., Greenwood, Hercowitz, and Krusell, 1997). This approach relies on strong assumptions that hold imperfectly in practice. For example, Basu, Fernald, Fisher, and Kimball (BFFK, 2013) show how utilization change and differences in production functions, as well as non-constant returns to scale and differential movements in markups, may all matter. However, BFFK find that these non-technological influences are much more important in the short run than the long run, where relative prices do primarily reflect relative technologies.

Figure 8 shows the resulting final-use TFPs. The figure uses equation (11) to decompose overall TFP into TFP for durable equipment investment (including consumer durables and inventories); structures investment; and consumption (measured as a residual). Equation (11) applies to growth rates, which are cumulated into log-levels. The final-use TFP measures do not control for utilization, but in the longer-run these should provide reasonable indicators of technology trends, i.e., the $\widehat{A}_j$.

The figure shows that according to this decomposition, all three sectors moved roughly together until the mid-1960s. At that point, the level of TFP for buildings began to drift steadily downward. By the early 1970s, consumption TFP has largely leveled off. In contrast, durables TFP continues to rise continuously through this period. Note that investment-specific technical change is given by the difference between the durable and consumption lines; the widening gap corresponds to the acceleration of investment-specific technical change in the 1970s (Greenwood, Hercowitz, and Krusell, 1997). In contrast to the implicit interpretation of much of the investment-specific-technical-change literature, the faster apparent pace of investment-specific technical change arises from slower growth in consumption TFP, not faster growth in equipment TFP.

In the mid-1990s, durables TFP does, in fact, pick up, reflecting especially faster TFP growth in producing IT goods. Given the scale of the figure, it's difficult to see, but consumption TFP also grew more quickly. Buildings TFP continues to trend down.

In the mid-2000s, all three series appear to show a reversal in their post-1995 growth pace. Durables TFP grows a bit more slowly prior to the Great Recession; consumption TFP dips a bit; and buildings TFP plunges along the lines suggested by the industry data on construction TFP discussed in Section 3.1. In the Great Recession itself, all three series fall somewhat and then bounce back. It is not clear from the figure whether there is a level adjustment as well as growth-rate (slope) changes.

[The model abstracts from some potentially important aspects. First, production functions and the capital aggregate are assumed equal across sectors, but actual sectoral factor shares are not equal and sectors differ in the intensity of, say, land or inventories (see BFFK, 2014). Second, the production and capital-aggregate functions are taken to be Cobb-Douglas. These two assumptions greatly simplify steady-state calculations. In practice, the calculation is best interpreted as a local approximation as long as shares do not change too dramatically. Third, we abstract from the open economy. If, say, the ability to import computer components reduces the relative price of computers, the model interprets the lower price as faster relative TFP. The lower relative price, in the closed-economy model or in a comparable open-economy model, encourages capital deepening. Hence, from the point of view of understanding the incentives of computer users to purchase computers, the closed-economy assumption is probably not a major issue.

Fourth, considerable recent literature, including the papers discussed in Section 3.2, focuses on intangible capital. Conceptually, this is an additional capital good that the economy produces and uses. However, we do not observe the investment (production) or the stock of intangibles that yields a flow of services (the uses). At different times, the investment versus service flow may dominate measurement. In steady-state, Basu, Fernald, Oulton, and Srinivasan (2003) show that the existence of intangible capital reduces measured TFP relative to true technology, since the service-flow effect dominates. That said, the steady-state mismeasurement is relatively minor.¹⁸

Finally, the steady-state focus of the model might be misleading. Jones (2002) and Fernald and Jones (2014) argue that the U.S. economy since 1950 has been growing above steady-state. They also argue that the transition dynamics could be quite persistent, and interpret steady-state “projections” as a local approximation, albeit one that might be reasonable over the span of a few decades.]

Table 1 shows that, despite the simplifications in the model, the steady-state implications match the historical data reasonably well. The overall and subsample “misses” are on the order of few tenths of a percentage point. The multisector model does a somewhat better job of matching the subsample variation; and the model with land does a better job of capturing the magnitude of the pickup in labor productivity after 1997. The main failure of the one-sector model is that it underpredicts capital deepening after 1973. Equivalently, because it assumes the capital-output ratio is constant in steady state, it misses the trend increase in the capital-output ratio in the data.

To use this model to do a steady-state projection of labor productivity in the business sector, we need to take a stand on TFP in producing investment (equipment and structures) as well as consumption. The typical approach to doing GDP projections (e.g., Byrne, Oliner, and Sichel, 2013 and Jorgenson, Ho, and Samuels, 2013) involves assuming that the future looks like some portion of the recent past. The question is, which past? That is, what window of data do you include in your scenario for the future? And to what extent does one rely on formal or informal assessments of breaks?

Pesaran and Pick (2011) argue that, although break-analysis of the sort done in Sections 2 and 3 is important for understanding history, it is not necessarily helpful for forecasting. Consider the current problem, where there is considerable uncertainty about the exact timing and magnitude of breaks in the three final-use technologies. After all, each series is highly volatile, and may break at different times (as we saw with the late 1960s/early 1970s slowdown in productivity, where buildings TFP slowed first and durables TFP never slowed). In such cases, Pesaran and Pick show that focusing solely on estimated break dates is generally suboptimal in terms of mean-squared forecast errors (MSFE). They argue for making forecasts by look at all the available data but then adjusting how much weight one puts on different observations to

¹⁸ Over shorter periods of time, the mismeasurement may be much larger, as Basu, Fernald, Oulton, and Srinivasan (2003) and Corrado, Hulten, and Sichel (2009) point out.

account for the fact that the world is changing over time. Their preferred approach, which they call AveW, involves forming a forecast for a range of windows and then averaging them. They find that the AveW approach works pretty well in terms of mean-squared forecast errors in both Monte Carlo simulations and actual applications. This approach deals with the uncertainty about the precise timing and magnitude of breaks in the data-generating process by averaging across them. It is similar to exponential smoothing in that it puts more weight on recent observations, since those observations appear in all of the windows.¹⁹

Motivated by P-P, my benchmark projection averages the individual projections based on all possible windows of length 24 quarters or more. This includes all windows ending in 2013:Q4 with starting dates from 1947:2 through 2007:4. That is, for any starting date $s \in [1947:Q2-2007:Q4]$, I calculate average TFP growth from s through 2013:Q4 for durables, buildings, and consumption. I then use those values to construct a forecast for labor productivity growth, $LP^f(s)$, according to equation (8). I then average these forecasts to get my benchmark. That is, using the 244 windows with starting dates from 1947:Q2 through 2007:Q4, I estimate $LP^{AveW} = (1 / 244) \cdot \sum_{s=1947:2}^{2007:4} LP^f(s)$. Note that data since 2007:Q4 get the highest weight because they appear in every projection window.

The model requires values for capital's share, α , and for $c_j, J \in (E, S, V, T)$. I use average values from 1995:Q4 through 2007:Q4. Capital's share, α , averaged 34 percent over this period. An important question is whether this is the right benchmark. That share showed no clear trend prior to 2001, with an average value of 32 percent and a range of 30 to 34 percent. From 2001 to 2012, however, that share rose from 31 to 38 percent. Other things equal, a higher capital share implies faster growth according to equation (8). As Fernald and Jones (2014) discuss, ongoing substitution of machines for workers could lead to higher capital shares.

The first column of results in Table 3 shows my benchmark inputs, and projections, for steady-state labor-productivity growth, using the LP^{AveW} measure. Row (6) shows that this benchmark projects labor-productivity growth of about 1.9 percent per year. Row (8) shows that, with the 2012 value of capital's share, that projection rises almost 2/10ths percentage point to 2.1 percent per year.

The columns to the right show particular windows. For example, row (6) of the "Since 1947:Q2" column shows $LP(1947:Q2)$, i.e., the prediction for labor productivity using the full sample. This particular forecast would be optimal if there were no breaks, so that it puts the same weight on the fast-growing 1960s as it puts on, say, the slow post-2003 data. That forecast is qualitatively similar to focusing on the post-1995 period alone, $LP(1995:Q4)$. At the other extreme, focusing on the past decade, $LP(2003:Q3)$, implies a notably slower forecast of 1.58 percent, very close to the forecast using data since 1973:1.

¹⁹ Of course, the implicit weights in the AveW measure may not be optimal. Pesaran, Pick, and Pranovich (2013) derive what they call "robust optimal weights." However, they find the AveW approach usually performs well.

Finally, the benchmark AveW forecast turns out to be very similar to *LP(1986:Q4)*. Thus, the benchmark forecast implicitly downweights the mid-1990s acceleration somewhat but not as much as focusing solely on the slow post-2003 period.

An important caveat is that projections are highly sensitive to the calibration of alpha. [Discuss]

4.2. From labor productivity to GDP growth

I combine my projection for potential labor productivity growth with projections for potential labor input and for non-business output from the Congressional Budget Office (CBO, 2014).²⁰

The CBO expects relatively slow labor-force growth in the long-term, compared with post-war experience. In particular, the CBO projects that potential non-farm business hours a decade from now (2024) will grow at 0.64 percent per year. This rate compares with growth of 1.4 percent per year from 1949 through 2007. In terms of labor quality, Jorgenson et al (2011) estimate that by the end of this decade, labor quality will plateau, reflecting the fact that new cohorts have stopped gaining educational attainment relative to retiring cohorts. I therefore assume zero labor-quality growth in the long run. These estimates imply that business output in the benchmark case will grow at the sum of growth in productivity (1.93 percent) and hours (0.64 percent) = 2.57 percent per year.

The analysis above gives projections for business output. To project GDP, I combine these with the CBO's forecasts for non-business output. The CBO's estimates that non-business output—primarily general government and the service flow from owner-occupied housing—will grow at 0.85 percent per year in the longer term.²¹ For comparison, non-business output rose at a 2.2 percent pace from 1973 through 2001, and a 1.3 percent pace from 2001-2013. The business sector averaged 76 percent of GDP from 1995 through 2007.

Together, the business and non-business projections imply relatively anemic long-run GDP growth of about 2.2 percent per year. In terms of total GDP per hour, this corresponds to growth of about 1.6 percent per year. By comparison, for the period 1950-2007, GDP per hour grew at 2.0 percent per year (Fernald and Jones, 2014).

Prior to the Great Recession, a typical long-run projection was 2-1/2 percent or higher. For example, prior to the Great Recession (in early 2007), the CBO projected growth 10 years out of 2.5 percent per year,

²⁰ CBO publishes projections for GDP and for (non-farm) business GDP. I assume farms grow with other businesses, and ignore the difference between non-farm and total business. Using the NIPA nominal business weights in GDP (0.76, averaged 1995-2007), I can back out an estimated non-business output. CBO also publishes projections for labor-force growth and for non-farm business hours.

²¹ Estimated from the difference between growth in potential GDP, and growth in potential non-farm business GDP, assuming a business share at its average value from 1995-2007.

and GDP per hour of 1.9 percent per year—close to its long-run trend.²² Since 2009, Federal Open Market Committee participants publish “longer run” projections for GDP growth four times a year. In January 2009, more than 60 percent of participants (10 out of 16) reported a longer-run projection of 2-1/2 percent, with the remaining higher than that.²³

When the first versions of this paper were written, in late 2011 and early 2012, the projections in this paper were at the very low end of what I could find published.²⁴ Typical projections from the CBO or the FOMC had changed only modestly since the beginning of the recession. For example, in early 2012, the CBO projected long-run growth of 2.4 percent.

In contrast, by early 2014, the numbers reported here are in line with, or even above, many other projections. The CBO (2014) itself projects growth of potential GDP of 2 percent and GDP per hour of 1.4 percent. Jorgenson et al (2013) and Gordon (2014) project GDP per hour growth 10 years out of 1.3 percent. Byrne, Oliner, and Sichel (2013) project GDP per hour of about 1-1/2 percent.

Actual long-run performance could, of course, differ substantially from these benchmark projections. Mueller and Watson (2013) estimate that the standard deviation on 10-year projections of GDP per hour range from 0.9 to 3.1 percent (check). My benchmark productivity assumptions are optimistic relative to the actual post-2003 experience. The GDP projections themselves depend on demographic assumptions about labor-force participation of different cohorts as well as immigration. (GDP is more important for budget projections than GDP per hour.)

Model assumes there is a steady-state, which might not be correct. Fernald and Jones (2014) discuss a model in which relatively steady growth of GDP per hour of 2 percent reflects transition dynamics as an increasing share of the labor force is devoted to research. The steady-state of that model is much lower. As they note, these transition dynamics could play out for a considerable time, and the rise of “frontier” research in China, India and elsewhere—as well as machine learning and robots—could make the future quite different than the past.

Need to discuss the high alpha case.

²² The CBO (e.g., CBO 2014) typically publishes a projection for potential overall economy labor force, and potential non-farm business hours. Growth in these variables typically differs. I assume economy-wide hours grow with non-farm business hours to allow for medium-run trends in hours per worker.

²³ Numbers are reported in the minutes at <http://www.federalreserve.gov/monetarypolicy/fomccalendars.htm>. There are at most 19 FOMC participants, and often fewer, depending on whether there are unfilled governor positions. Projection data are presented in bins. I have rounded the “2.4 to 2.5 percent” bin to 2-1/2 percent. Estimates are for total GDP, and so it is not possible to decompose FOMC projections into productivity or demographics.

²⁴ The earliest public working paper version of this paper was in September 2012, and projected long-run growth of 2.1 percent per year.

5. Implications for Measures of Recent and Near Future Slack

The slow rate of productivity growth implies that economic slack, as of 2013, may be narrower than estimated by the CBO (2014). For comparability, I follow the CBO (2001) production-function approach to measuring potential output, which defines potential as “an estimate of the level of GDP attainable when the economy is operating at a high [i.e., normal] rate of resource use” (CBO 2001, page 1). This definition is different than typically used in dynamic stochastic equilibrium (DSGE) models, but the factors I am focused on (technology, mainly, and secondarily capital) are important in those models, as well.

5.1. Alternative Definitions of Potential

An appealing, theoretically coherent, alternative to the CBO production-function method comes from the DSGE literature. That literature typically defines the potential (or natural) rate of output as its value in the absence of nominal frictions (sticky prices and wages) and, often, markup shocks.²⁵ As with the CBO definition, technology shocks directly affect the natural rate of output. But other shocks may also induce deviations in frictionless equilibrium inputs—including the desired intensity with which factors are used—in ways that are ruled out by the CBO method. Other shocks that do not affect the production function itself, such as to the labor-leisure choice or to time preference, can also affect the natural rate of output even in the absence of nominal rigidities.

There are several potential challenges with the DSGE approach in the present context. First, its estimates of potential are model-specific. Different models may interpret the same data quite differently. Second, most DSGE models assume that growth in technology and labor productivity have constant means, which is inconsistent with the evidence presented earlier. A fully-specified regime-switching (or more general) model can be fairly complicated. The need to specify how the underlying trends evolve is an example of the model-specificity of the natural-rate estimates.

Nevertheless, Justiniano, Primiceri, and Tambalotti (2011) argue that the output gap in a fairly-standard New Keynesian DSGE models is highly correlated with CBO output gaps (and looks a lot like detrended labor), so the differences between the CBO and DSGE approaches might not be so large in practice. Indeed, since my main focus is the role of technology fluctuations, that affects output gaps in DSGE models as well as the CBO approach. Finally, the CBO estimates provide a widely cited benchmark.

5.2. Alternative Estimates of Slack in the CBO Approach

It’s useful to simplify the general production function for the (nonfarm) business sector to be Cobb-Douglas and write it as:

²⁵ See, Basu and Fernald (2009) or Kiley (2010) for an extended discussion and references..

$$Y_t^{Bus} = K_t^\alpha (H_t LQ)^{1-\alpha} \quad TFP_t = K_t^\alpha H_t^{1-\alpha} (Util_t LQ_t^{1-\alpha} A_t)$$

The CBO does not explicitly consider labor quality, so the term in brackets in the far right expression is measured TFP gross of the contribution of labor quality. This measure of TFP differs from technology both because of utilization, and also because of labor quality.

The CBO's production-function measure of potential output is defined as what the economy could produce given current technology and capacity, assuming that labor and capital are utilized at "normal" (steady-state) levels. Normalizing $Util^* = 1$, potential output is:

$$Y_t^{Bus,*} = K_t^\alpha H_t^{*1-\alpha} (LQ_t^{*1-\alpha} A_t). \quad (12)$$

Taking the ratio, the output gap for the business sector is:

$$\frac{Y_t^{Bus}}{Y_t^{Bus,*}} = \left(\frac{H_t}{H_t^*} \right)^{1-\alpha} Util_t \left(\frac{LQ_t}{LQ_t^*} \right)^{1-\alpha} \quad (13)$$

The CBO has a view on full-employment hours worked, H_t^* , based on microeconomic analysis of demographics, trend labor-force participation, mismatch, and other factors. Capital is calculated using perpetual-inventory methods as in Section 2.2.

The big challenge is how to identify underlying technology (inclusive of the effects of labor quality). The CBO in essence appears to make the identifying assumption that its path evolves relatively smoothly, with a level I denote $LQ_t^{*,CBO} A_t^{*,CBO}$.²⁶ That is, they assume that, apart from infrequent adjustments in trend, most fluctuations in measured TFP (inclusive of labor quality) reflect utilization. Hence, $Util_t^{CBO} = (LQ_t \cdot TFP_t) / (LQ_t^{*,CBO} A_t^{*,CBO})$, where the denominator is measured TFP. Given this utilization measure, the CBO output gap is then:

$$\frac{Y_t^{Bus}}{Y_t^{Bus,*}} = \left(\frac{H_t}{H_t^*} \right)^{1-\alpha} Util_t^{CBO} \quad (14)$$

The CBO publishes the data to calculate the business-sector output gap on the left-hand side, and the hours-gap on the right-hand side. Using my benchmark capital share from Section 4.1, Figure xx plots the implied CBO utilization gap against the cumulated Fernald utilization series. I have normalized the level of the Fernald series to match the CBO's as of 1987. Over the full sample, the correlation of the two series is 0.77. Clearly, the two series are closely related. However, the Fernald model-based measure suggests that the recent behavior of utilization is very different from that assumed by the CBO.

²⁶ Of course, they regularly revisit the assumptions they make, drawing on a range of subjective and objective evidence.

The flip side of this is that the my data suggest different behavior of TFP than assumed by the CBO. The top panel of Figure 9 shows the CBO’s smooth “potential” TFP series along with the Fernald utilization-adjusted series and the BLS MFP series.²⁷ The series track reasonably well over time, in that—for much of history—the CBO measure appears plausibly to be a smoothed measure of the MFP series. But even prior to the Great Recession, several periods of divergence are notable. [DESCRIBE]. But the Great Recession is a particularly striking anomaly.

Clearly, this series is quite different from the Fernald one in the recent period. This is the flip side of the divergence on TFP trends. Since the CBO assumes underlying technology is stronger than my estimates imply, they correspondingly assume a utilization gap that is larger than mine.

The CBO view is defensible in that, historically, labor gaps and utilization gaps are strongly positively correlated. When there is a labor gap—and CBO (2014) estimates that as of 2013, $H / H^* = -5.4$ percent—there is typically a utilization gap in the same direction. (Interestingly, prior to the Great Recession the correlation of the hours gap with the utilization gap is a bit higher with the Fernald utilization measure (0.70) than with the CBO utilization measure (0.61).) However, the persistence of the utilization gap, six years after the Great Recession began, is suspect given the evidence discussed in Section 2 that utilization bounced back relatively quickly.

Two alternative identifying assumptions therefore suggest themselves. The first is to use a model-based measure of utilization, such as the Basu-Fernald-Kimball measure plotted in Figure xx. That provides the benchmark estimate of the output gap in Figure 1.

The second is to assume there are no utilization gaps, so that actual TFP properly measures technology. There will still be an output gap to the extent there is still a labor gap. Of course, since actual factor utilization surely is cyclical, this measure of the output gap will not move enough—and will imply a measure of potential output that moves too much with actual output. However, it has the advantage of not requiring any specific model of utilization. And after a sufficient amount of time, when utilization can safely be assumed to have returned to normal levels, it will correctly measure the gap.

Note that either of these two alternatives is robust to measurement error in growth in capital or in underlying technology. The reason is that TFP is measured as a residual. Hence, *ceteris paribus*, anything that affects actual output affects measured TFP as well. And actual output depends on true capital and

²⁷ The CBO measure has been adjusted for trend labor quality, where LQ^* is estimated as a local mean, using a biweight kernel with bandwidth of 40 quarters. It has also been adjusted for deviations in capital and for trend differences between the business sector and the non-farm business sector.

technology. This is the reason why capital and technology do not appear in the “output gap” ratio

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(LQ is more challenging.)

Together, these assumptions imply the “Fernald” path of potential shown in Figure 2. The “Fernald” estimate here decomposes about 3/4 of the shortfall relative to the 2007 trend into a downgrade of potential, and about half into an output gap (output below potential). [Need to describe mapping from business sector to GDP, which assumes no gap in the non-business sector. Historically, the CBO attributes almost all movements in the output gap to the non-farm business sector, so that assumption is fairly innocuous.]

It would be inappropriate to consider that path of potential output to be exogenous, since the potential output definition uses actual capital input which is affected by cyclical factors. That is obscured by the focus on gaps but, quantitatively, a major reason for the shortfall is weak capital growth. [This should be straightforward to calculate, and potentially calculate a ‘capital gap’ that, in steady state, should close]

Once transitory/business-cycle dynamics play out, the neoclassical model would imply that the marginal product of capital will be high relative to steady state, encouraging capital formation. Hence, potential growth will temporarily “overshoot” on its return to steady-state. In other words, some of the reduction in potential is simply a consequence of the recession itself.

Another risk to the near-term projections for potential output is that persistent weakness in aggregate demand could corrode supply. For example, workers could lose skills and, potentially, drop out of the labor force permanently. This risk highlights that persistently weak demand could lead potential to be even weaker than anticipated here.

Discuss what this means for the pre-crisis period. [Finally, consider the period prior to the crisis, say in 2006, where I simply used the CBOs estimates. The CBO estimates that output was only slightly above potential at that time. The methodology in this section implicitly estimates the output gap in 2012 by projecting the CBO’s gap from 2006 using actual GDP growth and an estimate of potential growth. Therefore, if actual output were, in fact, further above potential prior to the crisis, then today’s output gap would be reduced.

There are clear reasons to believe that aspects of the economy were unsustainable in the mid-2000s. However, these do not necessarily imply that the *level* of output was unsustainable. With hindsight, one could easily argue that in the mid-2000s, there were two related problems: (i) the economy was producing the “wrong” stuff (too many houses), and (ii) economic agents were buying the wrong stuff (e.g., using home

²⁸ Regarding capital, a potential concern is unobserved scrappage rates. The resulting bias could go either way. On the one hand, if the economy has too much auto capacity, say, or too many back hoes, this capital could have been scrapped. On the other hand, firms may have deferred scrappage and continued to use old but still serviceable capital rather than replacing it.

equity as an ATM to finance too-much consumption). Both problems are consistent with the CBO estimates. Conceptually, the economy built capital goods (houses) that turned out not to be productive. In the CBO estimates, that construction was part of actual and potential output when it was built. Later on, when the housing did not provide a service flow, then both actual and potential non-business output (the services of owner-occupied housing) has been lower than one would have anticipated in 2007. That is one reason for the downward revision in potential (though not the primary reason). In terms of buying too much consumption, the implied impetus to aggregate demand is consistent with output being above potential prior to the crisis. But much of the consumption was imported, and “paid for” by borrowing from abroad, not by overproducing domestically.]

6. Conclusions

In assessing recent dynamics of labor productivity and potential output, this paper makes four points. First, after accelerating in the mid-1990s, labor productivity growth slowed again after the early to mid 2000s. This slowdown preceded the Great Recession and is consistent with reduced investment in intangible organizational capital associated with information technology. There is little evidence so far that underlying productivity trends have substantially changed further during the recession and recovery.

Second, in contrast to informal commentary, labor and total-factor productivity performance during the Great Recession and early in the subsequent recovery was largely in line with previous recession experience. Peak to trough, total factor productivity (TFP) saw the sharpest downturn in the post-war period, consistent with labor and capital hoarding. Labor productivity did not decline as much, reflecting a surge in capital deepening during the recession (since labor fell much more than capital) and labor quality (as low-skilled workers disproportionately lost their jobs). During the recovery, as measures of factor utilization fairly quickly returned to normal, TFP and labor productivity returned roughly to their mid-2000s trend.

Third, using a multi-sector neoclassical growth framework, steady-state potential output is likely to rise at about a 2.2 percent pace. Finally, during the recession and recovery, potential output growth was well below that pace—reflecting not only the slower underlying growth in technology but also the sharply reduced capital growth during the recession and early recovery. Despite this substantially slower pace of potential, actual output is even lower.

An open issue remains whether the Great Recession itself might leave a permanent mark on potential. The slow underlying technology trends appear to pre-date the Great Recession itself. And to the extent the reduced recent pace of physical capital formation is cyclical, it should rebound when the economy finally recovers. Nevertheless, one can tell stories in which the recession reduces investment in innovation that permanent affects the path of output (see, e.g., Barlevy, 2004). And there could also be permanent labor

market scars, to the extent unemployed workers lose skills or labor-market attachment. These forces could become more apparent over time. But the estimates in this paper do suggest that future assessments will need to be careful not to conflate the pre-crisis slowdown in underlying technology with permanent crisis effects.

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Appendix A: Data

Fernald (2012) Quarterly Growth-Accounting Data

These data are available at http://www.frbsf.org/economics/economists/jferald/quarterly_tfp.xls. They include quarterly growth-accounting measures for the business-sector, including output, hours worked, labor quality (or composition), capital input, and total factor productivity from 1947:Q2 on. In addition, they include a measure of factor utilization that follows Basu, Fernald, and Kimball. They are typically updated one to two months after the end of the quarter (for example, data through 2011:Q4 were posted on February 2, 2012, following the release of BLS Productivity and Cost data for the fourth quarter). Once aggregated to an annual frequency, they are fairly close to the annual BLS multifactor productivity estimates, although there are some differences in coverage and implementation.²⁹ The data are described in greater detail in Fernald (2012).

Key data sources for estimating (unadjusted) quarterly TFP for the U.S. business sector are:

- (i) Business output: A geometric average of output as measured from the income and expenditures sides, as recommended by Nalewaik (2011). The expenditure (gross domestic product) side is reported in NIPA tables 1.3.5 and 1.3.6 (gross value added by sector). Nominal business income (the counterpart of gross domestic income) is GDI less nominal non-business output from table 1.3.5. Real business income uses the expenditure-side deflators.
- (ii) Hours: From the quarterly BLS productivity and cost release.
- (iii) Capital input: Weighted growth in 15 types of disaggregated quarterly capital (5 types of non-residential equipment, 5 types of structures, 3 types of intellectual property, plus inventories and land.) Estimated user costs are used to generate weights in capital input. For equipment, structures, intellectual property, and inventories, the underlying source is the BEA. For land, I interpolate and extrapolate from BLS estimates of land input into the business sector.
- (iv) Factor shares: Based on NIPA data on corporate business total business factor costs as well as payments to labor and capital. Following Jorgenson, Gollop, and Fraumeni (1987) and the BLS, cost equals revenue net of taxes on production and imports (TOPI), plus subsidies, plus the portion of TOPI that is properly allocated to capital (property and motor vehicle taxes). I allocate proprietors' income between labor and capital so that labor's share of non-corporate, non-government businesses matches the share for non-financial corporations.
- (v) Labor composition: From 1979:1 on, I use estimates that follow Aaronson and Sullivan (2001), as updated by Bart Hobijn and Joyce Kwok. Prior to 1979, I interpolate and extrapolate annual data from BLS multifactor productivity data.
- (vi) Investment versus consumption technology: To decompose aggregate TFP along final demand lines, I create three Tornquist price indices from NIPA data. The first is the price of "equipment," defined as equipment, software, and consumer durables. The second is the price of structures, defined as residential and non-residential structures. The third is the price of non-durable "consumption," defined as everything else—i.e., the price of business

²⁹ To name six minor differences: (i) BLS covers *private* business, Fernald covers total business. (ii) BLS uses expenditure-side measures of output, whereas Fernald combines income and expenditure-side measures of output. (iii) BLS assumes hyperbolic (rather than geometric) depreciation for capital. (iv) BLS uses the more disaggregated investment data available at an annual frequency. (v) Fernald does not include rental residential capital. (vi) There are slightly different methodologies for estimating labor quality. Some of these differences reflect what can be done quarterly versus annually. For a review of the methodology and history of the BLS measures, see Dean and Harper (2001).

output less equipment and structures. I assume the relative price of equipment investment corresponds, quarter-by-quarter, to TFP in consumption relative to equipment investment. (This measure of relative TFP is not, of course, necessarily equal to technology change period by period.)

To estimate a quarterly series on aggregate utilization, the key data source is the following:

- (vii) Hours-per-worker (H^i / N^i) by industry from the monthly employment report of the BLS. These are used to estimate a series on industry utilization $\Delta \ln U_i = \beta_i \Delta \ln(H^i / N^i)$, where β_i is a coefficient estimated by Basu, Fernald, Fisher, and Kimball (BFFK, 2013). I then calculate an aggregate utilization adjustment as $\Delta \ln U = \sum_i w_i \Delta \ln U_i$, where w_i is the industry weight from BFK (taken as the average value over the full sample).

The resulting utilization-adjusted series differs conceptually from the BFFK purified technology series along several dimensions. BFFK use detailed industry data to construct estimates of industry technology change that control for variable factor utilization and deviations from constant returns and perfect competition. They then aggregate these residuals to estimate aggregate technology change. Thus, they do not assume the existence of a constant-returns aggregate production function. The industry data needed to undertake the BFFK estimates are available only annually, not quarterly. As a result, the quarterly series estimated here does not control for deviations from constant returns and perfect competition.³⁰

BLS Industry Data

- MFP
- Finance share
- IT intensity

BLS hours data

Maybe state data

Also how I use the CBO data

- Non-farm-business labor gap is from comparing BLS data on hours worked in non-farm business to CBO's published potential non-farm business hours. The published BLS productivity-and-cost hours data are an index, but BLS staff provided the underlying published levels.³¹

³⁰ The output data also differ, both in vintage and data source, from the annual data used by BFK.

³¹ I thank Bob Arnold at the CBO and John Glaser at BLS for help understanding the data.

Appendix B: Projecting Labor Productivity in Neoclassical Growth Models

This appendix discusses how to estimate steady-state labor productivity growth from estimates of underlying technology growth. It uses a neoclassical model to derive the implications for capital deepening. Section A summarizes the familiar one-sector Solow model. Section B develops a two-sector Solow model, which highlights the key takeaways and intuition for the multi-sector model. Section C derives the (straightforward, but somewhat tedious) extension to the case with consumer durables, land, and inventories.

A few equations will be useful as preliminaries. Let hats over a variable represent log changes. As an identity, output growth, $\hat{Y}$, is labor-productivity growth plus growth in hours worked, $\hat{H}$:

$$\hat{Y} = (\hat{Y} - \hat{H}) + \hat{H}.$$

We focus here on full-employment labor productivity, so we abstract from utilization.

Growth in total factor productivity, or the Solow residual, is defined as

$$\widehat{TFP} = \hat{Y} - \alpha \hat{K} - (1 - \alpha) \hat{N} \quad (14)$$

where α is capital's share of income and $(1 - \alpha)$ is labor's share. Defining $\hat{N} \equiv \hat{H} + \widehat{LQ}$, where $\widehat{LQ}$ is labor "quality" (composition) growth³², output per hour growth is:

$$(\hat{Y} - \hat{H}) = \widehat{TFP} + \alpha(\hat{K} - \hat{N}) + \widehat{LQ}. \quad (14)$$

Growth in output per hour worked reflects TFP growth; the contribution of capital deepening, defined as $\alpha(\hat{K} - \hat{N})$; and increases in labor quality. Economic models suggest mappings between fundamentals and the terms in this identity.

It is sometimes useful to rearrange (14) to yield:

$$(\hat{Y} - \hat{H}) = \widehat{TFP} / (1 - \alpha) + \alpha(\hat{K} - \hat{Y}) + \widehat{LQ} \quad (14)$$

We now show how a one-sector and two-sector model map to these equations. Then we allow for a third sector, and for inventories, and land.

A. The one-sector Solow model

The Solow model provides a particularly simple model that maps exogenous growth in technological progress and the labor force to endogenous capital deepening.

Consider an aggregate production function $Y = K^\alpha (AN)^{1-\alpha}$, where labor-augmenting technology A grows at rate g , and labor input N (which captures both raw hours H and labor quality LQ —henceforth, I do not generally differentiate between the two) grows at rate n . Expressing all variables in terms of "effective labor" AN yields:

$$y = k^\alpha, \text{ where } y = Y / AN \text{ and } k = K / AN. \quad (14)$$

Capital accumulation takes place according to the perpetual-inventory formula, $\dot{K} = I - \delta K$. Let s is the saving rate, so that sy is investment per effective worker. In steady-state:

$$sy = (n + \delta + g)k \quad (14)$$

Because of diminishing returns to capital, the economy converges to a steady state where y and k are constant. At that point, investment per effective worker is just enough to offset the effects of depreciation, population growth, and technological change on capital per effective worker. In steady state, the unscaled levels of Y and K grow at the same rate $g+n$; capital-deepening, K/N , grows at rate g . Labor productivity Y/N , i.e., output per unit of labor input, also grows at rate g .

³² In the BLS multifactor productivity dataset, from 1948 through 2012, hours grew 1.10 percent per year, and labor quality/composition grew 0.32 percent per year. Hence, more than a quarter of labor input growth in the MFP data reflects labor quality. As discussed in the text, labor quality, in turn, reflects the mix of hours across workers with different levels of education, experience, and so forth.

From the production function, measured TFP growth is related to labor-augmenting technology growth by:

$$\widehat{TFP} = \hat{Y} - \alpha \hat{K} - (1 - \alpha) \hat{N} = (1 - \alpha)g.$$

The model maps directly to equations (14) and (14) above. In steady state, $\hat{K} = \hat{Y}$, and, as in equation (14), output per unit of labor grows at $g = \widehat{TFP} / (1 - \alpha)$. Alternatively, in terms of equation (14), the endogenous contribution of capital deepening to labor-productivity growth is

$\alpha(\hat{K} - \hat{N}) = \alpha g = \alpha \cdot \widehat{TFP} / (1 - \alpha)$. Thus, we can write growth in output per hour in a form that corresponds closely with the two-sector version below:

$$\hat{Y} - n = \widehat{TFP} + \alpha \cdot \widehat{TFP} / (1 - \alpha) \quad (14)$$

Growth in output per unit of labor depends on standard TFP growth and induced capital deepening.

B. The two-sector Solow model

In contrast to the predictions of the one-sector model, the capital-output ratio in the data rises steadily after the early 1970s. The literature on investment specific technical change suggests a straightforward fix for this model failure: Capital-deepening doesn't depend on *overall* TFP, but on TFP in the investment sector. A key motivation for this literature is the declining price of business investment goods, especially equipment and software, relative to the price of other goods (such as consumption). The most natural interpretation of the declining relative price is faster technical change in producing investment goods (especially high-tech equipment).³³

Consider a simple two-sector Solow-type model, where s is the share of nominal output that is invested each period.³⁴ One sector produces investment goods that are used to create capital; the other produces consumption goods. The two sectors use the same Cobb-Douglas production function, but with potentially different technology levels:

$$I = K_I^\alpha (A_I N_I)^{1-\alpha}$$

$$C = Q K_C^\alpha (A_I N_C)^{1-\alpha}$$

In the consumption equation, we have implicitly defined labor-augmenting technological change as $A_C = Q^{1/(1-\alpha)} A_I$ in order to decompose consumption technology into the product of investment technology A_I and a "consumption specific" piece, $Q^{1/(1-\alpha)}$. Let investment technology A_I grow at rate g_I and the consumption-specific piece Q grow at rate q . Perfect competition and cost-minimization imply that price equals marginal cost. If the sectors face the same factor prices (and the same rate of indirect business taxes), then relative marginal costs depend solely on relative technology:

$$\frac{P_I}{P_C} = \frac{MC^C}{MC^I} = Q$$

The sectors also choose to produce with the same capital-labor ratios, implying that $K_I / A_I N_I = K_C / A_I N_C = K / A_I N$. We can then write the production functions as:

$$\begin{aligned} I &= A_I N_I (K / A_I N)^\alpha \\ C &= Q A_I N_C (K / A_I N)^\alpha \end{aligned} \quad (14)$$

³³ On the growth accounting side, see, for example, Jorgenson (2001) or Oliner and Sichel (2000); see also Greenwood, Hercowitz, and Krusell (1997).

³⁴ This model is a fixed-saving rate version of the two-sector neoclassical growth model in Whelan (2003) and is isomorphic to the one in Greenwood, Hercowitz, and Krusell (1997). Greenwood *et al.* choose a different normalization of the two technology shocks in their model.

We can now write the economy's budget constraint in a simple manner:

$$Y^{\text{Inv. Units}} \equiv [I + C / Q] = A_I (N_I + N_C) (K / A_I N)^\alpha, \text{ or} \\ y^{\text{Inv. Units}} = k^\alpha, \text{ where } y^{\text{Inv. Units}} = Y^{\text{Inv. Units}} / A_I N \text{ and } k = K / A_I N. \quad (14)$$

Output here is expressed in investment units, and “effective labor” is in terms of technology in the *investment* sector. The economy mechanically invests a share s of nominal investment, which implies that investment per effective unit of labor is $i = s \cdot y^{\text{Inv. Units}}$.³⁵

Capital accumulation turns out to take the same form as in the one-sector model, except that it is only growth in investment technology, g_I , that matters. In particular, in steady state:³⁶

$$s y^{\text{Inv. Units}} = (n + \delta + g_I) k \quad (14)$$

The production function (14) and capital-accumulation equation (14) correspond exactly to their one-sector counterparts. Hence, the dynamics of capital in this model reflect technology in the investment sector alone. In steady state, capital per unit of labor, K/L , grows at rate g_I , so the contribution of capital deepening to labor-productivity growth from equation (14) is

$$\alpha(\hat{K} - \hat{N}) = \alpha g_I = \alpha \cdot \widehat{TFP_I} / (1 - \alpha) \quad (14)$$

Consumption technology in this model is “neutral,” in that it does not affect investment or capital accumulation; the same result generally carries over to the Ramsey version of this model, with or without variable labor supply. (Basu, Fernald, Fisher, and Kimball, 2011, discuss the idea of consumption-technology neutrality in greater detail.)

In the data, output is not expressed in investment units but as chained units. Chain GDP growth is defined as share-weighted growth in final expenditure categories:

$$\hat{Y} = s \hat{I} + (1 - s) \hat{C}$$

From equation (14), in steady state, when $k = K / A_I N$ is constant, $\hat{I}$ grows at rate $(n + g_I)$ and $\hat{C}$ grows at rate $(n + g_I + \hat{q})$. Hence, $\hat{Y} = n + g_I + (1 - s) \hat{q}$ and the capital-output ratio grows at $\hat{K} - \hat{Y} = (n + g_I) - (n + g_I + (1 - s) \hat{q}) = -(1 - s) \hat{q}$. Since consumption TFP growth is generally lower than investment TFP growth, $\hat{q}$ is negative in the data, and the model predicts that the measured capital-output ratio is increasing. Note that overall TFP growth in chain-units is:

$$\begin{aligned} \widehat{TFP} &= \hat{Y} - \alpha \hat{K} - (1 - \alpha) \hat{N} \\ &= n + g_I + (1 - s) \hat{q} - \alpha(n + g_I) - (1 - \alpha)n \\ &= (1 - \alpha)g_I + (1 - s) \hat{q} \end{aligned} \quad (14)$$

Hence, using (14) and (14), growth in output per unit of labor can be written:

$$\hat{Y} - n = g_I + (1 - s) \hat{q} = \widehat{TFP} + \alpha \frac{\widehat{TFP_I}}{(1 - \alpha)} \quad (14)$$

This equation takes the same form as (14), except that capital deepening is solely in terms of investment-sector TFP growth.

To take this model to the data, we need to decompose aggregate TFP growth (calculated from chained output) into its consumption and investment components. Given the conditions so far, the following two equations hold:

³⁵ $s \cdot y^{\text{Inv. Units}} = [P_I I / (P_I I + P_C C)] [(I + P_C C / P_I) / A_I N] = I / A_I N$

³⁶ The time-derivative $\dot{k} = d/dt(K/AN) = (K/AN)(\dot{K}/K - n - g_I)$. Substituting the capital accumulation equation, $\dot{K}/K = I/K - \delta$, yields $\dot{k} = i - (n + g_I + \delta)k$. In steady-state, $\dot{k} = 0$. Substituting for i yields (14).

$$\widehat{TFP} = s \cdot \widehat{TFP}_I + (1-s)\widehat{TFP}_C$$

$$\widehat{P}_C - \widehat{P}_I = \widehat{TFP}_C - \widehat{TFP}_I$$

Prices, investment shares, and aggregate TFP are known. Hence, these are two equations in two unknowns— $\widehat{TFP}_I$ and $\widehat{TFP}_C$.³⁷

C. Three sector model

In practice, there are multiple types of capital. The most important distinction is between fast-growing equipment and more slowly growing structures. The argument would naturally extend to more types of capital, as well. Suppose that there's a **Durable** sector that produces equipment, a **Building** sector that produces structure, and a **Consumption** sector:³⁸

$$\begin{aligned} D &= (K_D)^\alpha (AN_E)^{1-\alpha} \\ B &= Q_B (K_B)^\alpha (AN_B)^{1-\alpha} \\ C &= Q_C (K_C)^\alpha (AN_C)^{1-\alpha} \end{aligned} \tag{14}$$

Some durable goods are consumed as durables. Other durable goods are invested and become equipment capital according to the usual perpetual inventory equation. Similarly, new buildings become gross investment in structures. All three sectors use the same capital aggregate, which uses equipment E and structures S .

$$K = E^{c_E} S^{1-c_E} = K_D + K_B + K_C \tag{14}$$

To solve for steady state growth rates, I follow Whelan (2003). In steady state, growth of equipment and structures must be the same in all uses, and labor growth (at rate n) is the same in all uses. Let g_X be steady-state growth in variable X . In steady-state, the perpetual-inventory formula implies that growth of investment in durables or buildings is equal to growth in the capital stocks of equipment and structures, respectively.³⁹ That is, $g_E = g_D$ and $g_S = g_B$. In growth rates, then:

$$\begin{aligned} g_D &= \alpha(c_E g_D + (1-c_E)g_B) + (1-\alpha)(\hat{a} + n) \\ g_B &= \alpha(c_E g_D + (1-c_E)g_B) + (1-\alpha)(\hat{a} + n) + \hat{q}_B = g_D + \hat{q}_B \\ g_C &= \alpha(c_E g_D + (1-c_E)g_B) + (1-\alpha)(\hat{a} + n) + \hat{q}_C = g_D + \hat{q}_C \end{aligned} \tag{14}$$

This is a straightforward system of simultaneous equations that yields:

$$\begin{aligned} g_D &= (\hat{a} + n) + \frac{\alpha(1-c_E)}{1-\alpha} \hat{q}_B \\ g_B &= g_D + \hat{q}_B \\ g_C &= g_D + \hat{q}_C \end{aligned} \tag{14}$$

³⁷ The calculations in the text use the official price deflators from the national accounts. Gordon (1990) argues that many equipment deflators are not sufficiently adjusted for quality improvements over time. Much of the macroeconomic literature since then has used the Gordon deflators (possibly extrapolated, as in Cummins and Violante, 2002). Of course, as Whelan (2003) points out, much of the discussion of biases in the CPI involve service prices, which also miss a lot of quality improvements, making the overall effect. Hobbijn and McKay (2007) also questions the hedonic adjustments in Gordon, Cummins, and Violante.

³⁸ The mnemonics—**D**urables rather than **E**quipment, for example—is to clearly differentiate the flow output of producing sectors from the accumulated stock of equipment and structures.

³⁹ In steady-state, $I / K = g + \delta$. Since the right-hand-side is constant, I must grow at the same rate as K .

Chain GDP growth is share-weighted growth in final expenditure categories. If s_D is the final-expenditure-share of durables and s_B is the final-expenditure-share of buildings, then:

$$\begin{aligned} g &= s_D g_D + s_B g_B + (1 - s_D - s_B) g_C \\ &= g_D + s_B \hat{q}_B + (1 - s_D - s_B) \hat{q}_C \\ &= (\hat{a} + n) + \left[\frac{\alpha(1 - c_E)}{1 - \alpha} + s_B \right] \hat{q}_B + (1 - s_D - s_B) \hat{q}_C \end{aligned} \quad (14)$$

Growth in output per unit of labor is then:

$$g - n = \hat{a} + \left[\frac{\alpha(1 - c_E)}{1 - \alpha} + s_B \right] \hat{q}_B + (1 - s_D - s_B) \hat{q}_C \quad (14)$$

Standard TFP growth for each sector is not in labor-augmenting form, so it equals:

$$\begin{aligned} \widehat{TFP}_D &= (1 - \alpha) \hat{a} \\ \widehat{TFP}_B &= (1 - \alpha) \hat{a} + \hat{q}_B = \widehat{TFP}_D + \hat{q}_B \\ \widehat{TFP}_C &= (1 - \alpha) \hat{a} + \hat{q}_C = \widehat{TFP}_D + \hat{q}_C \end{aligned} \quad (14)$$

Overall TFP growth in this economy is output growth less share-weighted input growth:

$$\widehat{TFP} = g - \alpha(c_E g_D + (1 - c_E) g_B) - (1 - \alpha)n \quad (14)$$

Using the second line of (14) and then substituting from (14), we find:

$$\begin{aligned} \widehat{TFP} &= [g_D + s_B \hat{q}_B + (1 - s_D - s_B) \hat{q}_C] - \alpha(g_D + (1 - c_E) \hat{q}_B) - (1 - \alpha)n \\ &= (1 - \alpha)g_D - \alpha(1 - c_E) \hat{q}_B + s_B \hat{q}_B + (1 - s_D - s_B) \hat{q}_C - (1 - \alpha)n \\ &= (1 - \alpha)(\hat{a} + n) + \alpha(1 - c_E) \hat{q}_B - \alpha(1 - c_E) \hat{q}_B + s_B \hat{q}_B + (1 - s_D - s_B) \hat{q}_C - (1 - \alpha)n \\ &= \widehat{TFP}_D + s_B \hat{q}_B + (1 - s_D - s_B) \hat{q}_C \end{aligned} \quad (14)$$

Note that aggregate TFP growth is also equal to share-weighted sectoral TFP growth from (14).

Define investment TFP growth, $\widehat{TFP}_I$, in terms of user cost (factor share) weights (rather than expenditure weights):

$$\begin{aligned} \widehat{TFP}_I &= c_E \widehat{TFP}_D + (1 - c_E) \widehat{TFP}_B \\ &= \widehat{TFP}_D + (1 - c_E) \hat{q}_B \end{aligned} \quad (14)$$

We can now write growth in output per unit of labor from (14) in terms of overall and investment-sector TFP growth:

$$\begin{aligned} g - n &= \hat{a} + \left[\frac{(1 - \alpha)s_B + \alpha(1 - c_E)}{1 - \alpha} \right] \hat{q}_B + (1 - s_D - s_B) \hat{q}_C \\ &= [(1 - \alpha) \hat{a} + s_B \hat{q}_B + (1 - s_D - s_B) \hat{q}_C] + \alpha \hat{a} + \left[\frac{(1 - \alpha)s_B + \alpha(1 - c_E)}{1 - \alpha} - s_B \right] \hat{q}_B \\ &= \widehat{TFP} + \left(\alpha \hat{a} + \left[\frac{\alpha(1 - c_E)}{1 - \alpha} \right] \hat{q}_B \right) \\ &= \widehat{TFP} + \frac{\alpha}{1 - \alpha} \widehat{TFP}_I \end{aligned} \quad (14)$$

Although the derivation is somewhat involved, this is exactly the same equation as for the two-sector model.

Finally, note that the existence of consumer durables (produced by the durable sector) does not affect this calculation. The weight on equipment in final expenditure, s_D , already includes all final uses of equipment output (whether for investment or for durable consumption). However, the user cost weight of equipment includes only the portion used for equipment investment.

D. Adding inventories, consumer durables, and land

In practice, there are not only multiple types of capital goods, but land. We can derive more general steady-state predictions using the same approach as with the three-sector model above.⁴⁰

Specifically, we assume the same production structure as in (14), above:

$$\begin{aligned} D &= (K_D)^\alpha (AN_E)^{1-\alpha} \\ B &= Q_B (K_B)^\alpha (AN_B)^{1-\alpha} \\ C &= Q_C (K_C)^\alpha (AN_C)^{1-\alpha} \end{aligned} \quad (14)$$

Now, some durable goods are used for consumption (which raises the weight of durables in final output). We also have inventories in capital. Inventories are goods (in the data, roughly half are durable and half are non-durable), but their relative price movements are less pronounced than for equipment. For generality in derivations, we'll allow both the durable and the non-durable sectors to produce inventories.

The capital aggregate now includes inventories, V , and land, T (for Terra), as well as equipment and structures:

$$K = E^{c_E} S^{1-c_E-c_V-c_T} (V_D^\delta V_C^{1-\delta})^{c_V} T^{c_T} = K_D + K_B + K_C \quad (14)$$

Using in (14) and (14), we can proceed in the same way as in the three-sector model:

$$\begin{aligned} g_D &= \alpha(c_E g_D + (1-c_E-c_V-c_T)g_B + c_V \delta g_D + c_V(1-\delta)g_C + c_T \hat{T}) + (1-\alpha)(\hat{a} + n) \\ g_B &= g_D + \hat{q}_B \\ g_C &= g_D + \hat{q}_C \end{aligned} \quad (14)$$

TFP growth in each sector is related to the “fundamental shocks” as shown in equation (14). TFP growth for “reproducible investment,” $\widehat{TFP_I}$, with user cost (factor share) weights, is then:

$$\begin{aligned} \widehat{TFP_I} &= \left(\frac{c_E + c_V \delta}{1-c_T} \widehat{TFP_D} + \frac{(1-c_E-c_V-c_T)}{1-c_T} \widehat{TFP_B} + \frac{c_V(1-\delta)}{1-c_T} \widehat{TFP_C} \right) \\ &= \widehat{TFP_D} + \frac{(1-c_E-c_V-c_T)}{1-c_T} \hat{q}_B + \frac{c_V(1-\delta)}{1-c_T} \hat{q}_C \end{aligned} \quad (14)$$

Solving the system of equations in (14) yields

$$g_D = \left(\frac{1-\alpha}{1-\alpha(1-c_T)} \right) (\hat{a} + n) + \frac{\alpha c_V(1-\delta)}{1-\alpha(1-c_T)} \hat{q}_C + \frac{\alpha(1-c_E-c_V-c_T)}{1-\alpha(1-c_T)} \hat{q}_B + \left(\frac{\alpha c_T}{1-\alpha(1-c_T)} \right) \hat{T} \quad (14)$$

⁴⁰ This analysis takes land as exogenous, though not fixed—it can be pulled from other uses, and in the BLS dataset, business use of land grows at about 1-1/2 percent per year. An alternative modeling strategy would be to tie it to the use of structures in some way. That said, the correlation in the BLS dataset between annual changes in structures and land is far from perfect (about 0.4).

Adding and subtracting $\widehat{TFP}_D$, rearranging, and substituting from (14), yields:

$$\begin{aligned}
 g_D &= \widehat{TFP}_D + \left[\frac{1}{1-\alpha(1-c_T)} - 1 \right] \widehat{TFP}_D + \frac{\alpha c_V(1-\delta)}{1-\alpha(1-c_T)} \hat{q}_C + \frac{\alpha(1-c_E-c_V-c_T)}{1-\alpha(1-c_T)} \hat{q}_B + \left(\frac{\alpha c_T}{1-\alpha(1-c_T)} \right) \hat{T} + \left(\frac{1-\alpha}{1-\alpha(1-c_T)} \right) n \\
 &= \widehat{TFP}_D + \left[\frac{\alpha(1-c_T)}{1-\alpha(1-c_T)} \right] \left[\widehat{TFP}_D + \frac{(1-c_E-c_V-c_T)}{1-c_T} \hat{q}_B + \frac{c_V(1-\delta)}{1-c_T} \hat{q}_C \right] + \left(\frac{\alpha c_T}{1-\alpha(1-c_T)} \right) \hat{T} + \left(\frac{1-\alpha}{1-\alpha(1-c_T)} \right) n \\
 &= \widehat{TFP}_D + \left[\frac{\alpha(1-c_T)}{1-\alpha(1-c_T)} \right] \widehat{TFP}_I + \left(\frac{\alpha c_T}{1-\alpha(1-c_T)} \right) \hat{T} + \left(\frac{1-\alpha}{1-\alpha(1-c_T)} \right) n
 \end{aligned} \tag{14}$$

Growth in reproducible capital per worker can be expressed as:

$$\begin{aligned}
 \hat{K}^R - n &= \left(\frac{1}{1-c_T} \right) ((c_E + c_V\delta)g_D + (1-c_E-c_V-c_T)g_S + c_V(1-\delta)g_S) - n \\
 &= g_D + \left(\frac{c_V(1-\delta)}{1-c_T} \right) \hat{q}_C + \left(\frac{1-c_E-c_V-c_T}{1-c_T} \right) \hat{q}_B - n
 \end{aligned}$$

If we substitute for g_D from (14) and rearrange, we find:

$$\hat{K}^R - n = \left[\frac{1}{1-\alpha(1-c_T)} \right] \widehat{TFP}_I + \left(\frac{\alpha c_T}{1-\alpha(1-c_T)} \right) (\hat{T} - n) \tag{14}$$

Overall capital deepening is

$$\begin{aligned}
 \alpha(\hat{K} - n) &= \alpha(1-c_T)(\hat{K}^R - n) + \alpha c_T(\hat{T} - n) \\
 &= \left[\frac{\alpha(1-c_T)}{1-\alpha(1-c_T)} \right] \widehat{TFP}_I + \left(\frac{\alpha c_T}{1-\alpha(1-c_T)} \right) (\hat{T} - n)
 \end{aligned} \tag{14}$$

From (14), output per worker is:

$$\begin{aligned}
 g - n &= \widehat{TFP} + \alpha(\hat{K} - n) \\
 &= \widehat{TFP} + \left[\frac{\alpha(1-c_T)}{1-\alpha(1-c_T)} \right] \widehat{TFP}_I + \left(\frac{\alpha c_T}{1-\alpha(1-c_T)} \right) (\hat{T} - n)
 \end{aligned} \tag{14}$$

This equation is a natural extension of the one- and two-sector models. If land's share, c_T , is zero, then this equation exactly matches (14) and (14). If $\widehat{TFP}_I = \widehat{TFP}$, then the equation matches (14).

In terms of comparing model projections, land is a complicating factor. Some comparisons are easier, however, since land affects the predictions equally. First, the predictions of the one-sector model with land are the case where $\widehat{TFP}_I = \widehat{TFP}$, so the difference in predictions (from (14)) is just:

$$(g^{\text{Multi-Sector}} - n) - (g^{\text{One Sector}} - n) = \left[\frac{\alpha(1-c_T)}{1-\alpha(1-c_T)} \right] (\widehat{TFP}_I - \widehat{TFP}).$$

Second, recall from the second line of equation (14) that, by the definition of chained GDP, that $g = g_D + s_B \hat{q}_B + (1-s_D-s_B) \hat{q}_C$. It follows that components of the capital-output ratio are:

$$g_D - g = s_B \hat{q}_B + (1 - s_D - s_B) \hat{q}_C$$

$$g_B - g = (g_D + \hat{q}_B) - g = (1 - s_B) \hat{q}_B + (1 - s_D - s_B) \hat{q}_C$$

Third, from equation (14) for growth in reproducible capital, and from the chain-GDP equation, it follows that the growth rate of the reproducible-capital-to-output ratio is:

$$\hat{K}^R - g = \left(\frac{1 - c_E - c_V - c_T}{1 - c_T} - s_B \right) \hat{q}_B + \left(\frac{c_V(1 - \delta)}{1 - c_T} - s_C \right) \hat{q}_C$$

Note that the inventory share of non-land capital payments is under 10 percent, whereas s_C is about 75 percent. Since $\hat{q}_C$ is negative in the data, the second piece tends to push growth in the reproducible-capital to output ratio positive. On the other side, the weight on building-specific TFP growth is the difference between structure's weight in reproducible capital (which averages about 45 percent), and building's share of GDP (which averages 5 percent). Since $\hat{q}_B$ is negative in the data, the building component tends to push this piece negative.

Table 1
Industry Data on Productivity

	Pre-1995	1995-2000	2000-2004	2004-07	2007-11	2004-11	Chng after 2004 (04-07 less 00-04)	Chng after 2004 (04-11 less 00-04)
Private business	0.83	1.58	2.19	0.63	0.90	0.79	-1.55	-1.40
Nat. resources (NR), construction, FIRE	0.09	0.71	-0.28	-1.38	0.76	-0.16	-1.11	0.12
Natural resources (Ag. and mining)	0.86	2.46	2.54	-3.88	-0.41	-1.90	-6.42	-4.44
Construction and real estate	-0.11	-1.62	-1.16	-2.57	1.26	-0.38	-1.41	0.78
Construction	0.41	-0.78	-2.16	-6.69	1.62	-1.94	-4.54	0.21
Real estate and leasing	-0.58	-2.40	-0.18	1.70	0.90	1.24	1.89	1.43
Finance and Insurance	-0.02	3.27	0.07	0.90	0.64	0.75	0.83	0.68
Business ex NR, constr. FIRE	1.08	1.87	3.10	1.42	0.95	1.15	-1.68	-1.95
IT producing	10.49	16.54	11.82	9.03	5.44	6.98	-2.79	-4.84
Non-IT prod. ex NR, const., FIRE	0.49	0.77	2.48	0.85	0.60	0.70	-1.63	-1.78
IT-intensive ex ag, mi, const, AND itprod	-0.10	0.14	2.69	1.09	1.09	1.09	-1.60	-1.60
Non-IT intensive ex ag, mi, cons	1.03	1.82	0.80	0.63	-0.25	0.13	-0.17	-0.68
Well measured ex NR, const., FIRE	1.78	2.53	5.19	2.97	1.67	2.23	-2.22	-2.96
Nondurable goods	0.59	-0.79	4.02	0.23	-0.05	0.07	-3.80	-3.96
Durable goods	2.45	6.66	5.97	6.07	2.25	3.89	0.11	-2.08
Computer and electronic product man	18.53	34.64	21.17	18.99	11.02	14.43	-2.18	-6.74
Equipment, exc comp. and semicond	-1.29	-0.22	2.84	4.39	-0.13	1.81	1.55	-1.03
non-equip durables (metal, mineral, w	0.52	0.07	2.05	-4.14	-2.32	-3.10	-6.19	-5.15
Utilities	1.89	-6.75	9.05	-0.57	4.26	2.19	-9.61	-6.86
Trade	2.41	5.17	2.96	0.45	-0.19	0.08	-2.51	-2.88
Wholesale trade	1.99	6.44	5.08	0.43	-1.33	-0.58	-4.65	-5.66
Retail trade	2.74	4.10	1.23	0.44	0.85	0.67	-0.79	-0.56
Broadcasting and telecommunications	3.02	-2.41	3.94	10.06	4.30	6.77	6.12	2.83
Poorly measured ex NR, const., FIRE	0.63	1.54	2.13	0.68	0.63	0.65	-1.46	-1.48
Publishing industries	1.53	1.88	8.08	1.39	-0.25	0.45	-6.69	-7.63
Other information	-3.77	-11.14	16.27	-1.90	0.33	-0.62	-18.17	-16.90
Services	-0.59	0.30	0.59	0.03	0.75	0.44	-0.55	-0.14
Professional, technical, and support	-0.15	0.51	1.59	-0.14	1.07	0.55	-1.73	-1.04
Educ, health, and soc assist	-2.27	-1.68	0.21	0.11	0.79	0.50	-0.10	0.29
Entertainment, accomm., and other	0.04	1.65	-1.44	0.41	-0.12	0.11	1.85	1.55
Finance intensive ex ag, mi, cons AND FI	0.62	1.49	1.42	0.45	0.50	0.48	-0.97	-0.94
Non-finance intensive ex ag, mi, const	1.42	1.65	5.45	3.27	1.80	2.43	-2.18	-3.02

Notes: Percent per year.

Table 2
Historical Predictions of Growth Models

A. No Land

	Overall TFP	Invest. TFP	One-Sector Predicted Y/L	Multi-Sector Predicted Y/L	Actual Output per Unit Labor	Memo: Labor Quality	Memo: Actual Output/Hour (5)+(6)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Full Sample</i>	1.3	1.8	1.9	2.2	2.0	0.4	2.4
<i>pre-1973Q2</i>	2.1	2.2	3.2	3.2	2.9	0.3	3.2
<i>1973Q2-1995Q4</i>	0.4	1.0	0.7	0.9	1.0	0.4	1.4
<i>1995:Q4-2007:Q4</i>	1.4	2.9	2.1	2.8	2.4	0.4	2.4

B. Adding Land as a Factor of Production

	Overall TFP	Invest. TFP	One-Sector Predicted Y/L	Multi-Sector Predicted Y/L	Actual Output per Unit Labor	Memo: Labor Quality	Memo: Actual Output/Hour (5)+(6)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Full Sample</i>	1.3	1.8	1.9	2.1	2.0	0.4	2.4
<i>pre-1973Q2</i>	2.1	2.2	3.1	3.1	2.9	0.3	3.2
<i>1973Q2-1995Q4</i>	0.4	1.0	0.6	0.8	1.0	0.4	1.4
<i>1995:Q4-2007:Q4</i>	1.4	2.9	2.0	2.6	2.4	0.4	2.8

Notes: Column (3) shows predictions of one-sector growth model for output per unit of (quality-adjusted) labor. In panel A, that prediction depends on column (1) according to $\widehat{TFP} / (1 - \alpha)$. Column (4) shows predictions of multi-sector growth model. In top panel, that depends on columns (1) and (2) according to $\widehat{TFP} + \alpha \cdot \widehat{TFP}_I / (1 - \alpha)$. See text for how land is incorporated as a factor of production in bottom panel. The predictions are compared with actual output per unit of quality-adjusted labor in Column (5). The more typical output per hour is shown in Column (7). All calculations take capital's share $\alpha=0.33$, which is the full-sample average in the Fernald dataset. Investment TFP averages equipment TFP and structures TFP, where the weight on equipment includes the weight of inventories.

Table 3
Projections for labor productivity (output per quality-adjusted hour)

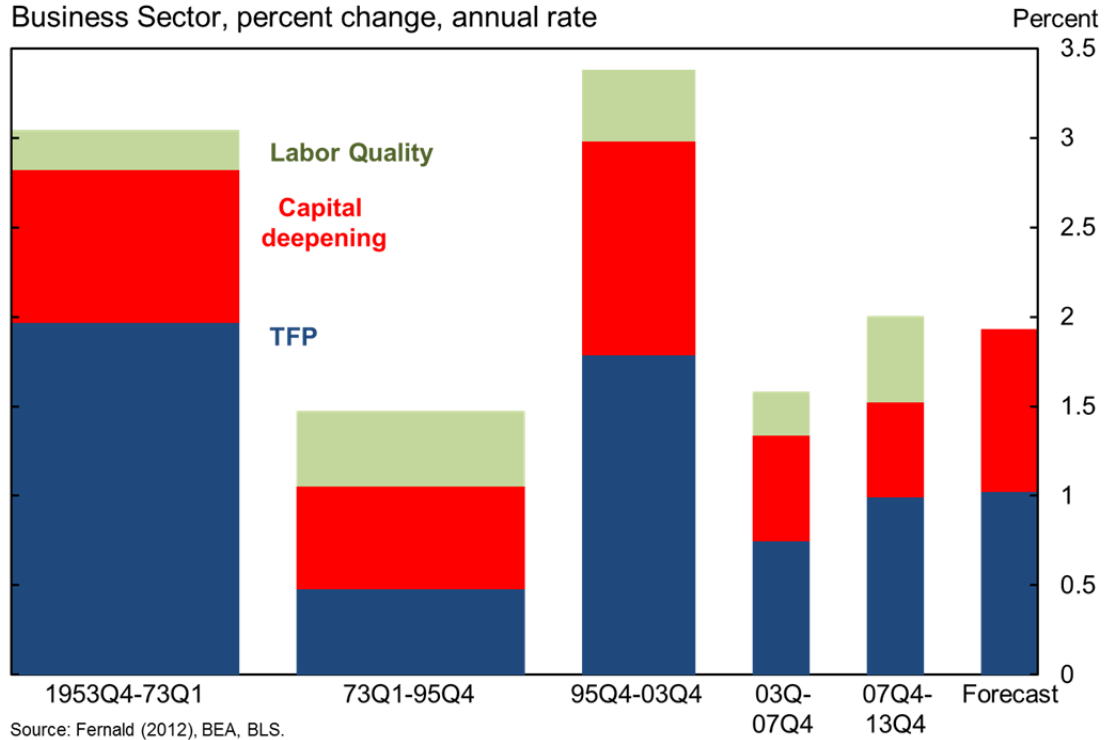
	Variable	AveW	Since 1947:Q 1	Since 1973:Q 1	Since 1986:Q 4	Since 1995:Q 4	Since 2003:Q 4
(1)	Durables TFP	3.04	2.68	2.73	3.24	3.91	3.05
(2)	Buildings TFP	-0.24	0.25	-0.44	-0.36	-0.56	-0.60
(3)	Consumption TFP	0.52	1.00	0.38	0.38	0.53	0.27
(4)	Overall TFP	1.02	1.31	0.83	0.97	1.21	0.79
(5)	Investment TFP	2.08	1.97	1.81	2.19	2.60	1.98
(6)	Labor productivity projection	1.93	2.16	1.62	1.92	2.35	1.65
(7)	GDP projection	2.15	2.34	1.92	2.15	2.47	1.94
(8)	<i>Lab. prod. proj. with 2012 cap. share</i>	2.11	2.34	1.78	2.12	2.58	1.83
(9)	<i>GDP proj. with 2012 cap. share</i>	2.30	2.47	2.05	2.30	2.65	2.08

Notes: All entries are percent per year. Each column shows inputs into projecting business-sector labor productivity (rows 6 and 8) as well as overall GDP growth (rows 7 and 9). Rows (1) to (5) show inputs into those projections under different assumptions. AveW is the arithmetic average of projections based on all windows that end in 2013:Q4, with starting quarters for the windows that range from 1947:2 through 2007:Q4. The remaining columns show selected windows. Labor productivity projections in rows (6) and (8) assume that the weight on durables and buildings in total “investment” TFP is its average from 1995:Q4 through 2007:Q4. Line (6) assumes that (reproducible) capital’s share is its average from 1995:Q4 through 2007:Q4. Line (8) assumes that (reproducible) capital’s share remains at its estimated 2013:Q4 level.

Figure 1
Productivity growth by sub-period

Contributions to Labor Productivity Growth

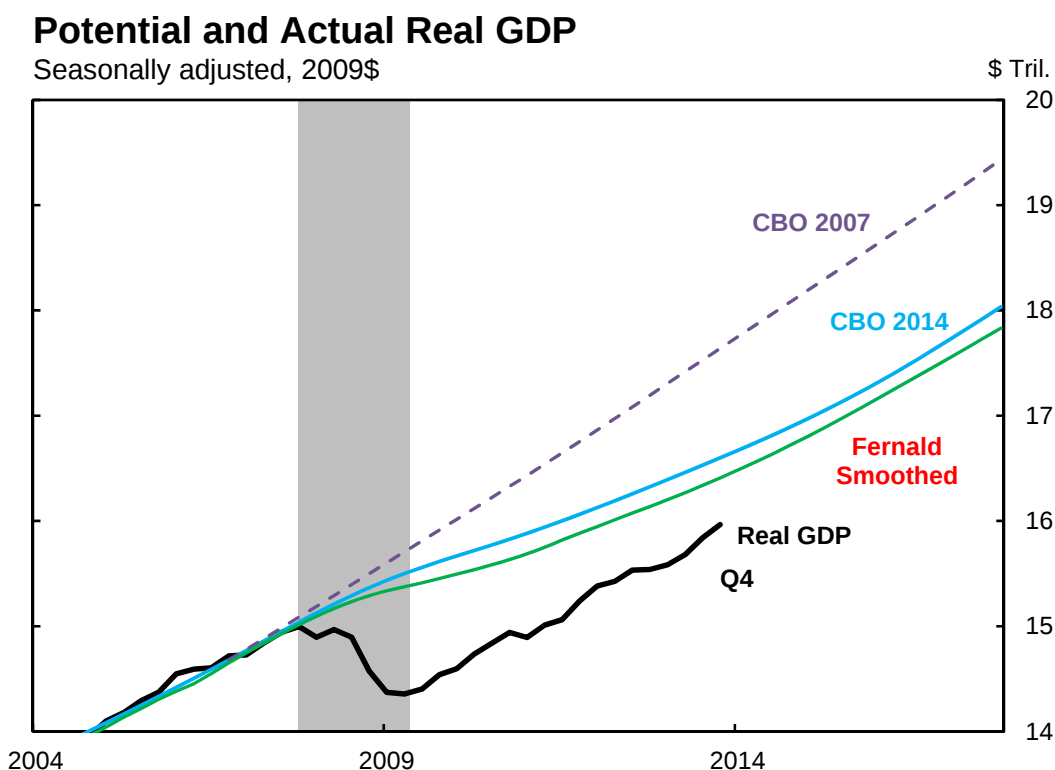
Business Sector, percent change, annual rate



Source: BLS and Fernald (2012)

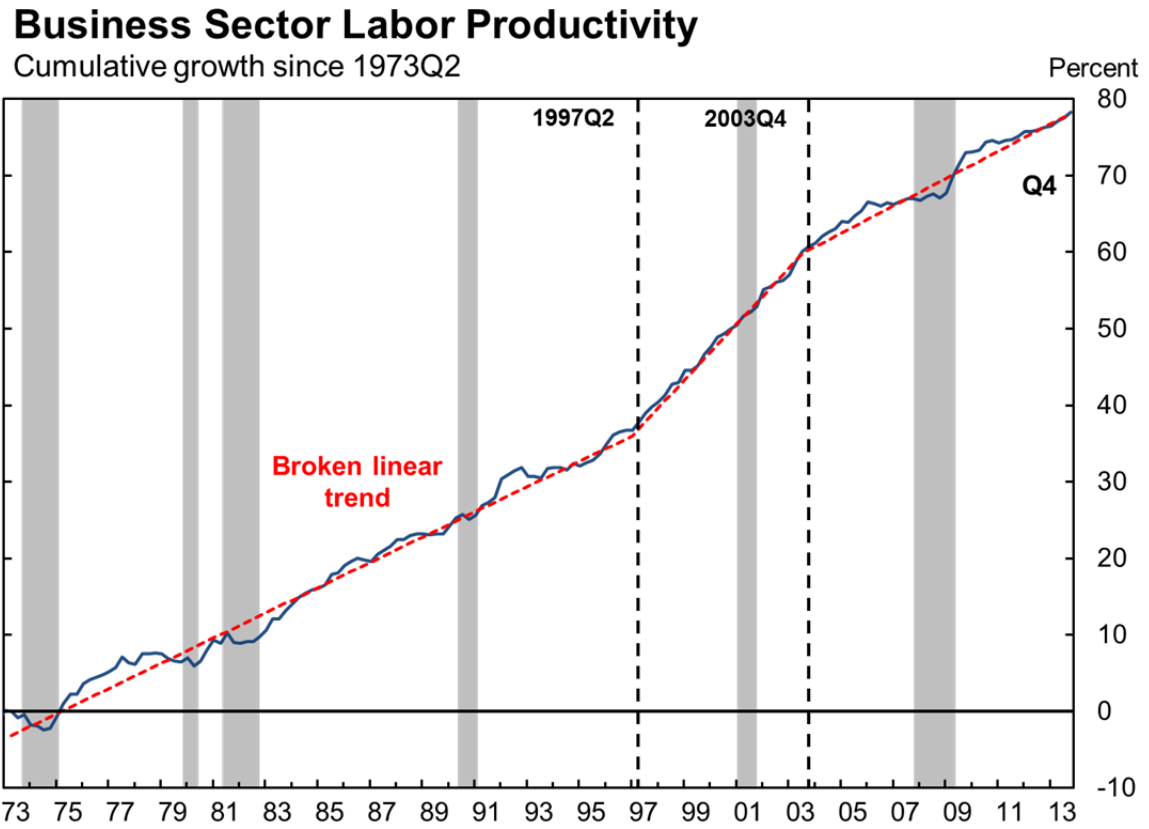
Figure 2
Potential output and its pre-crisis trend

(The CBO figures are updated. The Fernald ones are not.)



Notes: Figure compares actual real GDP to the CBO's projections for potential prior to the Great Recession (the 2007 line) to CBO's February 2014 projection, as well as the author's calculation of potential following the CBO methodology but with different assumptions about deviations of factor utilization from steady-state. The "2007" estimates are from January 2008, but are based on data through 2007:Q3. These estimates have been rescaled to 2009\$ keep the 2006:Q4 output gap at its then-estimated level.

Figure 3
Labor productivity since 1973

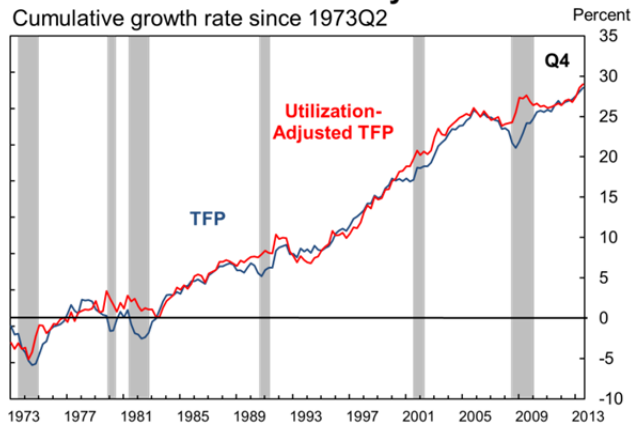


Source: BLS and Fernald (2012)

Figure 4
Evolution of Key Growth-Accounting Variables

A. Total Factor Productivity

Cumulative growth rate since 1973Q2



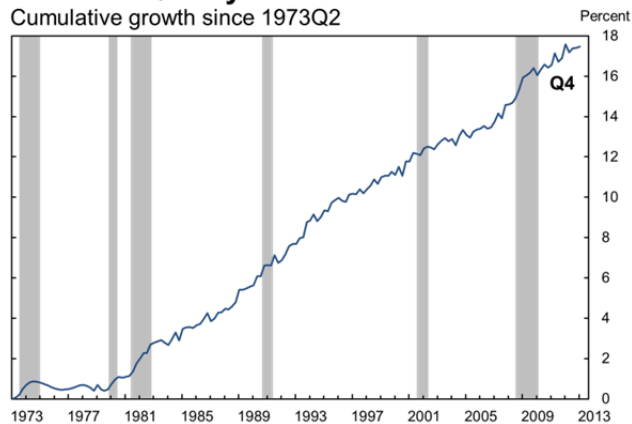
B. Quality-Adjusted Capital-Labor Ratio

Cumulative growth since 1973Q2



C. Labor Quality

Cumulative growth since 1973Q2



D. Utilization

Cumulative growth since 1973Q2



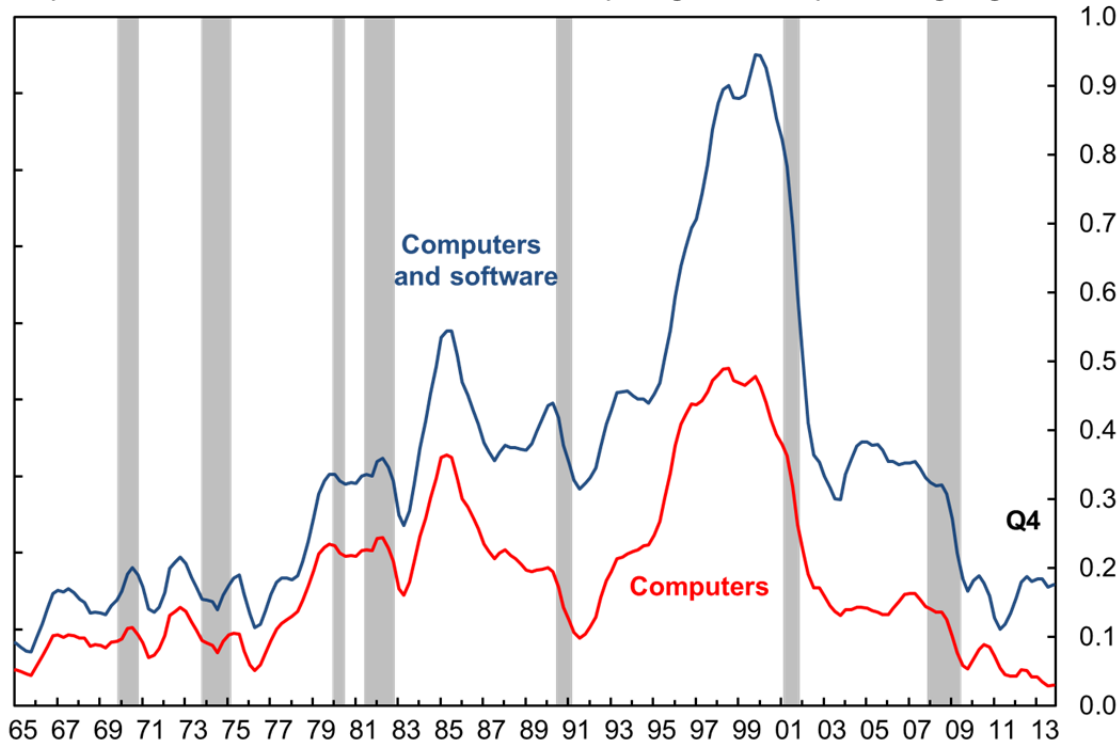
Notes: Level of utilization is set to zero in 1987:Q4, roughly consistent with the CBO's estimate that the output gap was close to zero at that point.

Source: Fernald (2012).

Figure 5
Basu, Fernald, Oulton, and Srinivasan (2003) proxy for intangible investment

Share-Weighted Growth in Computers and Software

Capital's cost share of value added times capital growth, 4-qtr moving avg. Percent

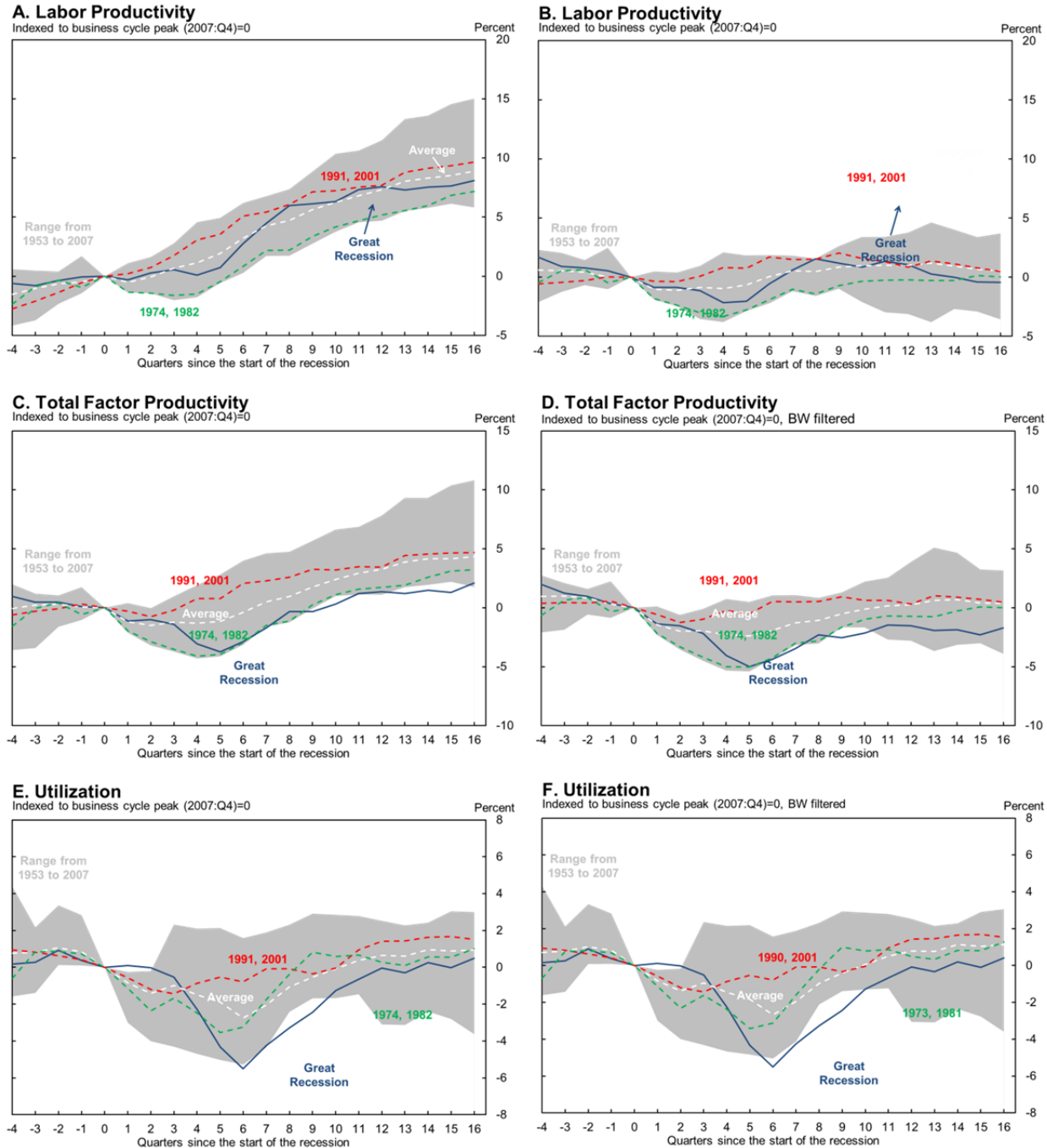


Source: BEA and Fernald (2012)

Figure 6
Comparing recessions (indexed to peak)

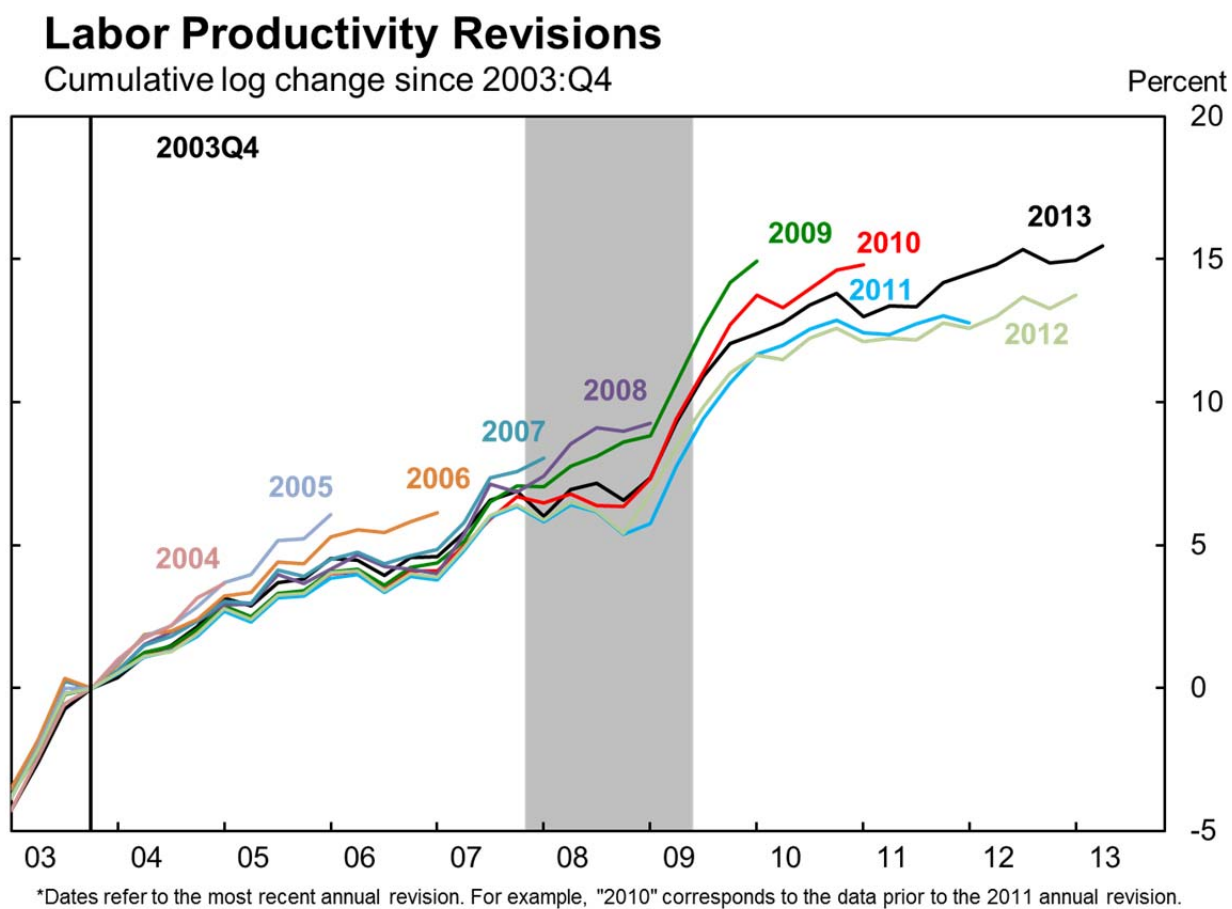
Raw Data

Local Means Removed



Note: For each plot, quarter 0 is the NBER business-cycle peak which, for the Great Recession, corresponds to 2007:Q4. The shaded regions show the range of previous recessions since 1953. The left-hand column shows raw data (in levels), the right-hand column is filtered with a biweight kernel with bandwidth 40 quarters. Source is Fernald (2012).

Figure 7
Labor productivity revisions

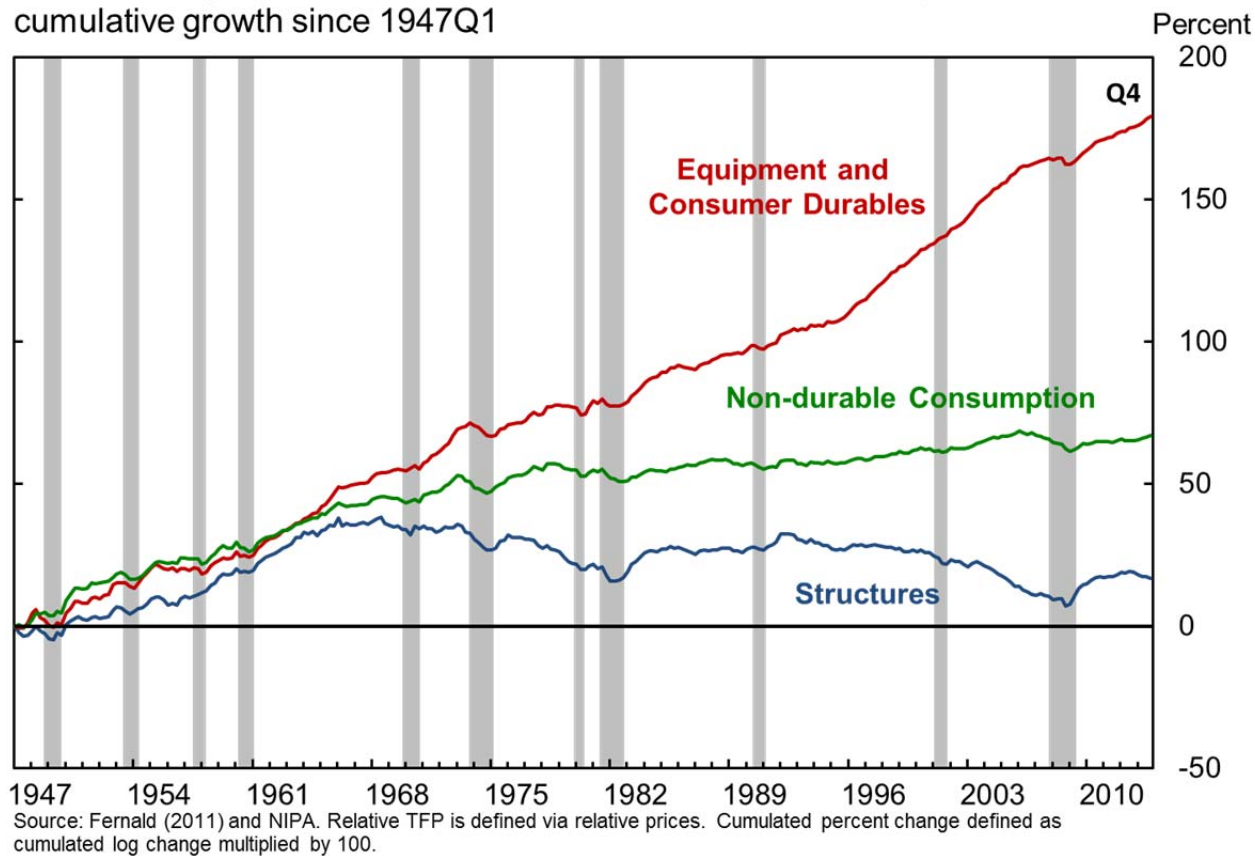


Source: BLS Productivity and Cost releases, and Haver. Output in these series correspond to the expenditure side of the national accounts rather than the average of the expenditure and income sides.

Figure 8
TFP by final use sector

TFP in Equipment, Structures and Consumption

cumulative growth since 1947Q1



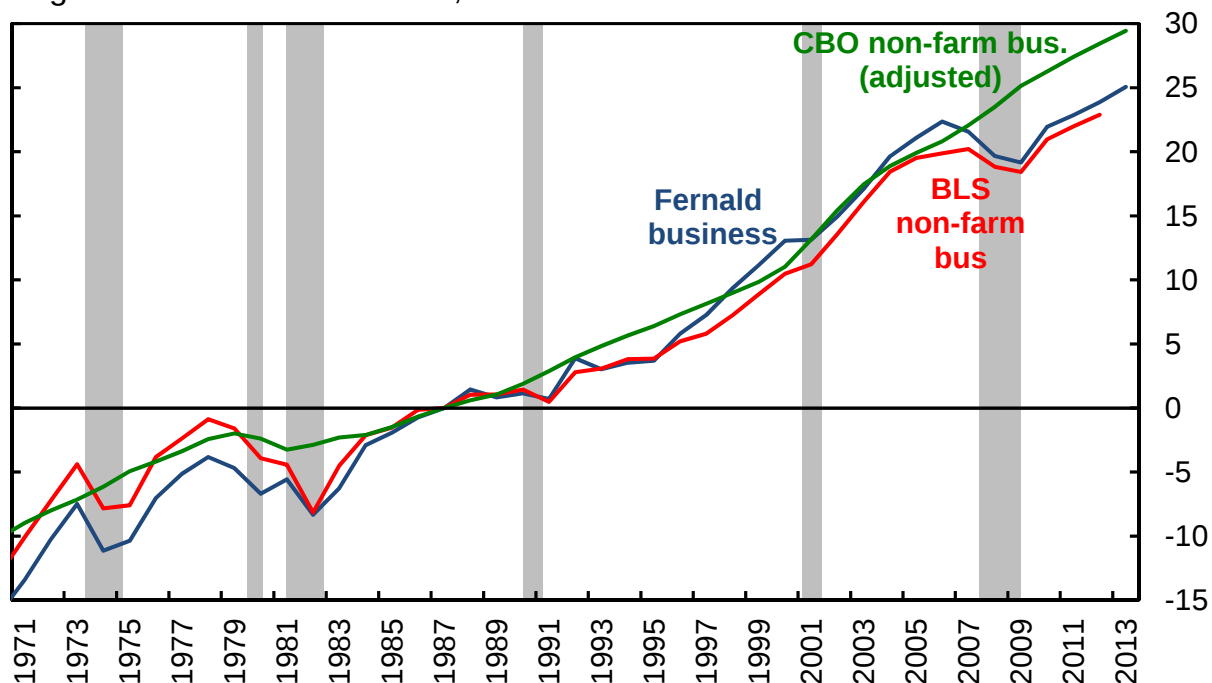
Source: Fernald (2012), BEA (for relative prices), and author's calculations.

Figure 9
CBO, BLS, and Fernald estimates of TFP

Comparative Levels of TFP

Log deviation from 1987 level, times 100

Percent, 1987=0



Source: CBO TFP for non-farm business is from Haver, and adjusts for trend labor quality and for differences in capital growth relative to BLS MFP. Trend labor quality is estimated using a biweight filter (with parameter of 10 years), so the mean adjustment of 0.33 percent per year matches the BLS MFP data prior to 2010. Differences in capital growth are relatively small for the full sample.