MISMEASUREMENT OF TFP AND THE MYTH OF PRODUCTIVITY SHOCKS

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Abstract

Changes in measured total factor productivity (TFP) are correlated with changes in real GDP. However, this may be due to measurement error that is correlated with business cycle or true cycles in unobservable true productivity. Using a labor productivity series based on manufacturing workers from 1899 to the present, I am able to address this issue of measurement error. This results in an acyclical productivity series, while measured TFP remains strongly cyclical. While a simulated real business cycle model for the Great Depression with measured TFP shocks matches changes in Real GDP data during the Depression well, the simulation with my alternative productivity series sees no decline in GDP (and even a counterfactual increase in the early 1930s). These findings cast doubt on the importance of productivity shocks in explaining business cycles.

Keywords: Total Factor Productivity, Labor Productivity, Real Business Cycle Models, Labor Productivity in Manufacturing

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1 Introduction

Measured productivity is correlated with the business cycle, but whether actual productivity fluctuations in a meaningful way at business cycles frequencies remains an open question. Changes in total factor productivity (TFP) are often taken to be a primary impulse of modern business cycle theory dating back to seminal contributions of Kydland and Prescott (1982) and Long and Plosser (1983) through to the present (Hansen and Ohanian, 2016).[1] However, skepticism about the existence, importance, and relevance of fluctuations in productivity for business cycles arose almost immediately (Mankiw, 1989; Summers, 2002). While there has been renewed focus in modern macroeconomics on models focusing on the importance of nominal rigidities or financial frictions, productivity shocks remain a primary source of business cycle fluctuations even in workhorse New Keynesian DSGE models (Smets and Wouters, 2003; Ireland, 2004).

Several previous studies have already shown serious weaknesses in the Technology-driven Real Business Cycle (RBC) paradigm. For example, Gali (1999), Basu et al. (2006), and Shea (1999) all find that productivity shocks are contractionary, leading to a decline in employment on impact, which is the opposite of the theoretical prediction of technology-driven RBC models. Angeletos et al. (2018) find that TFP shocks are uninformative for business cycle fluctuations. Bai et al. (2012) show that demand shocks can generate fluctuation in measured TFP in the absence of any true productivity shocks. This paper takes a different approach, and uses an alternative measure of productivity to see if the cyclicality of measured productivity is robust to alternative measures of productivity. I find that an alternative measure of productivity is acyclical, with a near zero correlation between output changes and productivity changes in the past century. This casts doubt on the important of productivity shocks in explaining business cycle fluctuations.

[1] One can find related theories dating at least as far back as Slutzky (1937).

The standard method to measure produtivity is the Solow residual, which assigns any change in output not explained by changes in factor inputs to changes in total factor productivity (Solow, 1957). Solow himself was aware of some of the shortcomings of this method for measuring underlying productivity, especially relating to issues in capital utilization. As the capital services from a given capital stock can vary based on product demand over the business cycle, capital will appear to become less productive in recessions though this reflects a lower utilization of a given capital stock and not a true decline in productivity. To address this issue, Solow assumed that capital underutilization was proportional to labor underemployment, proxied by the unemployment rate (Solow, 1957, p. 314). The reduces the cyclicality of productivity significantly relative to the unadjusted Solow residual as can be seen in Figure 1.[2] Okun (1962) also uses a similar method by assuming that capital and labor are utilized at normal rates whenever the unemployment rate corresponding to potential GDP prevails. This was just the start of a literature that would propose a multitude of explanations for procyclical productivity.[3]

Solow discusses the phenomenon of labor hoarding extensively. This occurs when firms do not fire workers during a downturn, but instead keep them partially or fully idle. While this is costly, this practice allows production to restart as soon as sales recover after the recession ends. With labor hoarding, measured labor input falls more slowly than output during downturns, which then will gives the appearance of a decline in productivity growth. Indeed, while Kydland and Prescott (1991) find that variation in the Solow residual can explain 70% of postwar business cycles, Eichenbaum (1991) shows that once labor hoarding is controlled for the explanatory power of productivity declines by 50%. Moreover, lags in

[2]Solow recognized that this method is "undoubtedly wrong" as it was a crude assumption (Solow, 1957, p. 314).

[3]Many of the modern explanations for measured procyclical productivity such as variable factor utilization, as well as increasing returns to scale and overhead labor, where discussed widely as early as the 1960s, as Kuh (1965) demonstrates. See Gordon and Solow (2003) for a clear and comprehensive exposition of the multitude of theories that have been developed in the meanwhile.

the realization by firms that a recession is imminent means that employment growth could continue even after output growth starts to slow, which Gordon (1979) labels the "end-of-expansion" effect. This causes measured productivity to plunge at the end of an expansion just as the downturn begins. Sbordone (1997) looks precifically at the manufacturing sector, and finds that procyclical productivity is due to cyclicality in the utilization of labor and not due to technological externalities.

Other explanations include a variable utilization rate of capital, which will similarly bias TFP over the business cycle (Jorgenson and Griliches, 1967; Burnside et al., 1995).[4] Evans (1992) also took issue with the exogeneity of changes in productivity, as money, government spending, and interest rates all Granger cause the Solow residual, and changes in aggregate demand explain much of the variation in the Solow residual, consistent with causality running from the business cycle to measured productivity and not the reverse. Hall (1988) and Hall (1989) argue for the importance of market power or increasing returns as explaining procyclical TFP. If firms have market power, then a small increase in output and product demand would allow them to produce more units with the same fixed cost, which appears as an increase in factor productivity.[5] Moreover, Hall finds that sectors that benefit from military spending see large increases in measured productivity when demand increases, while productivity should be invariant to demand shocks.

To account for these factors affecting the measurement of productivity, a combination of papers written by a combination of Basu, Fernald, and Kimball as co-authors have con-

[4]Barro and King (1984) discuss the benefits and costs to using variable capacity utility versus productivity shocks in modeling business cycles. Jorgenson and Griliches (1967) also attempt to proxying for capital services with the utilization rates of electric motors in manufacturing, rather than using the Okun-Solow unemployment adjustment. Basu (1996) uses materials input usage to control for utilization rates, as material inputs do not have variable utilization, and finds that factor utilization is highly cyclical, returns to scale are nearly constant, and productivity is almost uncorrelated with output or hours. Similarly, Burnside et al. (1995) use electrical usage to proxy for capital utilization and find significant variability in utilization rates over the business cycle.

[5]Hall shows that under perfect competition when prices are flexible, labor hoarding does not affect the cyclicality of productivity, though Rotemberg and Summers (1990) show that price inflexibility makes labor hoarding generate procyclical productivity again.

structed an increasingly sophisticated measure of productivity that adjust for factors like capacity utilization, labor hoarding, increasing returns to scale and the other factors discussed above.[6] Fernald (2012) outlined a measure of TFP that provides a correction for potential sources of error or bias. Fernald applies growth-accounting methods to factor inputs and applies utilization adjustments to consumption and investment to account for investment-specific productivity growth. Most importantly, Fernald adjusts for variation in factor utilization including labor utilization and the workweek of capital. More recent studies have looked at the cyclicality of productivity using disaggregated data of firm productivity. Kehrig (2015) find that the dispersion of productivity across firms rises in recessions.

The period in United States history with the largest decline in the Solow residual is the Great Depression. Early attempts to provide a real theory of the Depression generally avoided discussing productivity productivity, e.g. Lucas and Rapping (1972). For many RBC theorists, the Depression was of a different nature than postwar business cycles and thus productivity-based theories were not applicable to this episode.[7] From 1929-1933, TFP fell by 18%, and so would require a significant degree of technological regress that is difficult to explain (Ohanian, 2001; Cole and Ohanian, 2004). However, this viewpoint evolved over time, and now there is a sizeable RBC literature on the Depression, e.g.Kehoe and Prescott (2002). After the trough in 1933, measured TFP recovers fairly rapidly. By 1936, TFP is close to trend, though output did not return to trend until the early 1940s (Cole and Ohanian, 1999).

To explain this sharp decline in productivity, Ziebarth (2011) argues that the banking failures of the early 1930s disrupted credit markets, which lead to a sharp rise in misallocation. Ohanian (2001) argues that declines in organizational capital due to the economic disrup-

[6] See Basu (1996); Basu and Kimball (1997); Basu and Fernald (1997, 2000); Basu et al. (2001); Basu and Fernald (2002); Basu et al. (2006, 2010); Fernald (2012).

[7] Prescott (2002) called this aversion to applying productivity-based RBC models to the Great Depression a "taboo."

tions of the Depression largely explain this decline. Ohanian (2001) considers and largely dismisses the labor hoarding argument, though this is just one factor of many that could cause mismeasurement of TFP in the 1930s. Bernanke and Parkinson (1991) finds that most interwar manufacturing industries had short-run increasing returns to scale, which would generate procyclicality in measured productivity without implying anything about the cyclicality of true productivity. Inklaar et al. (2011) finds significant evidence of labor and capital hoarding which generate increasing returns, and that productivity shocks do not affect hours worked which is inconsistent with the predicted effect of exogenous productivity shocks. My findings are similar, in that once we eliminate some sources of mismeasurement from productivity, productivity is essentially acyclical. This is true even during the Depression which saw enormous declines in measured TFP. To this end, I simulate a simple RBC model with productivity shocks, to see how closely linked measured TFP and my proposed series, which eliminates some sources of mismeasurement, fit the data. The results are starkly different, with the manufacturing worker productivity series predicting no decline in GDP in the Depression or even slightly higher output. Moreover, using this alternate series for productivity does not fix the ways that the predictions of an RBC model deviate from the data.

Sims (1974) uses production worker manhours in manufacturing to examine lags in the response of changes in manhours to changes in manufacturing output. This paper uses the same measure of productivity: manufacturing output divided by total production worker manhours. This allows for several factors that could cause the mismeasurement of productivity to be eliminated. Capital often has a high degree of fixity and thus utilization varies. Moreover, capital is a fixed cost which will generate short-run increasing returns, so considering labor productivity mitigates that this problem as well. The problem of overhead labor such as managers, accountants, salesmen, and so on, who are a relatively fixed labor input, is also mitigated by only considering production workers, who are a variable labor input. This then reduces the potential for variable utilization rates of all inputs, which allows for more accurate measurement of productivity over the business cycle. Overall, we can see that this alternative mitigates the bulk of the potential sources of mismeasurement outlined above. Some factors still remain that could cause issues with mismeasurement even for this alternative measure of productivity. For example, variable labor utilization rates is still possible with production workers, as they could be reassigned during downturns to conduct maintenance or do other tasks which do not immediately produce output. However, as we will see, labor utilization does not appear to be a significant driver of mismeasurement.

We can measure productivity using manufacturing workers long before we have official data to construct a TFP series. This allows both for a longer time series as well as the possibility to consider other episodes, including the Great Depression. The data to construct manufacturing worker productivity are available back to 1919 monthly, and back to 1899 annually. Even in the present, there is no monthly series for TFP. Quarterly data is the highest frequency available. While one reason manufacturing data is used is because a series is available for manufacturing workers and because manufacturing data provide the longest time series available, there are some benefits beyond those of convenience. The manufacturing sector has output which is straightforward to value as compared with the service sector. Productivity is more straightforward to quantify in manufacturing as well. But the most important reason this series is used is that the manufacturing worker productivity series will eliminate almost all of the cyclical biases in TFP, which will result in an acyclical productivity series. Shapiro (1993) found that, once the workweek of capital in manufacturing is accounted for, productivity is acyclical, which is similar to the conclusion of this paper. (Field, 2003, p. 177-179) argued that procyclical productivity was primarily due to variation in capital utilization, which finds support here as well.

2 Data

The primary measure considered in this paper is a measure of labor productivity for employees in manufacturing. The reason for the focus on manufacturing is to get broader historical coverage and because data on manufacturing are more readily available, even in the postwar period. Moreover, the manufacturing sector is both a highly cyclical industry as well as one which has seen enormous productivity growth since the Industrial Revolution, so if variation in productivity growth should matter somewhere, it should matter in the manufacturing sector. While the data is collect for slightly different groups of workers over the period of over a century considered here, the result are relatively similar throughout. The measure of the productivity of manufacturing worker productivity is constructed as a ratio of manufacturing output to total manufacturing manhours in manufacturing. The construction of this key variable is straightforward: an index of manufacturing output is divided by an index of manufacturing worker manhours. The manufacturing worker manhour index itself is constructed by multiplying weekly hours worked in manufacturing by an index of manufacturing worker employment. This equation can be seen in Equations 1 and 2.[8]

$$\text{Worker Manhours / Week} * \text{Total Manufacturing Employment} = \text{Manufacturing Manhours Index} \tag{1}$$

$$\text{Manufacturing Worker Productivity} = \frac{\text{Total Manufacturing Output}}{\text{Manufacturing Manhours Index}} \tag{2}$$

These monthly data are constructed based on roughly two periods: modern and historical. The data for the historical period is not seasonally adjusted, while that of the modern

[8]While one would need to multiply weekly hours by weeks worked per year to have a direct measure of manhours, this would require an unavailable series on weeks worked per year in manufacturing. Since we are interested in changes over time and not the levels themselves, this manhours index is sufficient for our purposes.

period is seasonally adjusted. Seasonality can be significant in Solow residuals,[9] but seasonal adjustment can distort the underlying series (Wright, 2013) and this study is concerned with cyclicality and not seasonality. The historical series covers the period 1920-1944 and the modern series covers the period 1939-2015. The overlapping years of 1939-1944 allows for the two data sources to be cross-checked, and the two series do indeed conform closely to one another during these years.

The view that exogeneous productivity changes can generate business cycle behavior would find support in Figure 2a, which shows quarterly percent changes in the Solow Residual and quarterly percent changes in Real GDP since 1947. These series move together closely. However, critics would argue that this relationship is driven by reverse causality, where quarterly changes in output generate quarterly changes in measured productivity due to the reasons outlined in the previous section. These critics would not find support from Figure 2b, which displays the manufacturing worker productivity measure, which is essentially acyclical and whose movements do not correspond with change in output.

The labor productivity measure considered here, output per production worker hour in manufacturing, should follow roughly the same trend as TFP. However, there are some potential reasons why manufacturing worker productivity could grow at a different rate from unobserved, true productivity. All labor productivity measures will tend to grow faster than aggregate productivity due to the tendency for modern economies to experience capital deepening. Another is that the share of manufacturing in total value added could vary over time. The share of production and nonsupervisory workers relative to supervisory workers or capital in production could change. Human capital intensities could change if production workers gain skills slower or faster than the supervisory workers. Labor quality could also

[9] For example, the Christmas season in the United States sees a sharp increase in measured TFP as capacity utilization is increased to boost produce in advance of demand for Christmas purchases. The following period (the first quarter) see a corresponding decrease in capacity utilization and measured TFP after the Christmas season ends. This effect is stripped out of seasonally adjusted data so is not widely known (Braun and Evans, 1998).

change, for example if low quality workers were fired during recessions, which would make the remaining production workers more productive. Labor hoarding occurs when workers are kept employed during recessions so employers have the option to ramp up production once sales growth accelerates in the early phases of recovery. Labor hoarding would also introduce a wedge between measured productivity and underlying productivity. As labor hoarding would be most salient for production workers (as they work directly in production of goods), this bias could potentially be very severe. A similar argument could be made for capital hoarding.

Overhead labor, such as teams of engineers, managers, or accountants, are also inflexible over business cycles, and this overhead labor can generate bias in TFP. This effect would be reduced in a productivity measure based on production worker hours as this category is not based on the manhours of many types of overhead labor (Oi, 1962). There could also be overhead capital such as structures which would be less flexible than other types of capital like equipment. There could also be variability in capital utilization, where capital is idled to reduce depreciation or to economize on labor costs. Similarly, labor could be utilized more intensively during downturns, for example using production workers to clean factories during times of slow sales, which would bias the manufacturing worker productivity measure as well as TFP. The primary factors that will be focused on here are capital utilization and overhead labor, as these factors will not affect the measurement of manufacturing worker productivity while TFP measurement would be affected by these sources of bias. If manufacturing worker productivity behaves differently over the business cycle than TFP, then these factors must be relevant in generating biases in measuring productivity. The comparison of the cyclical mismeasurement factors for both productivity measures are outlined in Table 2.

Despite all these caveats, manufacturing worker productivity appears to have similar trend movements as other measure of productivity, such as the Solow residual. As most of the sources of divergence between the two measures, such as the share of manufacturing in output, are relatively low frequency, this is perhaps unsurprising. So if underlying variation in productivity, driven by factors like technological change, saw large changes at business cycles frequencies, this should appear as a change in both TFP and in labor productivity, even as measured by hours worked by production worker in manufacturing. That these two series do not line up points to significant issues of mismeasurement in TFP which, when corrected, yield a time-series driven primarily by low-frequency movements in trend and few changes at business cycle frequencies.

An annual series is derived from the analysis of Fabricant (1940, 1942), who compiled a series on manufacturing employment and output from 1899-1939 using information from the biennial Census of Manufactures. The first step is to construct an index of manufacturing man-hours by multiplying hours worked per week by manufacturing wage earners by an index of manufacturing employment. Wage earners is a similar concept as production and nonsupervisory workers, and includes jobs that generally require less education than salaried employees and management. One of the goals of this exercise is eliminate mismeasurement arising from overhead labor that doesn't vary much over the business cycle. As this overhead labor will tend to be salaried, focusing on wage earners will be an effective way to strip out this source of mismeasurement. To obtain the manufacturing hours productivity measure, manufacturing output is divided by the manufacturing hours index. This series is presented in Figure 3a, where the observation are distinguished by recession or non-recessionary (boom) years by color and shape. There is no tendency for recessionary years to see lower productivity as measure by this manufacturing worker hour measure, or for boom years to see higher productivity, as roughly as many points lie above the trend line as below. Kendrick (1961) compiles a series for labor productivity using his measure of real output divided by his measure of labor input, plotted in 3b. Here the large blue circles representing recession years, and the small red circles representing non-recession years. A Hodrick-Prescott trend is estimated with smoothing paramteter 6.25 as the data is plotted from 1890 to 1941 with varying trend growth rates. The results are similar for labor productivity as for manufacturing worker productivity, with little tendency for labor productivity to be above trend during booms or below trend in recessions. Even back to the 19th century, productivity is acyclical.

There are two monthly series which can be constructed. The first covers the period 1920-1944, and is based on the Federal Reserve's series on industrial production in manufacturing, production and nonsupervisory worker employment from the Bureau of Labor Statistics (BLS), and average hours worked from the Conference Board. The second covers the period 1939-2014 and is based on the Federal Reserve's series on industrial production in manufacturing, production and nonsupervisory employees in manufacturing from the BLS, and average weekly hours of production and nonsupervisory employees in manufacturing also from the BLS establishment survey.[10] There is overlap between the series, but the first series is historical data which does not have seasonal adjustment available, while the modern series is seasonally adjusted when available.

For each, average weekly hours of production workers is multiplied by production worker employment to form the production worker hours index. Then, manufacturing output is divided by the hours worked index to form the manufacturing worker productivity measure. The hours index and the output index for 1920-1944 are graphed in Figure 5a. For 1939-2014, the hours and output series are displayed in Figure 5b. Output grows much more quickly than hours, as productivity is rising. While it is hard to see the stability of productivity growth on this figure, Figures 6a and 6b make this more clear. Despite large changes in manufacturing output at a monthly frequency, the manufacturing worker productivity measure displays

[10]The BLS defines Nonsupervisory Employees as: "those individuals in private, service-providing industries who are not above the working-supervisor level. This group includes individuals such as office and clerical workers, repairers, salespersons, operators, drivers, physicians, lawyers, accountants, nurses, social workers, research aides, teachers, drafters, photographers, beauticians, musicians, restaurant workers, custodial workers, attendants, line installers and repairers, laborers, janitors, guards, and other employees at similar occupational levels whose services are closely associated with those of the employees listed."

Table 1: Correlation of HP-filtered Productivity Measure with HP-filtered Real GDP

Period	Solow Residual	Manufacturing Worker Productivity	Labor Productivity
1921-1943	0.88	-0.70	0.22
1921-29,1935-1941	0.87	**0.01**	-0.01
1947Q2-2020Q1	0.70	**0.02**	0.41
1984Q1-2020Q1	0.60	**0.01**	-0.05

Notes: Variables detrended using Hodrick-Prescott filter, with smoothing Parameter of 6.25 (annual) or 1600 (quarterly).

almost no cyclicality. While the manufacturing worker productivity series displays little cyclicality, it has similarly trends as the Solow residual series, as can be seen in Figure 1 for the historical period and in Figure 4 for the modern period.[11] To see the lack of cyclicality in the manufacturing worker measure more clearly, a Hodrick-Prescott (HP) trend is estimated, using the parameters suggested in Ravn and Uhlig (2002) (Hodrick and Prescott, 1997).[12] Observations during recessions (blue, squares) are distinguished from observations during booms (red, triangles) are displayed in displayed in Figures 7a and 7b. There is no tendency for recessions to see productivity below trend or for booms to see productivity above trend.

Simple correlations between Hodrick-Prescott detrended levels of these variables reveals similar patterns as can be seen in Table 1. For the historical period 1921-1943, the correlation between HP-filtered Real GDP and the Solow Residual is 0.88, a close correlation. The correlation between Real GDP and Manufacturing Worker Productivity is -0.70. This negative result is surprising, and will be analyzed in more depth later in this paper. The correlation of HP-filtered Real GDP and Labor Productivity is 0.22, a weak but not negative correlation. As found earlier, labor productivity is much less cyclical than measured TFP

[11]Recall that the main difference between these two series will be the degree of capital deepening, which will augment labor productivity but not TFP.

[12]The HP Filter is used as it is fairly standard in the macroeconomics literature. Hamilton (2018) has proposed an alternative where the trend is constructed using a forecast based on the four previous observations. This trend was attempted, but the trend is so close to the time-series that there was essentially no cycle to speak of.

but is not acyclical in all periods. Removing the downturn phase of the Depression and the wartime period eliminates these anomalies. Limiting ourselves to the periods 1921-1929 and 1935-1941, the correlation for the Solow Residual is 0.87, a similarly strong correlation as for the entire interwar period. The correlation between Manufacturing Worker Productivity and Real GDP is 0.01. For overall Labor Productivity, we find a correlation of -0.01. As both correlations are essentially zero, we can say productivity is acyclical.

Similar results are obtained for the modern quarterly series from 1947Q2 to 2020Q1. Here the correlation between HP-filtered Solow Residual and Real GDP is 0.80, while for Manufacturing Worker Productivity the correlation is 0.02, again very close to zero. For Labor Productivity, I find a correlation of 0.41, much lower correlation than for TFP but non-zero here. However we can restrict the sample to be only from 1984Q1-2020Q1, corresponding to the period since the Great Moderation. Previous work had found that since the 1980s aggregate labor productivity is no longer cyclical in the United States (Gali and van Rens, 2008; Berger, 2012) or even countercyclical (Fernald and Wang, 2016). We find similar results for HP-filtered Labor Productivity, as the correlation with HP-filtered Real GDP is -0.05, a mildly countercyclical result. Manufacturing Worker Productivity is still acyclical, with a correlation of 0.01, and the correlation of HP-filtered measured TFP is reduced but remains important at 0.60.

Hazarding a guess for why labor productivity stopped being procyclical in the 1980s is beyond the scope of this paper.[13] However, aggregate output volatility declines sharply during the 1980s, a phenomenon often call the Great Moderation (Stiroh, 2009). This is consistent with reduced volatility of the American business cycles leading to reduced volatility

[13] McGrattan and Prescott (2010) and McGrattan and Prescott (2012) argue that the lack of procyclical labor productivity can be resolved by assuming that intangible capital investment is mismeasured in the national accounts, though given the intangible nature of this capital there is no direct evidence to support their hypothesis. Wang (2014) finds that the evidence does not support the McGrattan-Prescott hypothesis. Moreover, she finds that declining cyclicality of labor productivity is related to an increase in the share of the service industry that is less capital intensive and thus less subject to some sources of mismeasurement steming from variable capital utilization and overhead capital.

of the mismeasurement of TFP stemming from the business cycle. The Great Moderation of output growth was also a great moderation of mismeasurement. Indeed, a model with credit frictions and financial frictions can explain this decline in labor productivity procyclicality since the 1980s through a channel of declining labor demand Yépez (2017).

These correlations are visualized using scatterplots in Figures 8a, 8b, and 9. Here the reader can see scatterplots and lines of best fit for the historical and modern data series for the cyclical component of the two productivity measures. The line of best fit for manufacturing worker productivity is close to completely flat, consistent with this measure of productivity being acyclical. Figures 2a and 2b are another way to view this relationship, by simply plotting quarterly changes in both measures with quarterly changes in real GDP. While the Solow Residual series move closely with the real GDP series, the quarterly changes in manufacturing worker productivity are close to zero and do not comove with changes in real GDP. This result again suggests that the procyclicality of TFP is based on mismeasurement, as alternate measures of productivity are uncorrelated with the business cycle.

3 Real Wages

In a standard neoclassical growth model with a Cobb-Douglass production function and perfect competition, real wages should grow at the same rate as productivity, whether measured by labor productivity or TFP. Real wages are available for the 1920-1947 period and for the 1939-2016 period, derived by dividing hourly nominal earnings for manufacturing workers by the consumer price index. In keeping with the findings of the Keynes-Dunlap-Tarshis debate (Dunlop, 1938; Tarshis, 1939; Keynes, 1939) and more recent findings by Bils (1985), real wages are essentially acyclical, with perhaps mild pro-cyclicality. This is also consistent with little cyclicality in productivity, as there should be a strong relationship between productivity and marginal labor product, and a strong relationship between marginal labor product and real wages.

Figure 10a shows the real wage series for the 1920-1947 period, with recessionary periods and booms distinguished, alongside the HP trend for the real wage series. As for manufacturing worker productivity, there is no clear cyclicality in real wages for this period. Figure 10b displays the real wage series for the 1939-2016 period, with recessionary periods and booms distinguished, alongside the HP-filtered real wages series. While there is some secular deviations between wage growth and productivity growth since roughly the 1970s, there is still no clear cyclicality, even in the modern period. Reducing the cyclicality of productivity means that the predictions of a neoclassical model of a close relationship between labor productivity and real wages now fits the data better than using a TFP measure of productivity.

4 Great Depression Simulation

If exogeneous changes in productivity are of a smaller magnitude and less correlated with output changes than the Solow residual would indicate, then simulated economies subject to productivity shocks alone will not be able to match the business cycle facts well. To test this, a simple RBC models is solved and simulated under two alternative productivity series: TFP shocks and changes in manufacturing worker productivity. The model is based on King et al. (1988, p. 215-218).[14] The model is chosen for simplicity, as it yields a closed form solution. The shocks here are the observed series for the Solow residual, based on the calculations of Kendrick (1961),[15] and the manufacturing worker productivity measure outlined above. The case of the Great Depression period is considered specifically, as this period was one which saw large changes in both output and measured productivity. If there was a time that the RBC model would predict a large downturn or recession, it should have

[14] I also simulated a similar, but more complex, model based on King and Rebelo (1999), but the results were not qualitatively different so, in the interests of brevity, the simpler model is presented.

[15] The data are derived from Appendix A of Kendrick (1961), in particular Table A-XXIII which contains data for the Private Nonfarm Domestic Economy.

been during the Great Depression.

The simulation results appear in Figure 11. We can see that the RBC model simulation for TFP fits the course of the Depression fairly well, though it does miss the 1937-1938 recession and does not explain all of the output movements. Thus it is perhaps not surprising that this type of explanation might be appealing for the Great Depression, given considerable explanatory power with a parsimonious model. However, already when we use Kendrick (1961)'s measure of overall labor productivity (output per unit of labor input), we see that the magnitudes are greatly reduced, as any labor productivity measure will reduce the biases introduced by procyclical capital utilization. However, by using the manufacturing worker productivity series, we can see that the cyclical is reduced to near zero, and even with the large upheavals of the Great Depression, a model based on these productivity shocks explains almost none of the variation. Moreover, not only is the manufacturing worker productivity measure essentially acyclical, but this measure is also not even acyclical for the entire this period. Productivity as measured by output produced per production worker manhour is actually *countercyclical* during the 1929-1933 Great Collapse period when output declines at a rapid rate. This counterintuitive result merits some explanation.

5 Depression Discussion

Field (2003) argued that productivity growth from 1929-1941 was at a record level, and productivity growth was even higher during this period than during the Second World War which immediately followed. While there were several factors that generate sluggish productivity growth during downturns, the Depression also saw some sectors, like railroads, where the downturn induced organizational changes and other efficiencies which likely offset the reduction in capital accumulation and technological implementation that occurs during a downturn.[16] While the manufacturing worker productivity does reduce some aspects of mismeasurement, it does introduce some other issues. This measure eliminates the mismeasurement problem of variable capital utilization do all labor productivity measures. However, an investment in new capital, once undertaken, is largely irreversible (Ramey and Shapiro, 2001). This means that during a severe downturn when gross investment falls to near zero (as it did during the Great Depression) and when net investment is negative due to depreciation, then capital is more abundant relative to both output and labor, despite the desire of firms to reduce capital input if unconstrained. As a result, the amount of capital available to each worker rises in a severe downturn, providing a form of cyclical capital deepening. This tends to increase labor productivity, though measured total factor productivity, which will be mismeasured due to capital utilization, will fall during a severe downturn. Each production worker hour is more productive, as there are fewer workers relative to the capital stock. So the underlying productivity trends, driven by steady technical change, are still likely acyclical during this period, as manufacturing worker productivity suffers from its own mismeasurement issues during deep downturns.

One explanation for cyclical variability in both TFP, labor productivity, especially manufacturing worker productivity, is labor hoarding. This effect can be found throughout the literature. However, given that manufacturing worker productivity is acyclical, labor hoarding must not be very important. While overhead labor is clearly important, as overall labor productivity is more cyclical than manufacturing worker productivity, labor hoarding appears to matter little, if at all. Indeed, during the Great Depression where labor hoarding might have been significant given the common expectations of a "recovery around the corner" (Mathy and Stekler, 2017), we see countercylical movements in measure manufacturing worker productivity, while a labor hoarding model would predict procyclical movements in manufacturing worker productivity. On the other hand, the other sources of productivity

[16]See Chapters 1 and 13 of Field (2003).

mismeasurement that manufacturing worker productivity eliminates, like capital utilization and overhead labor, appear to be salient in generating biases in TFP.

A similar discussion can be had regarding productivity during the Second World War. Standard measures of TFP show large increases during this wartime period, which McGrattan and Ohanian (2010) attribute to government investment in the research and development of new technologies and the introduction of new techniques to wartime production like the assembly line. In the same way as during the Depression where manufacturing worker productivity and the Solow Residual move in different directions, during the mid-1940s TFP rose while manufacturing worker productivity stagnated. This is intuitive considering that during the war period the goal was to maximize output and not profits, and so even low productivity production workers would have been kept on the assembly lines to pump out as many planes, tanks, and guns as possible to win the war. This mindset of production at any cost would imply that all workers with any positive marginal product would be considered for employment, and not just the workers whose revenue productivity exceeded their marginal cost. This effect could only have depressed output per production worker. However, considering that capital and labor were being utilized very intensively,[17] measured TFP shows large increases during the war period, e.g. McGrattan and Ohanian (2010), as these measures do not fully account for the biases introduced by procyclical utilization.

6 Conclusion

While productivity shocks can generate plausible business cycles, care must be taken with interpreting that use of Solow residual as underlying productivity shocks due to potential measurement issues. This paper has used a measure, manufacturing worker productivity,

[17]The steel capacity utilization rate was 19.9% in 1932 at the bottom of the Depression and 98.4% in 1941 and 1943 during the wartime boom (Rogers, 2009, p. 69, 87), citing Moody's *Industrial Manual* and American Iron and Steel Institute, 1930-1940.

which strips out some sources of mismeasurement that are correlated with business fluctuations, particular mismeasurement factors like capital utilization and overhead labor. As a result, productivity grows steadily over time and shows little variation over the business cycle from the 19th century to the present. Once trend productivity growth is eliminated, the correlation between output growth and the manufacturing worker productivity measure is essentially zero. Results from overall labor productivity similarly exhibit weak or no cyclicality (or even countercyclicality in some periods). In simulations of a simple RBC model for the Great Depression, the manufacturing worker productivity series predicts essentially no change in output, a result at odds with the data. Recessions do not tend to see reduced productivity, nor do booms see increased productivity. The observed cyclicality of TFP results from some of the potential sources of measurement which are correlated with the business cycle. The results in this paper suggest that factors like capital utilization and inflexibility of overhead labor like managers are more important factors in explaining this mismeasurement, while factors like labor hoarding or variable labor utilization of non-managerial workers are less important.

Given these issues with mismeasurement of TFP, there has been widespread skepticism in the literature regarding the importance of fluctuations in measured productivity for the business cycle. Not only are episodes of technological regress difficult to identify in historical experience, but technological regress does not appear when using alternative productivity measures to TFP, such as manufacturing worker productivity, are used. While the primary benefit of the manufacturing worker productivity series propsed in this paper elimination of many of the biases that plague TFP, this measure can also be constructed for over a century. The relationship established here applied over five decades before TFP was formalized in the 1950s. Strikingly, the long-run productivity growth trends can also continue unperturbed even during massive macroeconomic crises like the Great Depression. While Kydland and Prescott (1991) find that TFP shocks, as measured by the Solow residual, can explain about

70% of business cycle fluctuations, I find that productivity shocks can explain almost none of the business cycle. It is perhaps time to revisit Francis and Ramey (2005)'s answer in the negative to the question: "Is the Technology-Driven Real Business Cycle Hypothesis Dead?".

References

Angeletos, George-Marios, Fabrice Collard, and Harris Dellas, "Business Cycle Anatomy," Technical Report, National Bureau of Economic Research 2018.

Bai, Yan, Jose-Victor Rios-Rull, and Kjetil Storesletten, "Demand shocks as productivity shocks," *Federal Reserve Board of Minneapolis*, 2012.

Barro, Robert J and Robert G King, "Time-separable preferences and intertemporal-substitution models of business cycles," *The Quarterly Journal of Economics*, 1984, *99* (4), 817–839.

Basu, Susanto, "Procyclical Productivity: Increasing Returns or Cyclical Utilization?," *The Quarterly Journal of Economics*, 1996, *111* (3), 719–751.

_ **and John Fernald**, "Why Is Productivity Procyclical? Why Do We Care?," NBER Working Papers 7940, National Bureau of Economic Research, Inc October 2000.

_ **and John G Fernald**, "Returns to scale in US production: Estimates and implications," *Journal of political economy*, 1997, *105* (2), 249–283.

_ **and** _ , "Aggregate productivity and aggregate technology," *European Economic Review*, 2002, *46* (6), 963–991.

_ **and Miles S Kimball**, "Cyclical productivity with unobserved input variation," Technical Report, National Bureau of Economic Research 1997.

_ **, John Fernald, Jonas Fisher, and Miles Kimball**, "Sector-Specific Technical Change," 2010.

_ **, John G Fernald, and Matthew D Shapiro**, "Productivity growth in the 1990s: technology, utilization, or adjustment?," *Carnegie-Rochester conference series on public policy*, 2001, *55* (1), 117–165.

_ **,** _ **, and Miles S Kimball**, "Are Technology Improvements Contractionary?," *The American Economic Review*, 2006, pp. 1418–1448.

Berger, David, "Countercyclical restructuring and jobless recoveries," *Yale University Manuscript*, 2012.

Bernanke, Ben S and Martin L Parkinson, "Procyclical Labor Productivity and Competing Theories of the Business Cycle: Some Evidence from Interwar US Manufacturing Industries," *Journal of Political Economy*, 1991, pp. 439–459.

Bils, Mark J, "Real wages over the business cycle: evidence from panel data," *Journal of Political economy*, 1985, *93* (4), 666–689.

Braun, R Anton and Charles L Evans, "Seasonal Solow residuals and Christmas: a case for labor hoarding and increasing returns," *Journal of Money, Credit and Banking*, 1998, pp. 306–330.

Burnside, Craig, Martin Eichenbaum, and Sergio Rebelo, "Capital utilization and returns to scale," in "NBER Macroeconomics Annual 1995, Volume 10," MIT Press, 1995, pp. 67–124.

Cole, Harold L and Lee E Ohanian, "The Great Depression in the United States From A Neoclassical Perspective," *Federal Reserve Bank of Minneapolis Quarterly Review*, 1999, *23* (1), 2–24.

_ **and** _ , "New Deal policies and the persistence of the Great Depression: A general equilibrium analysis," *Journal of Political Economy*, 2004, *112* (4), 779–816.

Dunlop, John T, "The movement of real and money wage rates," *The Economic Journal*, 1938, *48* (191), 413–434.

Eichenbaum, Martin, "Real business-cycle theory: wisdom or whimsy?," *Journal of Economic Dynamics and Control*, 1991, *15* (4), 607–626.

Evans, Charles L, "Productivity shocks and real business cycles," *Journal of Monetary Economics*, 1992, *29* (2), 191–208.

Fabricant, Solomon, *The Output of Manufacturing Industries, 1899-1937*, NBER, 1940.

_ , "Employment in Manufacturing, 1899-1939: An analysis of its relation to the volume of production," *NBER Books*, 1942.

Fernald, John, "A quarterly, utilization-adjusted series on total factor productivity," *Federal reserve bank of San Francisco working paper*, 2012, *19*, 2012.

Fernald, John G and J Christina Wang, "Why has the cyclicality of productivity changed? What does it mean?," *Annual Review of Economics*, 2016, *8*, 465–496.

Field, Alexander J, "The most technologically progressive decade of the century," *American Economic Review*, 2003, pp. 1399–1413.

Francis, Neville and Valerie A Ramey, "Is the technology-driven real business cycle hypothesis dead? Shocks and aggregate fluctuations revisited," *Journal of Monetary Economics*, 2005, *52* (8), 1379–1399.

Gali, Jordi, "Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?," *American Economic Review*, 1999, *89* (1), 249–271.

_ **and Thijs van Rens**, "The vanishing procyclicality of labor productivity," Economics Working Papers 1230, Department of Economics and Business, Universitat Pompeu Fabra August 2008.

Gordon, Robert J., "The" End-of-Expansion" Phenomenon in Short-Run Productivity Behavior," *Brookings Papers on Economic Activity*, 1979, pp. 447–461.

_ **and Robert M. Solow**, "Are Procyclical Productivity Fluctuations a Figment of Measurement Error?," in "Productivity Growth, Inflation, and Unemployment," Cambridge University Press, 2003, pp. 239–272. Cambridge Books Online.

Hall, Robert E, "The Relation between Price and Marginal Cost in US Industry," *The Journal of Political Economy*, 1988, pp. 921–947.

_ , "Invariance properties of Solow's productivity residual," Technical Report, National Bureau of Economic Research 1989.

Hamilton, James D, "Why you should never use the Hodrick-Prescott filter," *Review of Economics and Statistics*, 2018, *100* (5), 831–843.

Hansen, Gary D and Lee E Ohanian, "Neoclassical Models in Macroeconomics," Technical Report, National Bureau of Economic Research 2016.

Hodrick, Robert J and Edward C Prescott, "Postwar US business cycles: an empirical investigation," *Journal of Money, credit, and Banking*, 1997, pp. 1–16.

Inklaar, Robert, Herman De Jong, and Reitze Gouma, "Did Technology Shocks Drive the Great Depression? Explaining Cyclical Productivity Movements in US Manufacturing, 1919–1939," *Journal of Economic History*, 2011, *71* (4), 827.

Ireland, Peter N, "Technology shocks in the new Keynesian model," *Review of Economics and Statistics*, 2004, *86* (4), 923–936.

Jorgenson, Dale Weldeau and Zvi Griliches, "The explanation of productivity change," *The Review of Economic Studies*, 1967, pp. 249–283.

Kehoe, Timothy J and Edward C Prescott, "Great depressions of the 20th century," *Review of Economic Dynamics*, 2002, *5* (1), 1–18.

Kehrig, Matthias, "The cyclical nature of the productivity distribution," *Earlier version: US Census Bureau Center for Economic Studies Paper No. CES-WP-11-15*, 2015.

Kendrick, John W., *Productivity Trends in the United States* NBER Books, National Bureau of Economic Research, Inc, December 1961.

Keynes, John Maynard, "Relative movements of real wages and output," *The Economic Journal*, 1939, *49* (193), 34–51.

King, Robert G and Sergio T Rebelo, "Resuscitating real business cycles," *Handbook of macroeconomics*, 1999, *1*, 927–1007.

_ , **Charles I Plosser, and Sergio T Rebelo**, "Production, growth and business cycles: I. The basic neoclassical model," *Journal of monetary Economics*, 1988, *21* (2), 195–232.

Kuh, Edwin, "Cyclical and secular labor productivity in United States manufacturing," *The Review of Economics and Statistics*, 1965, pp. 1–12.

Kydland, Finn E and Edward C Prescott, "Time to build and aggregate fluctuations," *Econometrica: Journal of the Econometric Society*, 1982, pp. 1345–1370.

_ **and** _ , "Hours and employment variation in business cycle theory," *Economic Theory*, 1991, *1* (1), 63–81.

Long, John B. and Charles I. Plosser, "Real business cycles," *The Journal of Political Economy*, 1983, pp. 39–69.

Lucas, Robert E and Leonard A Rapping, "Unemployment in the Great Depression: Is there a full explanation?," *The Journal of Political Economy*, 1972, pp. 186–191.

Mankiw, N Gregory, "Real Business Cycles: A New Keynesian Perspective," *Journal of Economic Perspectives*, 1989, *3* (3), 79–90.

Mathy, Gabriel and Herman Stekler, "Expectations and forecasting during the Great Depression: Real-time evidence from the business press," *Journal of Macroeconomics*, 2017, *53*, 1–15.

McGrattan, Ellen R and Edward C Prescott, "Unmeasured Investment and the Puzzling US Boom in the 1990s," *American Economic Journal: Macroeconomics*, 2010, *2* (4), 88–123.

_ **and** _ , "The great recession and delayed economic recovery: A labor productivity puzzle?," *Government policies and the delayed economic recovery*, 2012, pp. 115–54.

_ **and Lee E Ohanian**, "Does neoclassical theory account for the effects of big fiscal shocks? Evidence from World War II," *International Economic Review*, 2010, pp. 509–532.

Ohanian, Lee E, "Why did productivity fall so much during the Great Depression?," *American Economic Review*, 2001, pp. 34–38.

Oi, Walter Y, "Labor as a quasi-fixed factor," *The Journal of Political Economy*, 1962, pp. 538–555.

Okun, Arthur M, *Potential GNP: its measurement and significance* 1962.

Prescott, Edward C, "Prosperity and depression," *American Economic Review*, 2002, pp. 1–15.

Ramey, Valerie A and Matthew D Shapiro, "Displaced capital: A study of aerospace plant closings," *Journal of Political Economy*, 2001, *109* (5), 958–992.

Ravn, Morten O and Harald Uhlig, "On adjusting the Hodrick-Prescott filter for the frequency of observations," *Review of economics and statistics*, 2002, *84* (2), 371–376.

Rogers, Robert P, *An economic history of the American steel industry*, Routledge, 2009.

Rotemberg, Julio J and Lawrence H Summers, "Inflexible prices and procyclical productivity," *The Quarterly Journal of Economics*, 1990, pp. 851–874.

Sbordone, Argia M, "Interpreting the procyclical productivity of manufacturing sectors: external effects or labor hoarding?," *Journal of Money, Credit, and Banking*, 1997, pp. 26–45.

Shapiro, Matthew D, "Cyclical productivity and the workweek of capital," *The American Economic Review*, 1993, *83* (2), 229–233.

Shea, John, "What do technology shocks do?," in "NBER Macroeconomics Annual 1998, volume 13," MIT Press, 1999, pp. 275–322.

Sims, Christopher A., "Output and labor input in manufacturing," *Brookings Papers on Economic Activity*, 1974, pp. 695–735.

Slutzky, Eugen, "The summation of random causes as the source of cyclic processes," *Econometrica: Journal of the Econometric Society*, 1937, pp. 105–146.

Smets, Frank and Raf Wouters, "An estimated dynamic stochastic general equilibrium model of the euro area," *Journal of the European economic association*, 2003, *1* (5), 1123–1175.

Solow, Robert M, "Technical change and the aggregate production function," *The review of Economics and Statistics*, 1957, pp. 312–320.

Stiroh, Kevin J, "Volatility accounting: A production perspective on increased economic stability," *Journal of the European Economic Association*, 2009, *7* (4), 671–696.

Summers, Lawrence H, "Some skeptical observations on real business cycle theory," *A Macroeconomics Reader*, 2002, p. 389.

Tarshis, Lorie, "Changes in real and money wages," *The Economic Journal*, 1939, *49* (193), 150–154.

Wang, J Christina, "Vanishing procyclicality of productivity? Industry evidence," Technical Report, Working Papers 2014.

Wright, Jonathan H, "Unseasonal seasonals?," *Brookings Papers on Economic Activity*, 2013, *2013* (2), 65–126.

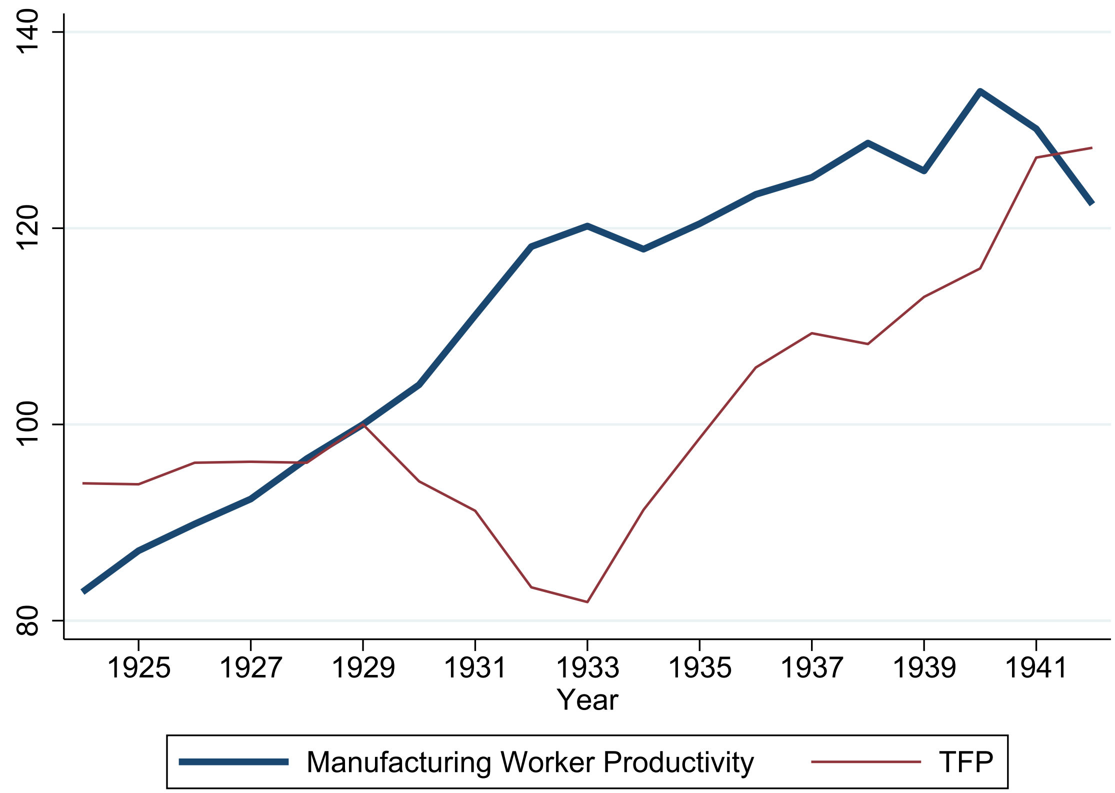
Yépez, Carlos A, "Financial conditions and labor productivity over the business cycle," *Economics Letters*, 2017, *150*, 34–38.

Ziebarth, Nicolas L., "Misallocation and Productivity during the Great Depression," *University of Iowa Working Paper*, 2011.

A Table, Model Appendix, and Figures

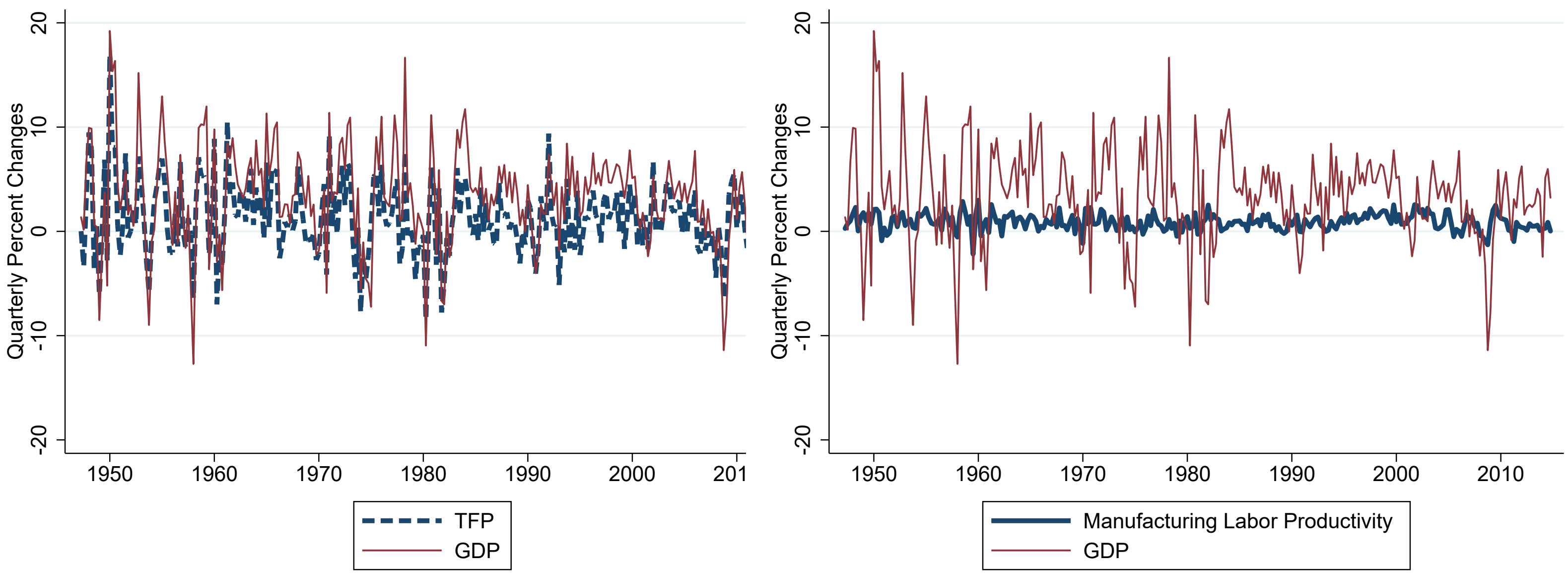
A.1 Figures

Figure 1: Historical Solow Residual and Manufacturing Worker Proodductivity



Note: Solow data from Solow (1957), TFP from Kendrick (1961), 100=1929.

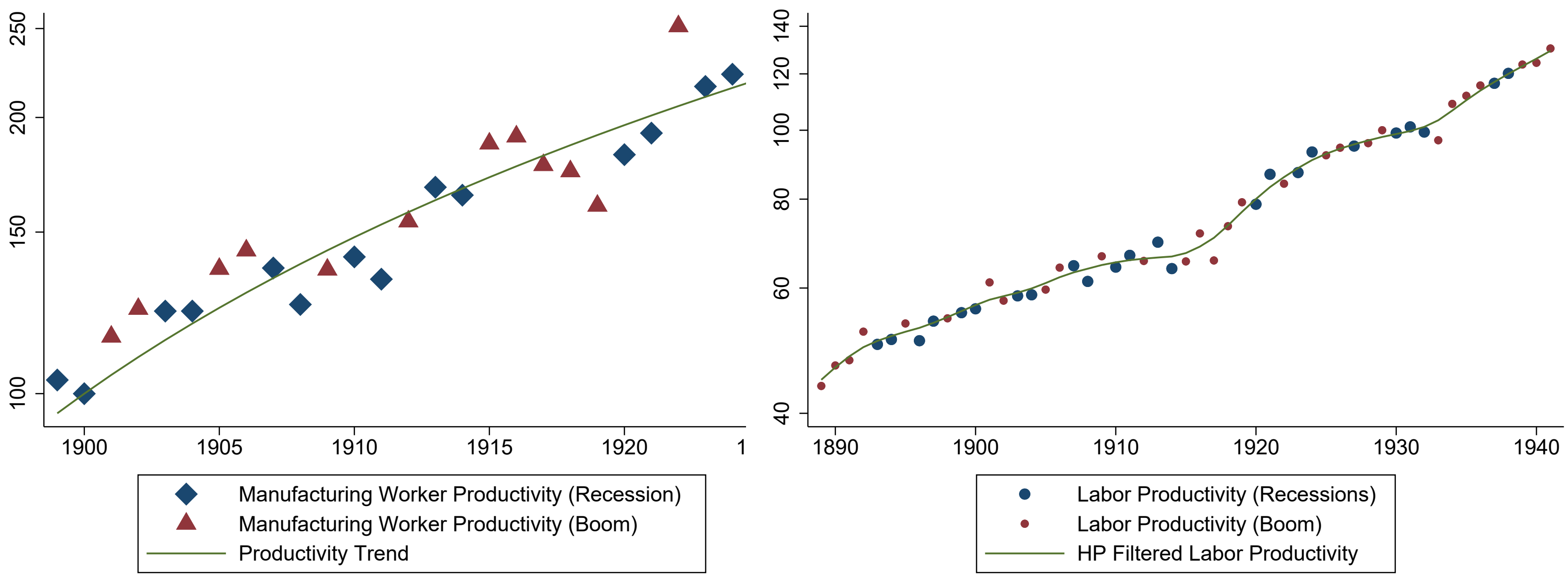
Figure 2: Quarterly Percent Change in Productivity and Real GDP: 1947-2020



(a) TFP, Utilization-adjusted TFP, & Real GDP (b) Manufacturing Worker Productivity & Real GDP

Fernald(2012, 2014), BEA/NIPA, Manufacturing Worker Productivity is manufacturing production (Federal Reserve Board) divided by production worker hours (BLS).

Figure 3: Manufacturing Worker Productivity and Labor Productivity in Recessions and Booms, 1890-1953

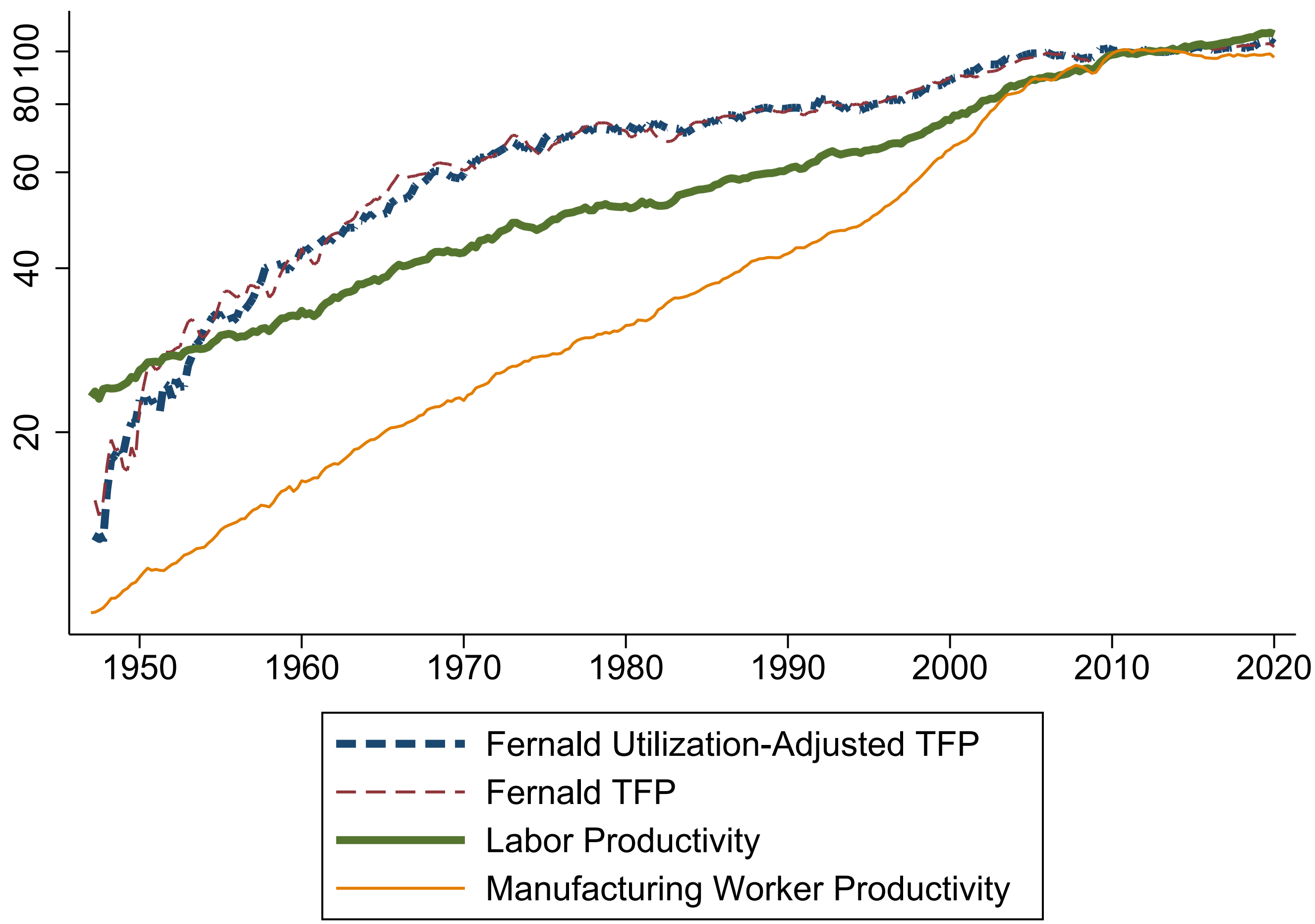


(a) Manufacturing Worker Productivity: 1899-1926 (Annual)

(b) Labor Productivity: 1890-1942

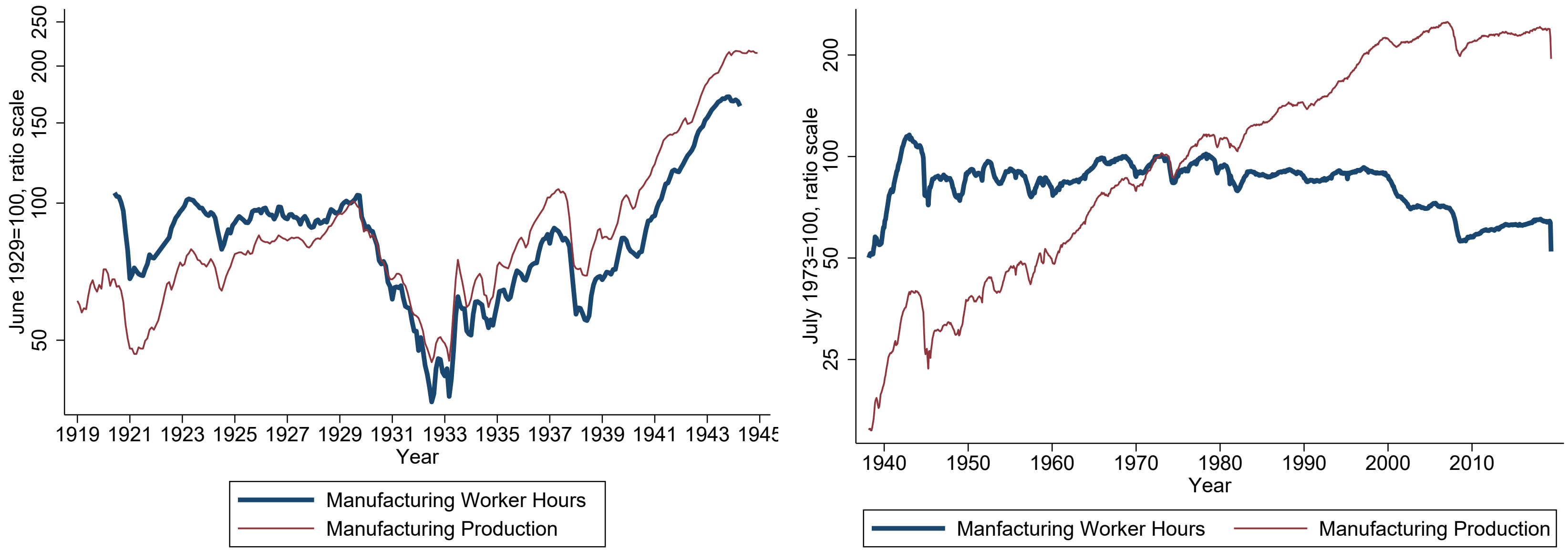
Notes: Manufacturing Worker Productivity is manufacturing output divided by the product of average weekly hours worked by manufacturing workers and the number of manufacturing wage earners, all from Fabricant (1942). Labor Productivity is from Kendrick (1961). Recession and boom years from NBER, Left panel, 1914=100. Right Panel, 1929=100, log scale.

Figure 4: Modern Solow Residual, Manufacturing Worker Productivity



Notes: TFP and Utilization Adjusted TFP from Fernald (2014). Manufacturing Worker Productivity is manufacturing production (FRB) divided by production worker hours (BLS). Y-axis is log scale. 100=2012.

Figure 5: Manufacturing Production Worker Hours and Manufacturing Production

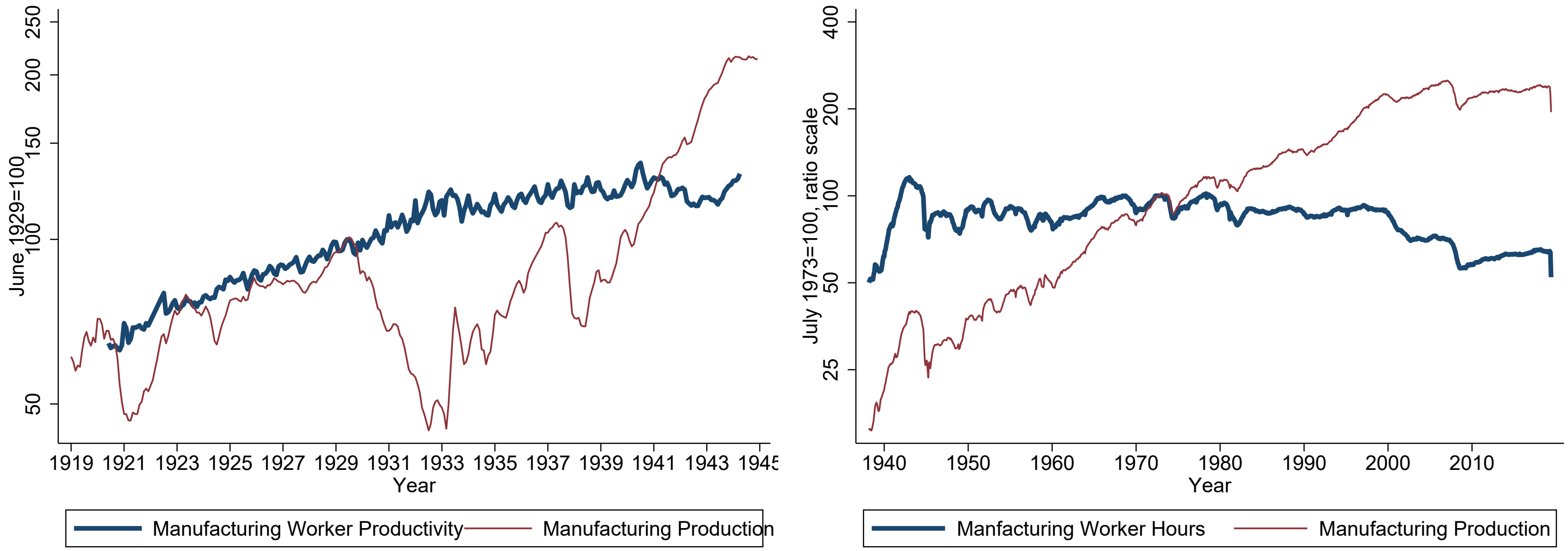


(a) 1919-1944

(b) 1939-2014

Notes: Manufacturing production from Federal Reserve Board and production worker hours from NBER/Conference Board/BLS), June 1920=100.

Figure 6: Manufacturing Worker Productivity and Manufacturing Production

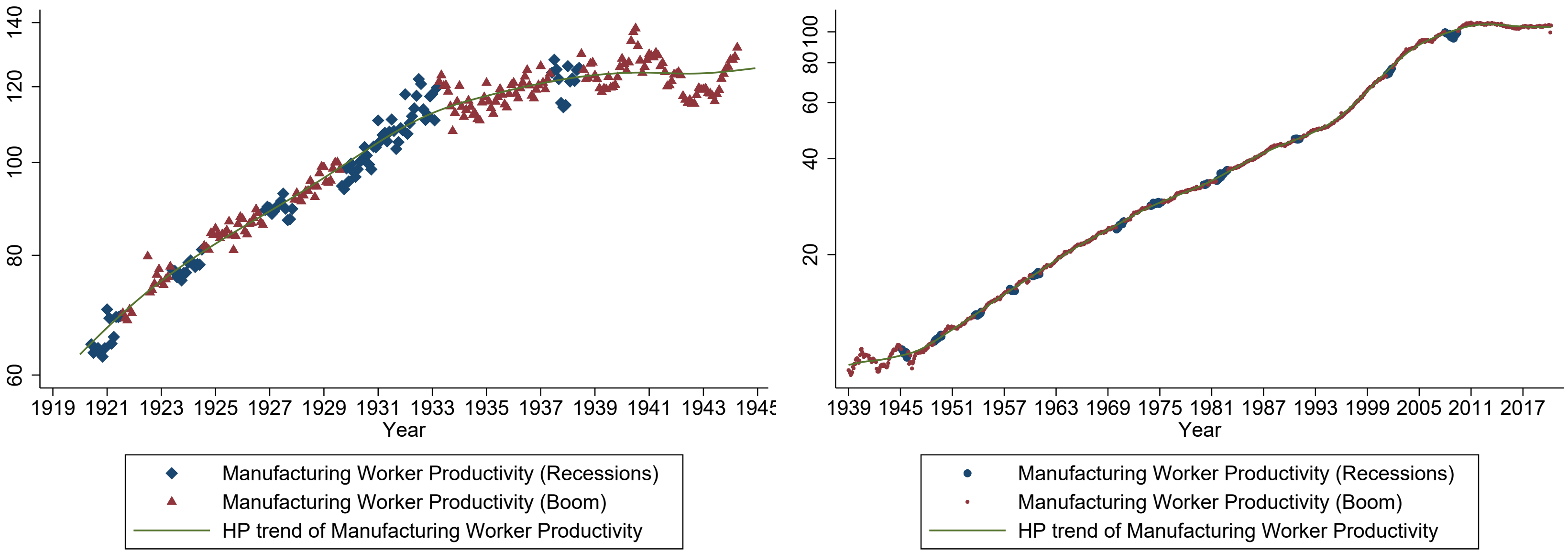


(a) 1919-1944

(b) 1939-2014

Notes: 1929=100 (left) or 1973=100 (right). Manufacturing Worker Productivity is manufacturing production (Federal Reserve Board) divided by manufacturing hours worked (NBER/BLS).

Figure 7: Manufacturing Worker Productivity in Recessions and Booms

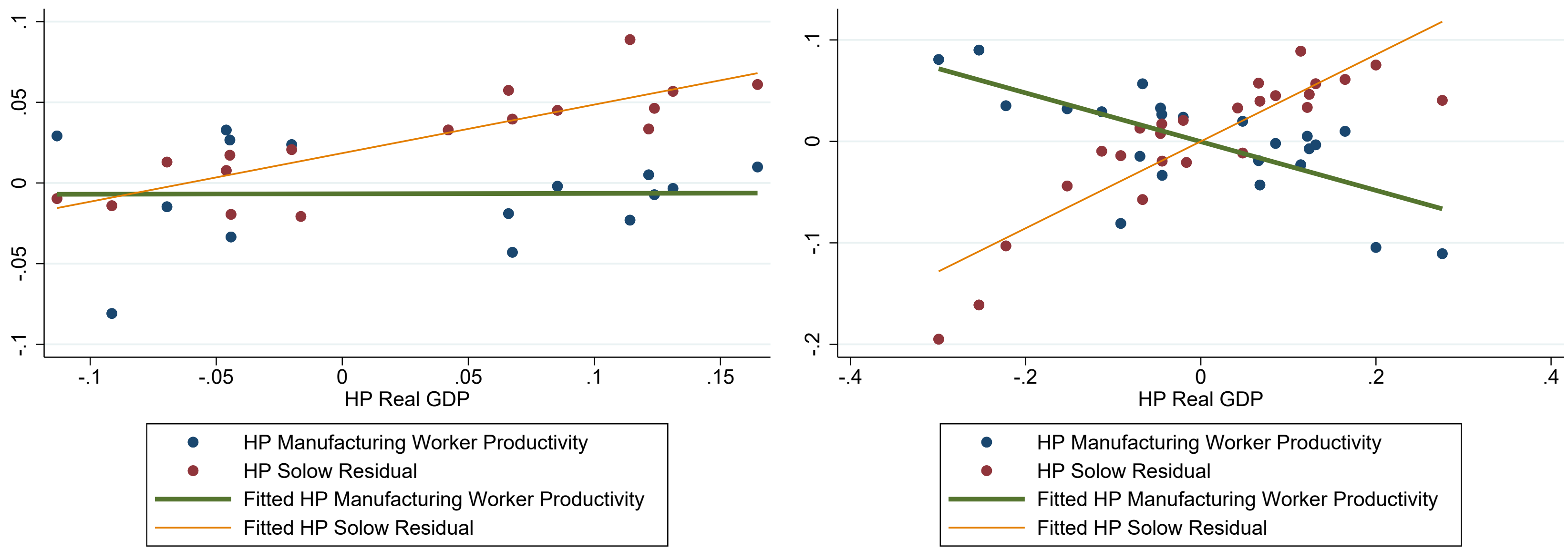


(a) 1920-1944

(b) 1939-2020

Notes: Recessions are NBER recessions, booms are all other periods. HP-filter uses smoothing parameter 129,600. Manufacturing worker productivity is manufacturing production (Federal Reserve Board) divided by production worker hours (NBER/BLS).

Figure 8: Scatterplot of Productivity Measures versus Real GDP I

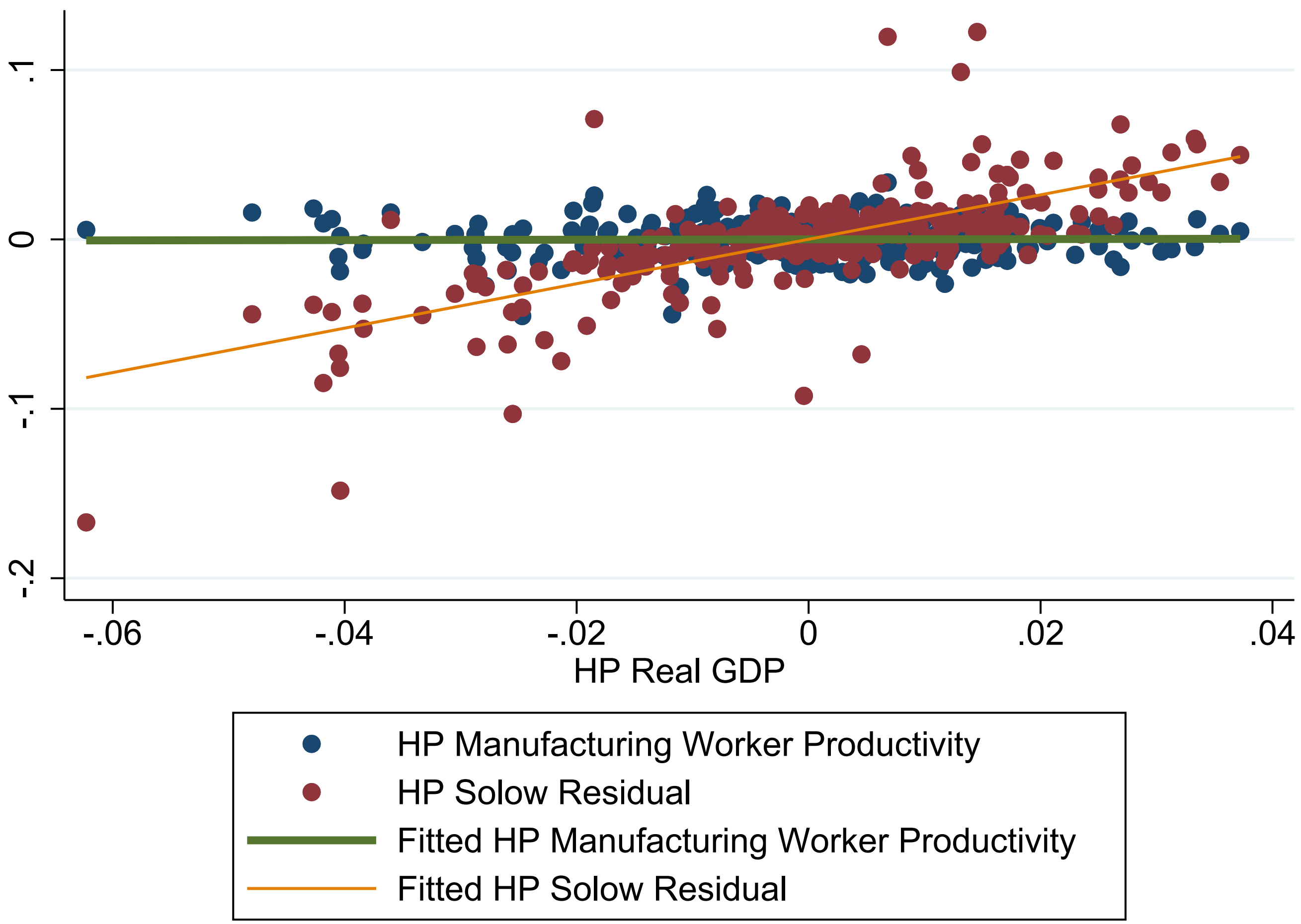


(a) 1921-29, 1935-1944

(b) 1921-1944

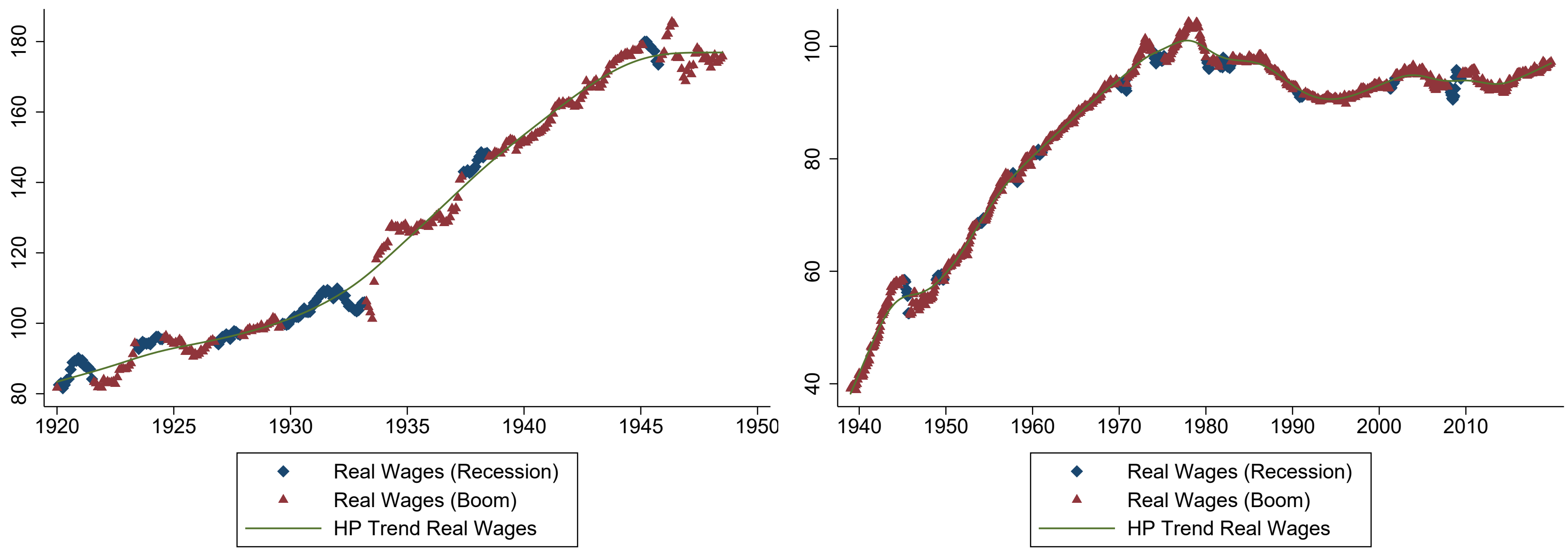
Notes: HP-filter applied to logged variables with smoothing parameter 6.25, annual data from 1921-1941 (right), with left panel excluding 1930-1934. Manufacturing Worker Productivity is manufacturing production (Federal Reserve Board) divided by production worker hours (NBER/BLS).

Figure 9: Scatterplot of Productivity Measures versus Real GDP 1947Q2-2020Q1



Notes: Hodrick-Prescott filter applied to logged variables with smoothing parameter 1600, quarterly data from 1947Q2-2020Q1. Manufacturing Worker Productivity is manufacturing industrial production (Federal Reserve Board) divided by production worker hours (BLS).

Figure 10: Real Wages in Recessions and Booms

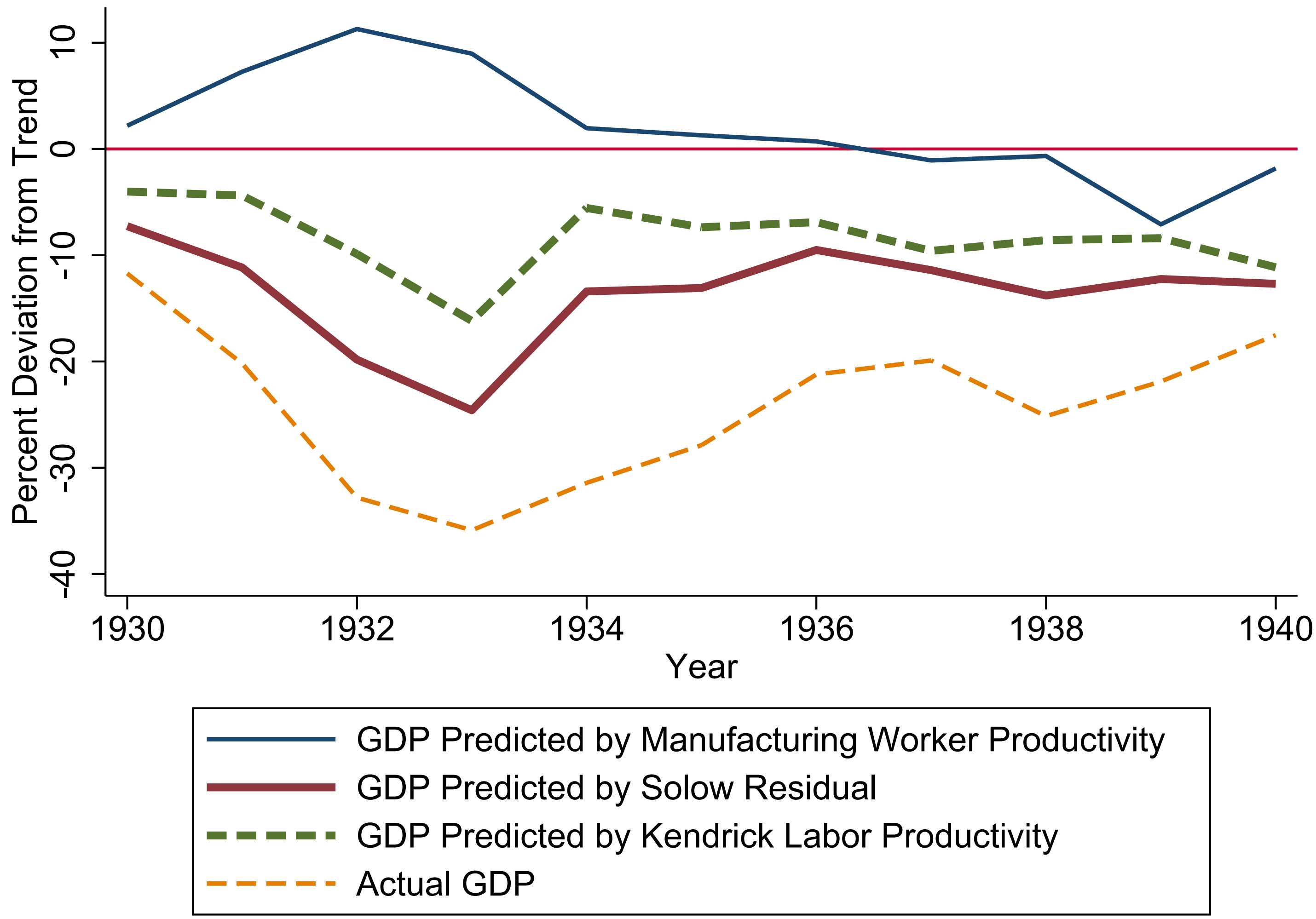


(a) 1921-1947

(b) 1939-2015

Notes: (a) Real Wages are Average Hourly Earnings, Twenty-Five Manufacturing Industries for United States (NBER) divided by the Consumer Price Index (BLS). Recession and boom years from NBER. 100=1929.
(b) Real Wages are Average Hourly Earnings of Production and Nonsupervisory Employees: Manufacturing (BLS) divided by the Consumer Price Index (BLS). Recession Dates from NBER. 100=1973.

Figure 11: Real Business Cycle simulation of Great Depression with alternative productivity measures



Source: Kendrick (1961), King et al. (1988) and author's calculations

A.2 Table

Table 2: Types of mismeasurement relevant for Manufacturing Worker Profuctivity and the Solow Residual

Avoids Mismeasurement	Solow Residual	Manufacturing Worker Productivity
Labor Hoarding	X	X
Capital Hoarding	X	✓
Labor Utilization	X	X
Capital Utilization	X	✓
Overhead Labor	X	✓
Overhead Capital	X	✓
Market Power	X	X
Increasing Returns to Scale	X	X

A.3 Model Appendix

The model requires 100% depreciation to permit a closed-form solution. This reduces some of the dynamics, but is much easier to solve. The autopersistence of productivity ρ is 0.9. The important parameter here is α, which is the coefficient on labor in the production function, with $\alpha = 0.58$, and $1 - \alpha = 0.42$. The law of motion for capital in deviations from steady-state, $\hat{k}$

$$\hat{k}_{t+1} = (1 - \alpha)\hat{k}_t + \hat{A}_t. \tag{3}$$

The percent deviation of output from steady-state, represented by $\hat{y}$, is a function of the deviation of productivity from trend $\hat{A}$ and the deviation of capital from the steady-state:

$$\hat{y}_t = (1 - \alpha)\hat{k}_t + \hat{A}_t. \tag{4}$$