Technological Change and the Roaring Twenties: A Neoclassical Perspective

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Abstract

Annualized output growth in the United States was highest during the 1920s, as compared to any other of Field's (2003, 2009) growth cycles. This motivates us to address the causes of the Roaring Twenties in the United States. In particular, we use a version of the real business cycle model to test the hypothesis that an extraordinary pace of productivity growth was the driving factor. Our motivation comes from the abundance of evidence of significant technological progress during this period, fed by innovations in manufacturing and the widespread introduction of electricity. Our estimated total factor productivity series generate artificial model output that shows high conformity with the data: the model economy successfully replicates the boom years from 1922-1929.

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1 Introduction

> "[The 1920s] represent nearly seven years of unparalleled plenty [...] during which the businessman was, as Stuart Chase put it, 'the dictator of our destinies,' ousting 'the statesman, the priest, the philosopher, as the creator of standards of ethics and behavior' and becoming 'the final authority on the conduct of American society.' For nearly seven years, the prosperity band-wagon rolled down Main Street." [Allen, 1931, 133]

After surviving the woebegone 1920-21 recession, the United States' annualized per capita output grew at a staggering pace of over 3.3 percent for the rest of the decade – about 1.5 percentage points higher than the 20th century average. In fact, annualized output growth was highest during the 1920s, as compared to any other of Field's (2003, 2009) growth cycles. What caused this unique episode in U.S. economic history? In this paper, we address this issue in the context of a neoclassical model of the business cycle. In particular, we use a version of the real business cycle (RBC) model to test the hypothesis that an extraordinary pace of productivity growth was the driving factor.[1] We also provide historical evidence of such growth.

This paper is not the first to apply neoclassical modeling techniques to the prewar era. Cole and Ohanian (1999, 2004) and Bordo, Erceg and Evans (2000), among others, evaluate the ability of RBC or sticky price money models to explain the Great Depression. In addition, Harrison and Weder (2006) assess the possibility that a model in which self-fulfilling beliefs (aka sunspots) drive business cycles might explain it. They provide evidence that extrinsic pessimism starting in 1930 turned what might have been a recession into the Great Depression.

Our goal here is to follow the lead taken by the above authors by extending the analysis to the experience of the US economy during the Roaring Twenties.[2] We believe that the RBC approach is an appropriate framework to attack this issue, not only because of its elegant simplicity and success in

[1] We define real business cycles in the sense of "[...] recurrent fluctuations in an economy's incomes, products, and factor inputs – especially labor – that are due to nonmonetary sources." [McGrattan, 2006, 1]. However, here we stress solely technological progress.

[2] We acknowledge that other factors might have contributed to the Roaring Twenties. (See for example Harrison and Weder, 2008.) However, the goal here is to examine the effects of technological changes in isolation.

explaining postwar cycles, but also in light of considerable evidence of much technological progress during the Roaring Twenties. In fact, the current paper is the first that numerically evaluates the general equilibrium effects of how and by how much identified productivity gains during the 1920s translated into the unwonted boom in U.S. economic activity.

As will be seen in more detail in the next Section, total factor productivity (TFP) growth during the 1920s was persistently above trend (shown in Figure 1). In addition, beginning right after the recession of 1920-21, output remained above trend for the entire decade. As does Field (2006), we attribute these TFP improvements to innovations that originated in manufacturing, which were chiefly made possible by switching production to the use of electricity:

> "[e]xtraordinary across-the-board gains from exploiting small electric motors, and reconfiguring factories from the multistory pattern that mechanical distribution of steam power required to the one story layout that was now possible. [Field, 2006, p 216]

In other words, innovations like the automobile industry's assembly line, the adoption of electric power and the use of the frictional horsepower electric motor led to increases in production possibilities in many sectors of the economy. We present detailed evidence in the next Section.

To evaluate the widespread effects that innovations in manufacturing and the switch to electricity had on the aggregate economy, we feed model-consistent estimates of TFP into a calibrated general equilibrium model. We use the canonical version of the RBC model, with the one added feature that utilization of the capital stock can vary over the cycle. We examine versions of the model, however, both with and without this feature. Without it, TFP is the standard Solow residual; while with this feature, our estimate of TFP takes into account a model-consistent measure of utilization.

Our data cover the period 1892-1941. In our analysis we examine the success of each model over the entire period, though our focus is on the 1920s. In particular, we examine each model's ability to replicate the expansive nature of the decade in general. In addition, since we calibrate the models to match business-cycle frequency data, we also examine their match with the three recessions that occurred: one large, from 1920:I to 1921:III; and two milder, from 1923:II to 1924:III, and 1926:III to 1927:IV. The models get the timing of the first two recessions wrong, as in each case the negative technology

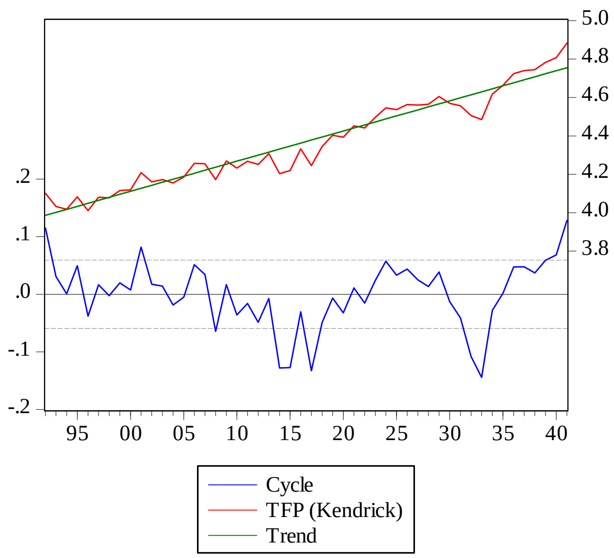

Figure 1: US total factor productivity, cycle denotes the percentage deviations from 1892-1941 trend. Data source: Kendrick (1961,Table A-XXIII).

shocks come too late. On the other hand, a fall in productive capacity does accompany the last recession. In addition, our results indicate that increases in the level of technology during the 1920s are essential for understanding its roaring nature, i.e. the above trend growth. The correlations over this period between model and data for the two models are 0.84 and 0.58 respectively. Eliminating the first, deepest recession, these correlations rise to 0.92 and 0.73. Our conclusion is that the standard RBC model replicates the data extremely well, while adjusting for variable utilization of capital weakens the power of the model.[3]

The rest of this paper proceeds as follows. In Section 2 we outline the technological experiences of the Roaring Twenties, providing supporting evidence, in historical perspective. Section 3 describes the model; and in Section 4 we present our results. Section 5 concludes.

2 The Roaring Twenties

> "Pick up one of those graphs with which statisticians measure the economic ups and downs of the Post-war Decade. You will find that the line of business activity rises to a jagged peak in 1920, drops precipitously into a deep valley in late 1920 and 1921, climbs uncertainly upward through 1922 to another peak at the middle of 1923, dips somewhat in 1924 (but not nearly so far as in 1921), rises again in 1925 and zigzags up to a perfect Everest of prosperity in 1929-only to plunge down at last into the bottomless abyss of 1930 and 1931. Hold the graph at arm's-length and glance at it again, and you will see that the clefts of 1924 and 1927 are mere indentations in a lofty and irregular plateau which reaches from early 1923 to late 1929." [Allen, 1931, 132f]

In this Section we provide economic background on the Roaring Twenties, from the perspective of technological change. We begin with data on output and on TFP, and conclude with evidence of specific innovations that were key factors in determining the growth experience of the 1920s.

[3] Temin (2008) questions the ability of the frictionless RBC model to explain the Great Depression. Here we do not claim that our theory can explain all fluctuations. For example, our model does not capture the 1920-21 recession precisely because it appears to have been caused by other shocks (see also Harrison and Weder, 2008).

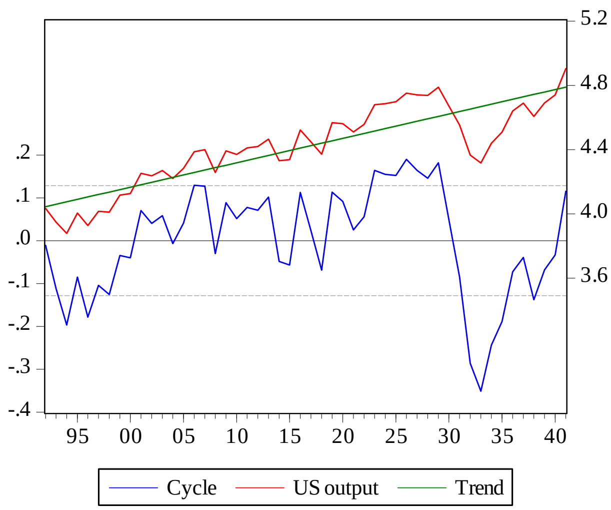

Figure 2: Prewar per capita output

2.1 Output

Figure 2 portrays US GNP (private domestic nonfarm) per capita over the period 1892-1941. GNP data is from Kendrick (1961, Commerce Concept). The population series (16 and over) is from the Historical Statistics of the US (Colonial Times to 1970). Also plotted is the implied pre-war (what Allen calls Post-war) trend.

Table 1 *US Annual output and TFP growth*

Years	Output	TFP
1892-1906	2.55	1.11
1906-1919	1.40	1.12
1919-1929	2.23	2.02
1921-1929	3.55	2.77
1929-1941	0.97	2.78
1941-1948	2.34	0.49
1948-1973	2.39	1.90
1973-1989	1.54	0.34
1989-2000	2.13	0.78

The average annual growth rate over the period is 1.52 percent.[4] This is about 0.4 percentage points lower than the 20th century's compounded rate of growth. Notable for us is the unique persistent deviation from trend starting in 1919. Figure 2 also shows that, starting in 1923, the economy stays above and parallel to trend, until 1929. The peak was in 1926. However, it is virtually indistinguishable from the 1929 value. Furthermore, the amplitude of the fluctuations declines dramatically after 1923. This is all true despite the two recessions that occurred from 1923:II to 1924:III and 1926:III to 1927:IV.

Table 1 provides more evidence of the remarkable growth in output during the 1920s. It contains, in the first column, data on per capita output growth over the period of our sample. The selection of periods follows Field (2003, 2006, 2009), whose aim is to measure peak-to-peak performances of growth cycles. (1892 is the first peak year for which Kendrick's data are available at an annual frequency.) The 1919-1929 output growth figure is above average. However, it does not stand out. Real vigor becomes visible by excluding the recession from 1920:I-1921:III, in the 1921-1929 row. Here compounded annual growth tops 3.5 percent, the largest of any period. The 1920-21 recession was quite deep, with per capita output falling about 5 percent, so many authors (including Olney, 1991) define the Roaring Twenties as starting after it. In fact, some of the highest growth occurs *right* after it, or as Allen notes:

> "The hopeless depression of 1921 had given way to the hopeful improvement of 1922 and the rushing revival of 1923." [Allen, 1931, 132]

2.2 Technology

Also included in Table 1 is TFP growth rates using Kendrick's (1961) measure of TFP: the ratio of GNP to an index of total factor input. This input measure is a factor share–weighted average of aggregate capital input and labor input. TFP growth picks up starting in 1919. While the same peak-to-peak interpretation does not apply here, the growth of TFP from 1921-1929 does stand out. It is virtually identical to that of the period Field (2003)

[4] We are aware of potential problems with Kendrick's data at business cycle frequencies predating 1908 (see Romer, 1989, however, Weir, 1986, for criticism of her method). Here we look at longer run movements, hence, these issues are of minor importance.

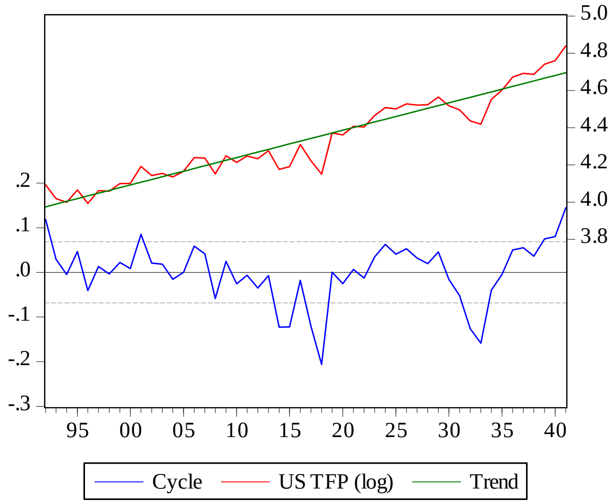

Figure 3: Naive TFP (Solow residual from Cobb-Douglas production function)

coined the "most technologically progressive decade," the 1930s. In addition, as seen in Figure 1, just like output, the cyclical component of TFP remains above-trend from 1923-1929. Over no other period in our sample does such a prolonged positive deviation from trend occur.[5]

For consistency with our theoretical model, Figure 3 displays TFP using a calibrated Cobb-Douglas production function with a labor share of 67 percent. (Details are in the next Section.) Capital input and labor input are taken from Kendrick (1961, private domestic nonfarm). Again, TFP growth is above trend and significantly less volatile starting in 1923. In fact, this low volatility growth appears to be unique over the considered period. Of significance for our later calibration, this TFP, detrended, as shown in Figure 4, is well-described by an AR(1) process with persistence parameter 0.55. Figure 4 also displays the residuals from this process. Though relatively small, these innovations are mostly positive during the 1920s. In fact, they are positive

[5] Noteworthy also is the deviation below trend during the war years, in particular the drop in 1914. There are a number of plausible factors behind this: amongst these stands the enactment of the Federal personal income tax in 1913. As per the introduction of an income tax, initially the rates were low with the the highest bracket at 7 percent. During the war however, rates were quickly increased in excess of 70 percent.

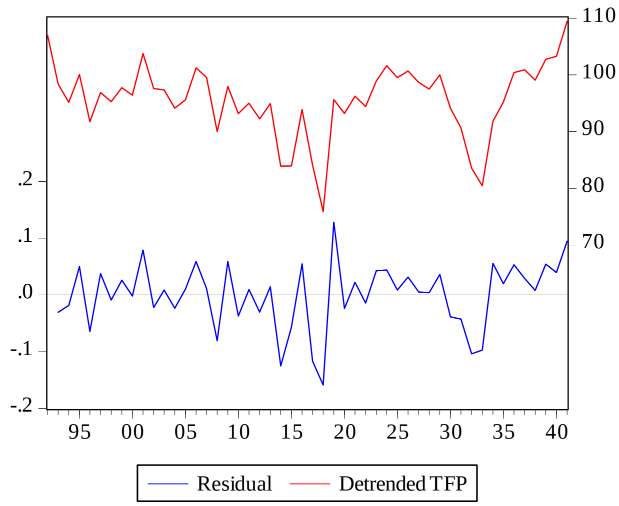

Figure 4: The dynamic process of TFP

for every year from 1923-1929.

2.3 Technological change during the 1920s

> "Within business cycle research, some open questions remain. What is the source of large cyclical movements in TFP? [...] Are movements in TFP primarily due to new inventions and processes that are, by the nature of research and development, stochastically discovered? Or are movements in TFP primarily due to changing government regulations that may alter the efficiency of production? Are they due to unmeasured investments that fluctuate over time?" [McGrattan, 2006, 9]

There is much evidence to support the measured surge in TFP during the 1920s, in the form of technological change. In particular, we argue that the economy-wide innovations were driven by two factors: (1) improvements made in manufacturing, and (2) the widespread adoptions of electricity, and the frictional horsepower electric motor in particular.

Support for both of these comes from the contemporary *Report of the Committee on Recent Economic Changes of the President's Conference on*

*Unemployment (*1929):

> "The increased supply of power and its wider uses; the multiplication by man of his strength and skill through machinery, the expert division and arrangement of work in mines and factories, on the farms, and in the trades, so that production per man hour of effort has risen to new heights." [1929, p ix-x]

The effects of these changes were exactly what one would expect from positive technology shocks:

> "[...] both energy savings and increased productivity in manufacturing contributed to the dramatic change in the energy-GNP ratio around 1920." [Devine, 1983, 372]

The importance of technological change in manufacturing is central to Field (2006), who reports that the surge in TFP first and foremost originated in that sector. Over the 1919-1929 span, manufacturing TFP's annual growth rate was 5.12 percent: more than double the 2.02 percent average for the aggregate economy.

Likewise, Oshima (1984) attributes much of the growth in the economy to that in manufacturing:

> "Mechanization raised output per worker at a faster rate than could be accomplished with the steam-driven technology of the nineteenth century [...]. The new machines – faster, more powerful [...] raised per capita output." [Oshima, 1984, p 161].

Perhaps the most-cited innovation in manufacturing during this period is Ford's adoption of the assembly line, realized between 1908 and 1913. Motor vehicle production rose tenfold from 1913 to 1928; and by the end of the 1920s, sixty percent of American families owned an automobile (Smiley, 2008).

The adoption of mass production, aided by the specialization of the assembly line, followed in many other industries, including communication, transportation, and consumer appliances:

> "[Executives'] confidence was strengthened by their almost invincible ally. And they were all of them aided by the boom in the

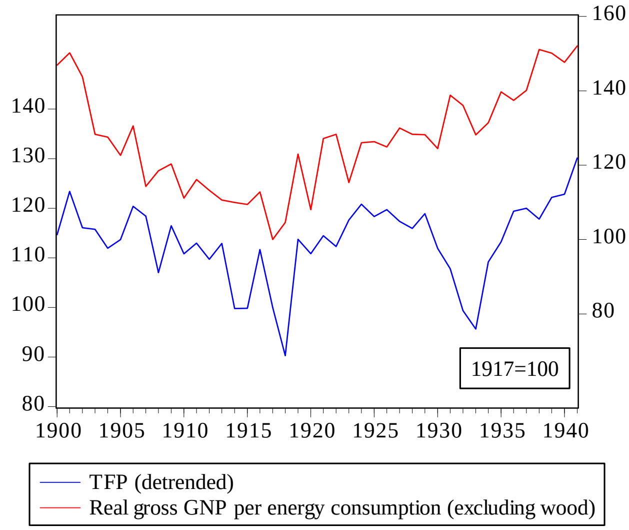

Figure 5: Trends in US energy consumption, original source of energy data: Schurr and Netschert (1960)

> automobile industry. The phenomenal activity of this one part of the body economic-which was responsible, directly or indirectly, for the employment of nearly four million men–pumped new life into all the rest." [Allen, 1931, 139]

The other important source of growth during the 1920s was the expanding use of electricity in production – the

> "[...] lever to increase production." [Devine, 1983, 363]

Kyvig notes:

> "Electric current, generated and controlled for human use, was not a new phenomenon by the 1920s, but, as with the automobile, in that decade it first came to be used by a multitude of people." [Kyvig, 2002, 43].

In 1919, 55% of manufacturing's power was supplied by electricity. By 1929, this number had increased to 82% (Atack and Passell, 1994). Figures

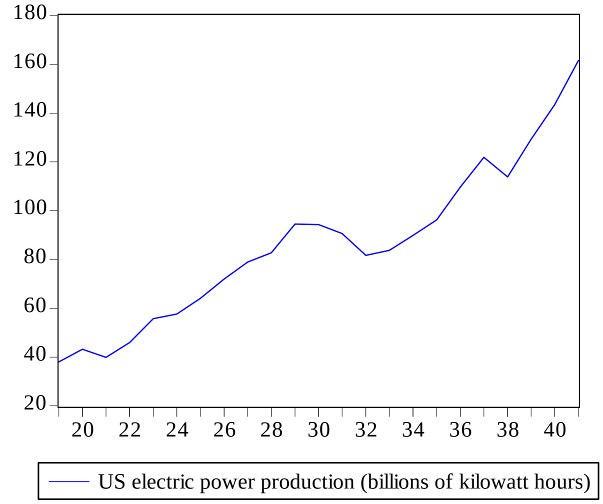

Figure 6: Electricity production. Source: NBER Historical Macro database.

5 and 6 illustrate. Figure 5 shows the marked increase in the productivity of energy (i.e. the energy-GNP ratio as mentioned by Devine, 1983) in the United States starting in 1917. Its general pattern is very similar to the (detrended) aggregate TFP series. Figure 6 plots the upward surge of electricity production – electric power production almost tripled from 1919 to 1929.

The innovations in manufacturing and the adoption of electricity resulted in a plethora of further inventions that were widespread and spurred on growth. These included radios, which helped to revolutionize the advertising business. After the first radio broadcast by KDKA Pittsburgh in November 1920, sales of radio sets, parts and accessories surged from $60 million in 1922 to over $842 million by 1929. Among the long list of other product inventions is irons, toasters, television and vacuum cleaners. Retail also exploded, with *Sears* opening stores in 1924 – previously, they were strictly mail order. *Montgomery Ward* and *Woolworth*, along with several grocery stores, followed (Smiley, 2008).

As an aside, Allen (1931) discusses the adoption of a more sophisticated organization of production, which likely also contributed to the observed dampening of the cycle:

> "Executives, remembering with a shudder the piled-up inven-

tories of 1921, had learned the lesson of cautious hand-to-mouth buying; and they were surrounded with more expert technical consultants, research men, personnel managers, statisticians, and business forecasters than ever before invaded that cave of the winds, the conference room." [Allen, 1931, 139]

Despite the overall expansionary nature of the decade, there were 3 recessions. While the first was certainly a post-WWI decline, it is also often blamed on inept monetary policy. The third may have been related to Ford's closing of his factories to switch from Model T to Model A:

> "The 1927 recession was also associated with Henry Ford's shut-down of all his factories for six months in order to changeover from the Model T to the new Model A automobile. Though the Model T's market share was declining after 1924, in 1926 Ford's Model T still made up nearly 40 percent of all the new cars produced and sold in the United States." [Smiley, 2008]

Below we examine our theory's ability to replicate the cycles that occurred during the Roaring Twenties, as well as the economically expansive nature of the decade in general.

3 The artificial economy

The artificial economy is a one-sector dynamic general equilibrium model with variable capital utilization. We assume that the economy is populated by identical consumer-worker households of measure one, each of which lives forever. There are N_t family members in every household in period t. The problem faced by a representative household is

$$\max_{\{c_t,h_t,u_t,k_{t+1}\}} E_0 \sum_{t=0}^{\infty} \beta^t \left[(1-\eta)\ln c_t + \eta \ln(1-h_t)\right] N_t$$

subject to

$$\begin{aligned} (1+a)(1+n)k_{t+1} &= (1-\delta_t)k_t + z_t(u_t k_t)^{\alpha}(A_t h_t)^{1-\alpha} - c_t \\ \delta_t &= \frac{1}{\theta} u_t^{\theta} \end{aligned}$$

and k_0 is given. We restrict the parameters $0 < \alpha < 1$, $0 < \beta < 1$, and $0 < \eta < 1$. The variables c_t, h_t, k_t, and u_t denote consumption, labor, capital (all in per capita terms) and the capital utilization rate. As in most studies with variable capital utilization, the rate of depreciation, δ_t, is an increasing function of the utilization rate, hence $\theta > 1$. This formulation follows Greenwood, Hercowitz and Huffman (1988). The constant population growth rate is given by n. Labor-augmenting technology, A_t, grows at the constant rate a. We denote productivity shocks by z_t, and assume that they follow the standard AR(1) process. All markets are perfectly competitive.

The first order conditions entail

$$\begin{aligned} \frac{\eta}{1-\eta}\frac{c_t}{1-h_t} &= (1-\alpha)\frac{y_t}{h_t} \\ u_t^{\theta} &= \alpha\frac{y_t}{k_t} \\ \frac{(1+a)(1+n)}{c_t} &= E_t\frac{\beta}{c_{t+1}}\left(\alpha\frac{y_{t+1}}{k_{t+1}} + 1 - \delta_{t+1}\right) \\ (1+a)(1+n)k_{t+1} &= (1-\delta_t)k_t + y_t - c_t \\ y_t &= c_t + x_t = z_t(u_t k_t)^{\alpha}(A_t h_t)^{1-\alpha}. \end{aligned} \tag{1}$$

We calibrate our economy to averages of the US economy over our sample period.[6] The fundamental period is a year. We set $\alpha = 0.33$, which corresponds to the capital share for the private domestic economy in 1929 (see also Johnson, 1954). In addition, $a = 0.015$ and $n = 0.019$. These numbers conform to our TFP and population measures' average growth rates. Lastly, we set the discount factor at $\beta = 0.96$ and the steady state rate of physical capital depreciation at $\delta = 0.055$, which we take directly from McGrattan and Ohanian (2007). Together, these values imply a capital to output ratio of 2.5, which is the average of Maddison's (1991) figures for the US gross non-residential capital stock to GDP ratio for 1890 and 1913. The calibration produces a consumption share of 77 percent. This is close to the average for 1892 to 1941, 75 percent (GNP, *Commerce Department* concept, derivation from Kuznets' estimates, from Kendrick, 1961). The parameter η is set such that households spent one third of their time endowment working. Lastly, θ is pinned down by the steady state conditions

$$\theta = \frac{(1+a)(1+n) - \beta(1-\delta)}{\beta\delta} = 2.56.$$

[6]See Cooley (1997) for an authoritative description of calibration.

4 Results

In this Section, we present our results. Our goal is to examine the ability of technology shocks in the model economy to replicate the US experience of the 1920s. First, we assume a constant capital utilization rate in production. Here, total factor productivity is simply the naive Solow residual. Then, we allow for the richness given to the model by allowing this rate to vary over time.

4.1 Standard real business cycle model

We start with the plain vanilla model, in which capital utilization remains constant.[7] Our first step is to estimate TFP via the standard Solow residual. This is accomplished by setting $u_t = 1$ for all periods in the production function and solving for z_t. Under our calibration, we have

$$z_t = \frac{y_t}{k_t^{0.33}(A_t h_t)^{0.67}}.$$

The resulting series $\{z_t\}$, as well as its log-linear detrended version and innovations, were presented in Figures 3 and 4. As mentioned in Section 2.2, the detrended TFP time series is well-described by an AR(1) process. Recall that TFP underwent a significant surge upward starting in 1923. It then remained above-trend until the end of the decade, at which point it collapsed.

Next, we feed the computed series $\{z_t\}$ into the artificial economy. Our detrending method suggests that Kendrick's 1892 capital input was about 15 percent below the 1892 to 1941 trend. Therefore, we start with an initial capital stock 15 below the steady state. This assumption impacts the beginning of the simulation, but has no effect on the results for the 1920s.[8]

Figure 7 compares artificial output and US data, starting with 1919. The US data are detrended by their 1892 to 1941 trend; and both series are scaled to equal 100 in 1929. Over this period, the correlation between model

[7] In terms of our model economy, this amounts to allowing costs of adjusting capital usage to become prohibitively large, or $\theta \to \infty$.

[8] Capital moves at low frequencies; and it turns out that the initial conditions will not have any significant impact on our results. For example, if we instead assumed that initial capital is 15 percent above steady state then the output in 1919 would be changed by a dwarfish 0.07 percent (see also the Appendix).

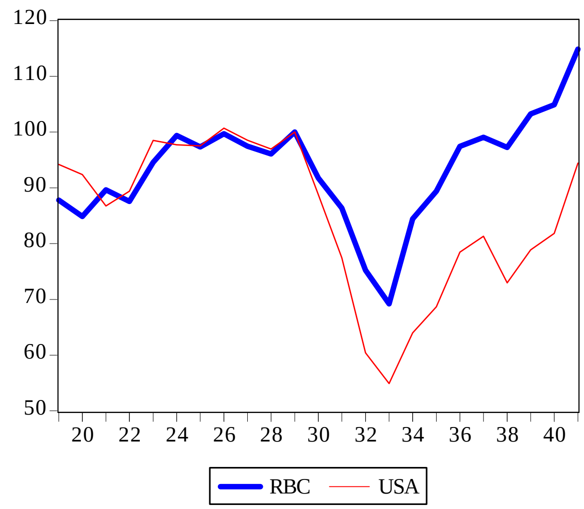

Figure 7: US and artificial output, 1919-1941, 1929=100

and data is 0.60. More relevant for us, the model is extremely successful in replicating the overall experience of the 1920s: this correlation is 0.84, and for the period from 1922-1929 there is an almost perfect fit (0.92). Starting at the trough of 1921, the model can explain 76 percent of the expansion through 1929: technological changes can account for almost all of the unique growth reported in Table 1. Just like in the data, the model's 1920s peak is in 1926; and the 1929 value is indistinguishable from this peak. As for the three recessions, output rises in the model from 1920-21. Recalling that this recession has been largely attributed to inept monetary policy (for example, Friedman and Schwartz, 1963), this is not surprising. Model output also rises during the period of the next, much milder, recession: from 1923-24. In both of these cases, however, model output falls in the year following the actual recession. TFP followed the same pattern: rising during the recession years and falling after. The model, by attributing fluctuations only to changes in technology, therefore predicts that both recessions come too late. The recession from 1926-27, is, however, well-captured by the model, with a simultaneous fall in TFP that, as discussed above, reflects the negative technology shock brought on by disruptions related to Ford's closing of his factories to switch from Model T to Model A. [9]

4.2 Variable utilization

> "Efforts to measure the percentage utilization of the productive capacity of real capital stocks are to be welcomed as adding to our information on explanatory variables. Unfortunately no reliable long-run measures of this variable are available either for the business economy or for most of its individual divisions." [Kendrick, 1973, 26]

There is considerable evidence that utilization rates of capital vary significantly over the short and medium run. The subsequent issue of mismeasurement of TFP at business cycle frequencies goes back at least to Summers' (1986) critique of RBC theory. Unfortunately, we do not have data for capital utilization over our sample period. Potential solutions to this include the use of a proxy. For example, Burnside, Eichenbaum and Rebelo (1995) employ electricity consumption and find that adjusted TFP is much less volatile than the naive Solow residual. Data on electricity production is in fact available for the 1920s. However, we are reluctant to use it because of the extraordinary structural changes in manufacturing's use of electricity during the 1920s. It would be hard to distinguish between trend and cycle.

Hence, we instead compute a series of model-consistent utilization rates.[10] In particular, (1) determines the optimal utilization rate as a function of both output and the capital stock. We therefore compute[11]:

$$u_t = \left(0.33\frac{y_t}{k_t}\right)^{1/2.56}.$$

Figure 8 plots the detrended series $\{u_t\}$. We see an unusually high, persistent and smooth rate of capital utilization during the 1920s: with 1929=100, the

[9] The reader will also notice that the model's fall in output starting in 1930 is not as deep as that in the data. This evidence, that productivity cannot explain the weakness of output, is reminiscent of that of Cole and Ohanian (1999), who find that technology shocks cannot explain fully the depth of and weak recovery from the Great Depression.

[10] See also Weder (2006).

[11] When we apply the same procedure to post-war data, the resulting series replicates well the *Federal Reserve*'s Industrial Production and Capacity Utilization Index. See Appendix.

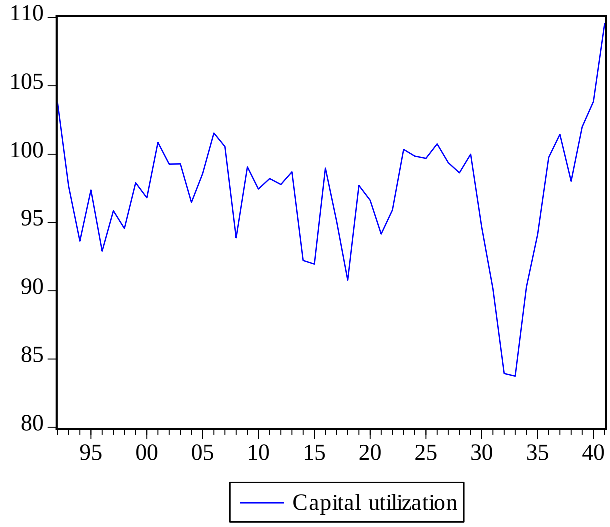

Figure 8: Utilization rate of capital, 1892-1941, 1929=100

index varies only from 94 to 101, and is on average quite high, especially over the later part of the decade. This is followed by a massive drop in utilization at the start of the Great Depression.[12] The high rate in 1941 very likely reflects the effects of the war in Europe on the United States.[13]

Next, a new series for total factor productivity is computed, accounting for variable utilization, by

$$z_t = \frac{y_t}{(u_t k_t)^{0.33}(A_t h_t)^{0.67}}.$$

The resulting (log-linearly detrended) series is well-described by a first order autoregressive process with $\rho = 0.54$.[14] Utilization-adjusted TFP is plotted vis-a-vis the naive version in Figure 9 (normalized in 1929). Since utilization

[12] As a benchmark for accuracy, Bresnahan and Raff (1991) suggest that about twenty percent of the aggregate capital stock lay fallow at the depth of the Depression in 1933. If we interpret the values for 1929 being near full utilization, our constructed series matches this figure.

[13] For example, Roosevelt signed the *Lend-Lease Act* in early 1941, which committed U.S. weapons to the Allied forces.

[14] Utilization does not affect long run TFP, as it does not follow a trend. Hence, the growth rates of naive and adjusted TFP are indistinguishable

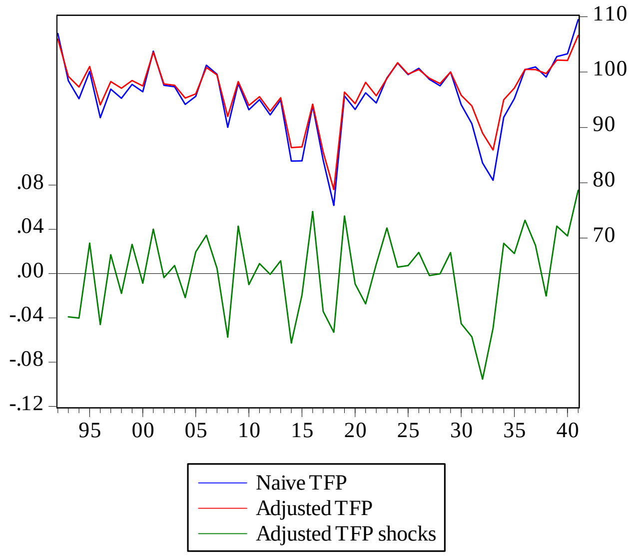

Figure 9: Utilization adjusted TFP (detrended, 1929=100)

of capital did not vary much during the 1920s, we expect the two series to be highly correlated; and their correlation coefficient is in fact 0.99. As is typical, adjusted TFP is less volatile, reflecting factor hoarding.

Figure 10 displays artificial output, when shocked with utilization-adjusted TFP, and US data on per capita output between 1919 and 1941. Again, the US data are detrended by their 1892 to 1941 trend and both series are scaled to equal 100 in 1929. The two series are again very similar. The year to year correlation is about the same as the plain vanilla model's: 0.61 versus 0.60 for 1919-1941. Overall, the model again is able to replicate the eight year boom followed by a massive four year drop in 1929. However, when evaluated numerically, for the 1920-1929 stretch the artificial economy now performs worse: the correlation falls to 0.58 from 0.84. (Starting from 1922, however, there is a 73% correlation between model and data.) Since TFP again falls only after each of the first two recessions, model output falls a year too late in each case. In addition, the model now peaks too early – in 1924; and this peak is about 4% higher than the value in 1929. Adjusting for utilization appears to take out some of the effects of technological progress that the naive accounting suggested for the 1920s.[15]

To better understand this result, Figure 11 displays the TFP input from each simulation. The two series correspond to the cycle component from Figure 3 and the equivalent series constructed from utilization-adjusted TFP. While they appear to be almost identical, the movements of utilization-adjusted TFP are usually smaller, again reflecting factor hoarding. The only exception is 1921 in which the adjusted TFP was larger. Again, other factors played a crucial role in this recession. Moreover, as can be seen from Figure 9, adjusted TFP is higher than the naive version during most of the early 1920s. Together with the stronger propagation mechanism of the endogenous-utilization economy, this produces two effects. First, there is a larger response to TFP's upswing in 1923 and 1924, resulting in output that is too high relative to data. Second, once either model is away from its (stable) steady state, it endogenously reverts back to it. This effect is also stronger in the variable utilization model, so output declines relative to the plain vanilla model, and to the US data. The second effect dominates later, since shocks to TFP are relatively small after 1924. In summary, the predictions for the 1920s of the utilization-corrected model are less successful than those of the standard RBC model.

5 Concluding remarks

This paper has examined the origins of the Roaring Twenties in the United States. In particular, we applied a version of the real business cycle model to test the hypothesis that an exceptional pace of productivity growth was the driving factor behind eight extraordinary years of economic boom.

Our motivation comes from abundant evidence of significant technological progress during this period. In particular, process innovations and the widespread adoption of electricity in manufacturing and in particular the frictional horsepower electric motor led to economy-wide increases in productivity. Therefore, we have included only technology shocks here. In fact, this paper is the first that numerically evaluates the general equilibrium effects of the technological change on the US economy during the 1920s. Using a plain vanilla RBC model, our estimated TFP shocks lead to artificial out-

[15]However, the model's performance is about the same as the standard RBC model's for the 1930s. This supports Ohanian's (2001) suggestion that accounting for utilization should not much affect the RBC model's predictions for the Great Depression.

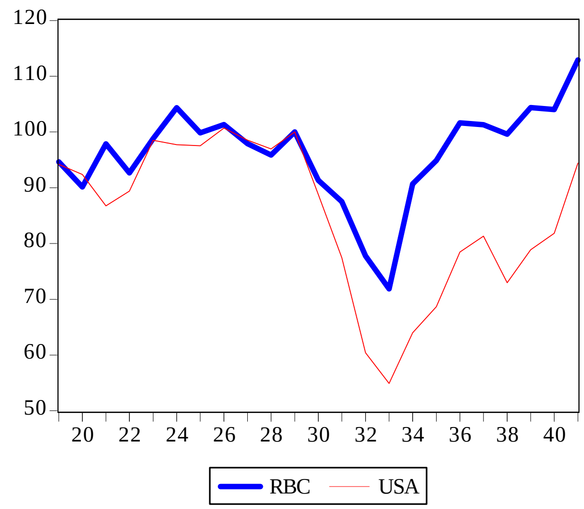

Figure 10: Artificial economy (variable capital utilization, 1929=100)

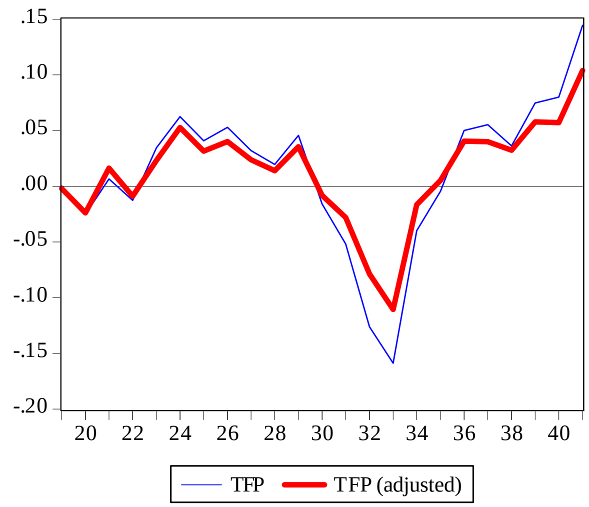

Figure 11: TFP (percentage) deviations from trend

put series that are highly correlated with the data, especially over the period 1922-1929. Since these years are generally considered the defining ones for the 1920s, we take it from our analysis, that extraordinary technological change was the main force behind the Roaring Twenties. The model also predicts well the 1926-27 recession. However, when we allow for variable capital utilization, the model is considerably less successful at replicating both the general nature of the decade, and its ups and downs.

In the future we may extend this analysis in several different directions. More information may be gleaned from a model in which technical change is allowed to be investment-specific. In addition, Olney (1991) attributes much of the robustness of growth during the 1920s to the expansion of the availability of credit. A model that incorporates this feature of the economy would shed more light on this unique episode in U.S. economic history.

References

[1] Allen, Frederick Lewis (1931): *Only Yesterday*, Harper & Row, New York.

[2] Atack, Jeremy and Peter Passell (1994): *A New Economic View of American History*, W.W. Norton New York.

[3] Berry, Thomas S. (1988): *Production and Population Since 1789: Revised GNP Series in Constant Dollars*, The Bostwick Press, Richmond.

[4] Bordo, Michael D., Christopher J. Erceg and Charles N. Evans (2000): "Money, Sticky Wages and the Great Depression", *American Economic Review* **90**, 1447-1463.

[5] Bresnahan, Timothy F. and Daniel M. Raff (1991): "Intra-industry Heterogeneity and the Great Depression: The American Motor Vehicles Industry, 1929–1935", *Journal of Economic History* **51**, 317–331.

[6] Burnside, Craig, Martin Eichenbaum and Sergio Rebelo (1995): "Capital Utilization and Returns to Scale", *NBER Macroeconomics Annual* **10**, 67-110.

[7] Cole, Hal L. and Lee E. Ohanian (1999): "The Great Depression in the United States from a Neoclassical Perspective", *Federal Reserve Bank of Minneapolis Quarterly Review* **23**, 2-24.

[8] Cole, Hal L. and Lee E. Ohanian (2004): "New Deal Policies and the Persistence of the Great Depression: A General Equilibrium Analysis", *Journal of Political Economy* **112**, 779-816.

[9] Cooley, Thomas F. (1997): "Calibrated Models ", *Oxford Review of Economic Policy* **13**, 55-69.

[10] Devine, Warren D., Jr. (1983): "From Shafts to Wires: Historical Perspectives on Electrification", *The Journal of Economic History* **43,** 347-372.

[11] Evans, Charles L. (1992): "Productivity Shocks and Real Business Cycles", *Journal of Monetary Economics* **29**, 191-208

[12] Field, Alexander (2003): "The Most Technologically Progressive Decade of the Century", *American Economic Review* **93**, 1399-1414.

[13] Field, Alexander (2006): "Technological Change and U.S. Productivity Growth in the Interwar Years", *The Journal of Economic History*, **66**, 203-236.

[14] Field, Alexander (2009): "US Economic Growth in the Gilded Age", *Journal of Macroeconomics* **31**, 173-190.

[15] Friedman, Milton and Anna Jacobson Schwartz (1963): *A Monetary History of the United States, 1867-1960*, Princeton University Press, Princeton.

[16] Greenwood, Jeremy, Zvi Hercowitz and Gregory Huffman (1988): "Investment, Capacity Utilization, and the Real Business Cycle", *American Economic Review* **78**, 402-417.

[17] Harrison, Sharon G. and Mark Weder (2006): "Did Sunspot Forces Cause the Great Depression?", *Journal of Monetary Economics* **53**, 1327-1339.

[18] Harrison, Sharon G. and Mark Weder (2008): "Technology, Credit and Confidence During the Roaring Twenties", Barnard College and University of Adelaide, mimeographed.

[19] Johnson, G. (1954): "The Functional Distribution of Income in the United States 1850-1952", *Review of Economics and Statistics* **36**, 175-182.

[20] Kendrick, John W. (1961): *Productivity Trends in the United States*, Princeton University Press, Princeton.

[21] Kendrick, John W. (1973): *Postwar Productivity Trends in the United States 1948-1969*, Princeton University Press, Princeton.

[22] Kyvig, David E. (2002): *Daily Life in the United States, 1920-1939: Decades of Promise and Pain,* Greenwood Press.

[23] McGrattan, Ellen R. and Lee E. Ohanian (2007): "Does Neoclassical Theory Account for the Effects of Big Fiscal Shocks? Evidence from World War II", Staff Report 315, Federal Reserve Bank of Minneapolis.

[24] McGrattan, Ellen R. (2006): "Real Business Cycles", in: *The New Palgrave Dictionary of Economics*, 2nd Ed (forthcoming).

[25] Maddison, Angus (1991): *Dynamic Forces in Capitalist Development*, Oxford University Press, Oxford.

[26] Ohanian. Lee E. (2001): "Why Did Productivity Fall So Much during the Great Depression?", *American Economic Review* **91**, 34-38.

[27] Olney, Martha (1991): *Buy Now, Pay Later: Advertising, Credit and Consumer Durables in the 1920s*, The University of North Carolina Press.

[28] Oshima, Harry T. (1984): "The Growth of U.S. Factor Productivity: The Significance of New Technologies in the Early Decades of the Twentieth Century", *The Journal of Economic History* **44**, 161-70.

[29] Report of the Committee on Recent Economic Changes of the President's Conference on Unemployment (1929), in *Recent Economic Changes in the United States*, Volumes 1 and 2

[30] Romer, Christina D. (1989): "The Prewar Business Cycle Reconsidered: New Estimates of Gross National Product, 1869-1908", *The Journal of Political Economy* **97**, 1-37.

[31] Schurr, Samuel H. and Bruce C. Netschert (1960): *Energy in the American Economy, 1850-1975*, John Hopkins Press, Baltimore.

[32] Smiley, Gene (2008): "US Economy in the 1920s". EH.Net Encyclopedia, edited by Robert Whaples, http://eh.net/encyclopedia/article/Smiley.1920s.final

[33] Summers, Lawrence H. (1986): "Some Skeptical Observations on Real Business Cycle Theory", *Quarterly Review Federal Reserve Bank of Minneapolis*, 23-27.

[34] Temin, Peter (2008): "Real Business Cycle Views of the Great Depression and Recent Events: A Review of Timothy J. Kehoe and Edward C. Prescott's Great Depressions of the Twentieth Century", *Journal of Economic Literature* **46**, 669–84.

[35] Weder, Mark (2006): "The Role of Preference Shocks and Capital Utilization in the Great Depression", *International Economic Review* **47**, 1247-1268.

[36] Weir, David (1986): "The Reliability of Historical Macroeconomic Data for Comparing Cyclical Stability, *Journal of Economic History* **46**, 353-365.

6 Appendix

This Appendix presents robustness checks of our reported results. First, we show that our data representation is not overly dependent on the detrending method. Let us follow Cole and Ohanian (1999) and trend-adjust by dividing output by its 20th century long-run trend growth rate – 1.9 percent relative to the reference date. Figure 12 illustrates. Except for the brief 1906-07 boom, the US economy did not spend much time as aloft as in 1920s. Overall, the higher trend does not change the punch-line of our paper. We are reluctant to use the "1.9 percent deflator" since TFP grew at a much smaller rate during the prewar era: the 1892 to 1941 grow rate was about 1.5 percent. Perhaps it is sensible to assume that there was a structural break after the war, in any case, we do not elaborate on this break issue here. Hence, we deflate by the prewar rate in the paper. We also note that our cyclical output time series is very similar to Berry's (1988).

Our other robustness check involves our decision to begin our simulations in 1892 with an initial capital stock 15% below trend. To show the small effect of this– resulting from the low frequency movements of the capital stock – we alternatively begin the simulation in 1919 with an initial capital stock that is ten percent below the model steady state. The ten percent reflect the resulting value after detrending the series on capital. Figure 13 shows that this has a negligible effect.

Figure 14 shows that our capital utilization series is very similar to the *Federal Reserve Bank*'s measure. The fit is not perfect but in the absence of any data for the 1920s, we have used our best estimate. The correlation is 0.72 overall, and 0.92 for the first twenty years. The two series diverge the most in the second half of the 1990s. This likely reflects IT-related structural changes – i.e. a break in trend – in the US economy (source of data: BEA).

Lastly, using the sample 1919-1941, we test if technology evolves exogenously. The results for an Evans (1992) like test were

$$\ln z'_{t+1} = \underset{(2.33)}{2.53} + \underset{(1.86)}{0.44}\ln z'_t - \underset{(0.60)}{0.003}\Delta \mathrm{m}_t - \underset{(0.23)}{0.003}\mathrm{i}_t - \underset{(0.58)}{0.00001}\Delta \mathrm{G}_t$$

where the numbers in parenthesis are absolute t statistics. Here z' denotes (detrended) TFP, $\Delta \mathrm{m}_t$ stands for the change in M2, i is the three month Treasury Bill and $\Delta \mathrm{G}_t$ is the change in (real) government purchases. All three additional variables were found to be statistically insignificant. Utilization adjusted TFP yields similar results.

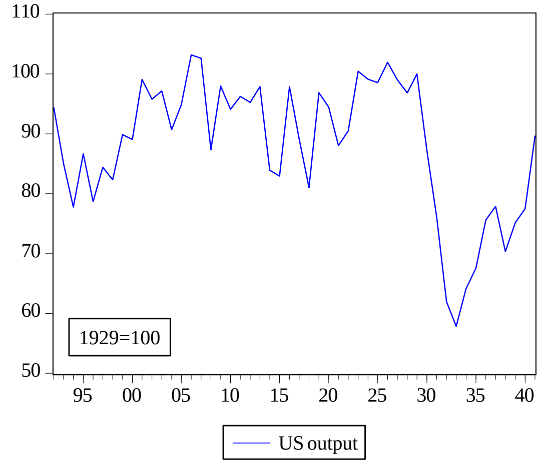

Figure 12: Detrended per capita output

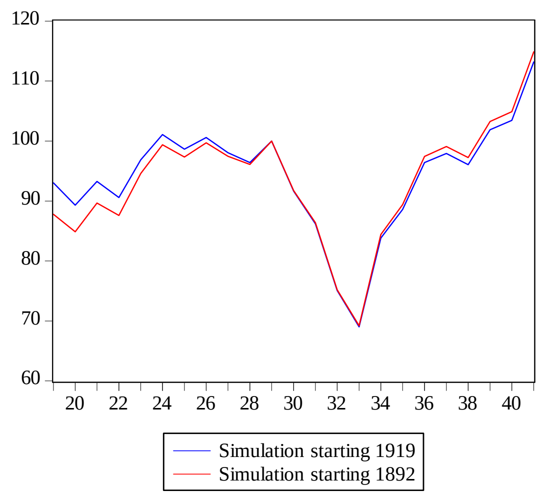

Figure 13: Simulation with different intial conditions.

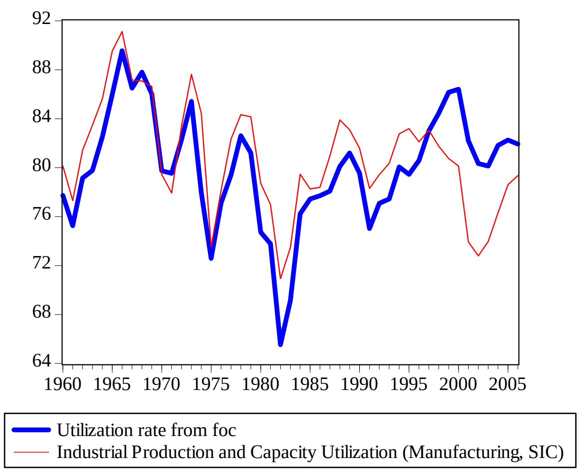

Figure 14: Capital utilization rates