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US Economic Growth in the Gilded Age

by

Alexander J. Field*
Department of Economics
Santa Clara University
Santa Clara, CA 95053
email: afield@scu.edu

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ABSTRACT

In the immediate postwar period, Moses Abramovitz and Robert Solow both examined data on output and input growth from the first half of the twentieth century and reached similar conclusions. In the twentieth century, in contrast with the nineteenth, a much smaller fraction of real output growth could be swept back to the growth of inputs conventionally measured. The rise of the residual, they suggested, was an important distinguishing feature of twentieth century growth. This paper identifies two difficulties with this claim. First, TFP growth virtually disappeared in the U.S. between 1973 and 1995. Second, TFP growth was in fact quite robust between the end of the Civil War and 1906, as was in fact acknowledged by Abramovitz in his 1993 EHA Presidential address. Developing a revised macroeconomic narrative is essential in reconciling our interpretation of these numbers with what we know about scientific, technological, and organizational change during the gilded age.

Introduction

In the immediate postwar period, Moses Abramovitz and Robert Solow both examined data on output and input growth for the United States and reached striking and similar conclusions. The pattern of disembodied technical change in the United States appeared to be markedly different in the twentieth century as compared with the nineteenth. In the twentieth century, a much smaller fraction of real output growth could be swept back to the growth of inputs conventionally measured: the residual, correspondingly, was much larger. Abramovitz published his findings in 1956, Solow in 1957, and their generalization rapidly became accepted as identifying a permanent change in the sources of economic advance. At the end of his career, Abramovitz continued to characterize the twentieth century as experiencing "Growth in the Era of Knowledge Based Progress", distinguishing it from the nineteenth (Abramovitz and David, 2000).[1]

Solow's 1957 study examined data covering the four decades between 1909 and 1949; Abramovitz's 1956 study examined growth up through an end period that averaged data between 1944 and 1953. The big acceleration in TFP growth during the interwar years (see below) surely colored their conclusions. Yet, as an examination of the U.S. growth experience during the last part of the twentieth century makes clear, their generalization about the nature of twentieth century growth was premature. After a lag

[1] TFP advance is often equated with disembodied technological change, which should be understood broadly. The residual captures growth in output not attributable to growth in inputs conventionally measured. This may be the consequence of organizational innovation. It can also reflect shifts in the economy from sectors with lower to those with higher productivity, as well as quality improvements in inputs not otherwise accounted for. Some of these considerations imply that TFP growth may overestimate the effect on output per hour of technological change narrowly defined, but it can also underestimate it to the degree the latter raises the return to capital, inducing higher saving, or skews income to households with higher income and higher propensities to save, in either case leading to rises in capital labor ratios. Those who devote time to refining these estimates must, however, believe that they tell us something of interest about the sources of economic growth. Abramovitz was famous for characterizing TFP growth as a "measure of our ignorance," but he also clearly felt that measures of the rate of advance of the residual bore some relationship to the growth of (useful) knowledge.

during the war period (1941-48), TFP growth persisted at high although somewhat more modest rates during the golden age (1948-73). But it then ground to an almost complete halt between 1973 and 1995. Output per hour continued to rise, albeit much more slowly, but this was almost entirely attributable to physical capital deepening. Data are now available for the entire century, and it is no longer possible to interpret the high rate of TFP advance during the interwar years that prompted the Abramovitz/Solow generalization as a defining characteristic of the century as a whole.

The collapse of TFP growth after 1973 is, however, only one aspect of the difficulty with the Abramovitz/Solow claim. The other is that TFP growth in the last part of the nineteenth century was in fact robust relative to long run historical trends, and indeed, far stronger than it was in the last part of the twentieth. It looks modest only in comparison with the exceptional performance in the second and third quarters of the twentieth century, but that would be true of almost any other period held up for comparison. The available data simply do not support the suggestion that almost all growth in the last third of the nineteenth century can be swept back to inputs conventionally measured.

The principal statistical source for this investigation is Kendrick (1961). Kendrick's work has been the starting point for almost all modern research on U.S. productivity growth prior to 1948. In the 1950s both Abramovitz and Solow worked with his then unpublished data, Abramovitz and David (1973) used Kendrick for their post 1909 analysis, and recent papers, such as Gordon (2000), also begin with Kendrick. I continue in that tradition although, in contrast to other papers (Field, 2003; 2006a,b; 2007 a,b,c,d), I focus here on data for the private domestic economy as well as the private nonfarm economy, because of the important contribution of agriculture in the late nineteenth and early twentieth century.

What does it mean empirically to say that "almost all" growth can be swept back to inputs conventionally measured? In an article coauthored with Paul David in 1973, Abramovitz wrote that "…over the course of the nineteenth century the pace of increase of the real gross domestic product was accounted for largely by that of the traditional, conventionally defined factors of production…. The long term growth rate of total factor productivity lay in a low range from .4 to .6 percent per annum" (Abramovitz and David, 1973, p. 429). They didn't argue that technological change was unimportant in raising output per hour but rather that its effects weren't necessarily apparent in TFP growth. Instead, they saw technical change as inducing a rise in the post Civil War saving rate by increasing the return to investment, and thus influencing the growth in output per hour by affecting the rate of capital deepening. Whatever the merits of this position, and whether or not a rise in the saving rate was a response to higher returns, an aim of this paper is to show that TFP growth was in fact quite robust from the 1870s through the first decade of the twentieth century.

Abramovitz and David reported TFP growth of .5 percent per year between 1855 and 1905, with approximately .3 percent per year up through 1890, accelerating to .8 percent between 1890 and 1905 (Abramovitz and David, 1973, p. 430). The authors did not present the numbers, in levels, that underlay their growth calculations,[2] which makes it difficult to ask of the data questions others than those they posed. They promised that "the full body of data (would) be presented for examination in a later publication" (Abramovitz and David, 1973, p. 431), but this promise has been only partially met. Some modifications in reported growth rates were, however, made in subsequent publications. The main change appears to have been recalculation for the private

[2] Output for example, was based on unpublished worksheets from Robert Gallman. See Rhode (2002).

domestic economy, as opposed to a somewhat larger aggregate in the earlier work. They reported TFP growth rates for the private domestic economy between 1855 and 1890 as .36 percent per year (Abramovitz, 1993, p. 223) or .37 percent per year (Abramovitz and David, 2000, p. 20).

A rate of TFP increase of .37 percent per year for 35 years is pretty low, and implies a total rise in the level of TFP over the period of less than 14 percent. Can this rate of growth be made consistent with the estimate of 1.22 percent per year between 1873.5 and 1892 derived from the Kendrick data (see Table 1 below)? That rate running from 1873.5 to 1890 would have raised the level of TFP by a total of more than 22 percent. So for the Abramovitz and David numbers to be consistent with those reflected in Table 1, derived from Kendrick, TFP would have had to have fallen between 1855 and 1873.5., at a rate approaching -.4 percent per year.

Precisely that possibility is in fact acknowledged in Abramovitz's presidential address to the Economic History Association, where he breaks down the 1855-90 epoch into two subperiods, reporting TFP growth for the PDE of -.4 percent per year between 1855 and 1871 and 1.00 percent per year between 1871 and 1890 (with .91 percent per year between 1890 and 1905) (Abramovitz, 1993, p. 228). He acknowledges that these subperiod calculations present potential problems for his interpretation:

> Those who prefer to form their view from the shorter long swings would look instead to the figures in Table 2. One might then tell a somewhat different tale. One might then say that the years when the growth of capital intensity was the dominant contribution to labor productivity growth were the mid century years, from 1835 to 1871. One might argue that a transition toward a development pattern resembling that of the present century began during the last quarter of the last century. And one would be supported in this view by the facts that in those years TFP became much larger…" (Abramovitz, 1993, pp. 227-28).

This reference to a possible alternative to what has become the standard narrative is, however, absent in Abramovitz and David (2000), where we are again given data only for the very long periods 1855-1890 and 1890-1927. [3] The low reported TFP growth between 1855 and 1890 obscures robust gilded age TFP advance because it combines the influence of the years 1855-1871, in which TFP fell, with a post 1871 period in which it rose.

As noted, the first part of this period, 1855 -1871, is one in which, according to Abramovitz, TFP fell at -.4 percent per year, which means that the level of TFP was about 6 percent *lower* in 1871 than it had been in 1855. Why might this have been? The impact of the Civil War is a plausible explanation. War can push technological frontiers forward in certain areas, but its overall impact is likely to be retardative. With over 600,000 fatalities in a population of roughly 31 million, with widespread physical destruction in the South, and with the wrenching changes associated with the demise of the peculiar institution, it is hardly surprising that the progress of innovation was set back. War requires sharp but transient dislocations of an economy, and while it is true that challenge or adversity can sometimes stimulate invention, war, on balance, does not generally provide a fertile environment for scientific, technical, and organizational progress (Field, 2000b; for an alternate view see Ruttan, 2006).

Understanding Abramovitz's estimate of .37 for TFP growth in the PDE between 1855 and 1890 as resulting from the combination of -.4 percent per year from 1855 through 1871 followed by 1.00 percent per year from 1871 through 1890, numbers which are similar to those in Table 1 below, we have the foundation, as Abramovitz recognized,

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[3]Editing by Cambridge University Press apparently eliminated the detailed appendix tables that would have included the sub period calculations (personal communication from Paul David). My point, however, is as much about narrative as it is about data. It remains true that the view into an alternate interpretation of the 19th century data, which one finds in Abramovitz (1993), is absent in Abramovitz and David (2000).

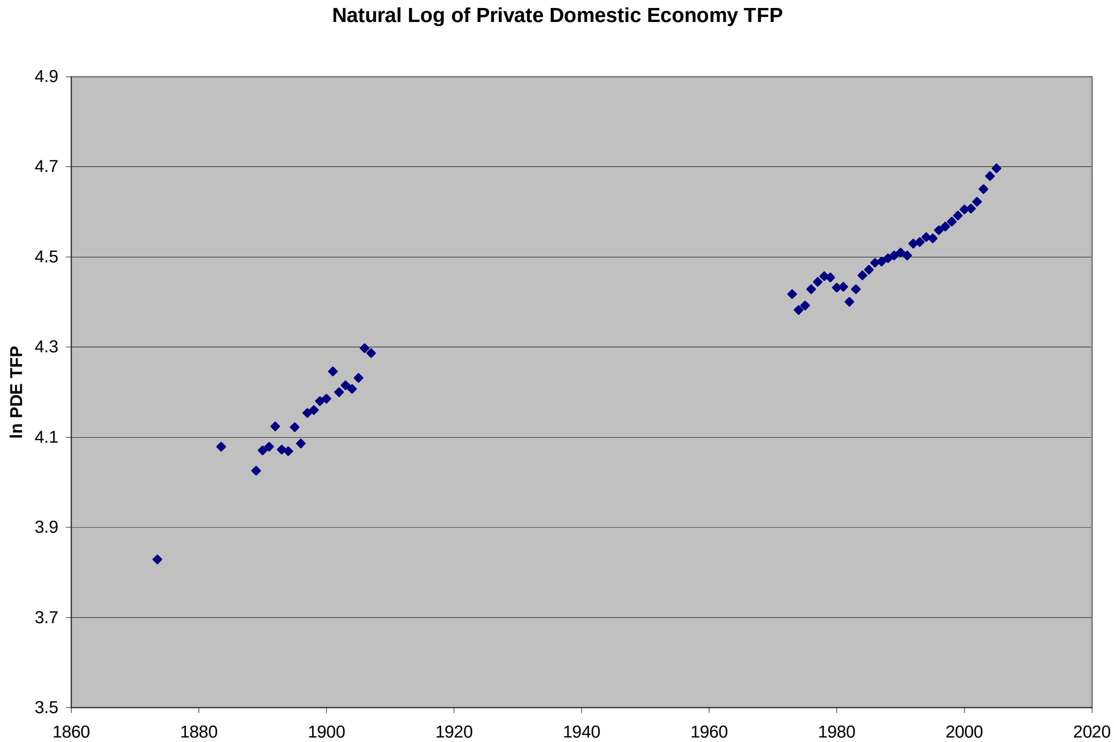
for a rather different narrative. As Kendrick's data show, and as Abramovitz acknowledged in 1993, TFP growth following the Civil War was robust by absolute standards. And as I will show, it was substantially higher than that experienced in a comparable period of the twentieth century.

Before moving to that task, a quick look backward, prior to the Civil War. It's clear from the analysis of the subperiod data that the post-1871 TFP growth rates pose difficulties for the Abramovitz-Solow narrative. This is less true for the 1835-1871 data, as presented by Abramovitz. The growth rate over that 36 year period also reflects the combined influence of two subperiods, the first between 1835 and 1855, in which growth of output per hour was largely attributable to capital deepening, and the second, as noted, in which TFP fell. Abramovitz has TFP essentially unchanged between 1835 and 1855, dropping at -.01 percent per year over the period (1993, p. 228). Perhaps this was due to the relatively modest rate of advance (compared to the post bellum period) in scientific, technical, and organizational knowledge and practice.

Prior to Fort Sumter, the fundamentals of telegraphic and railroad technology were established, and the country began to build nationwide networks for both. But only 30,000 miles of rail had been put in place on the eve of the Civil War, as opposed to a quarter million miles of main track on the eve of the First World War, and the first transcontinental telegraph line was completed only in 1861. The influence of modern business enterprise was still modest. Railroads, the most important sector in which that organizational innovation would be applied, still comprised a relatively small portion of overall output. And until nationwide networks of railroad and telegraphic communication were filled in, the technical preconditions for the spread of modern business enterprise to distribution and some sectors of manufacturing were incomplete.

The Abramovitz/David calculations, relatively more conjectural for the earlier part of the nineteenth century, show TFP roughly unchanged between 1835 and 1855 before declining across the Civil War period.

Chart 1



But the concern of this paper is with the postwar years, the period imprecisely known as the gilded age – extending from the mid 1870s up through the business cycle peak in 1906. And the basic data in Kendrick – and Abramovitz and David's analysis of subperiod data -- support a conclusion of robust TFP growth over these years. Kendrick provides us with annual data starting in 1889, and prior to that, with estimates for 1869-78 and 1879-88. On chart 1 I have plotted the logged values of Kendrick's TFP estimates for the first two decadal averages and then annually through 1907, along with the logged values of private domestic economy multifactor productivity (TFP) for 1973-2005 from the Bureau of Labor Statistics website. The relative position of these groups of data is not of interest here, because the index numbers in the two clusters of data use different base years. What is relevant are the relative slopes evident in the two groups of data. Visual inspection suggests a steeper slope, and thus faster rate of growth, in the earlier period, an impression confirmed by running a time trend through each cluster.

Ideally, in comparing growth rates in different periods, we would like to measure peak to peak, with each peak at or close to potential output, so as to control for the procyclicality of TFP (Field, 2007d). The NBER dates a strong business cycle peak in May of 1907; Lebergott's annual unemployment series, as well as Romer's filtered series, bottom out in 1906 (Lebergott, 1964; Romer, 1986). This is clearly the end of an important expansion. Because the 1869-78 observation includes roughly two complete peak to trough cycles according to the NBER chronology (June 1869 – December 1870 and October 1873 to March 1879), an estimate for the average over that period cannot be interpreted as corresponding to a business cycle peak. A calculation from the initial observation (treating it as corresponding to 1873.5, the midpoint of the interval) to 1906 shows compound annual growth of TFP of 1.44 percent per year. If TFP was procyclical, however, this growth rate estimate will be biased upward, because the initial data point cannot be treated as corresponding to a peak.

A better estimate is obtained by regressing the log of TFP from 1873.5 through 1907 on a time trend, which yields an estimate of annual TFP growth of 1.23. A relatively straightforward peak to peak estimate runs from 1892 to 1906 (both troughs in the annual unemployment estimates). This yields a rate of 1.24 percent per year for that subperiod, at least 50 percent higher than the .8 percent suggested by Abramovitz and David in their 1973 article for 1890-1905,[4] and substantially higher than rates registered

[4] Abramovitz (1993) reported TFP growth of 1 percent per year between 1871 and 1890 and .91 percent per year for the PDE between 1890 and 1905 (1993, p. 228).

over a comparable period at the end of the twentieth century (.87 percent per year from 1973 through 2005). Abramovitz and David used five year averages centered on years they considered peaks. The choice of beginning and endpoints matters in avoiding cyclical confounds, and on this score 1892 and 1906 – both troughs in annual unemployment series, are on this score more defensible than 1890 and 1905.[5]

The rate of TFP growth implied for the period from after the Civil War to 1892 is more than three times higher than what Abramovitz and David report for the entire period 1855-1890, although much closer to the 1 percent per year Abramovitz reported for 1871-1890 in his Presidential address. These data also suggest the absence of a major discontinuity in TFP growth rates from the end of the Civil War to the 1906 business cycle peak.[6] In contrast with the rapid growth prior to 1906, there follows afterwards a substantial slowdown in TFP growth through 1919, prior to the TFP experience of the 1920s, which, as I have shown elsewhere (Field, 2006a), is almost entirely due to advance in manufacturing.

TFP displays its fastest growth between 1929 and 1941. The calculated growth rates over the periods 1929-1941 and 1941-1948 are based on a cyclically adjusted level

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[5] There are, as the text notes, a set of issues about whether 1892 and 1906 are to be preferred to 1890 and 1905 as business cycle peaks. Another set of issues involves the 5 year averaging method. This is sensible if the most important problem is simply noise in the data. But it is more difficult to defend in the presence of strong cyclical effects. Consider comparing a sharp business cycle peak, with steep drop offs on either side, with a rounded one (close to potential output on either side). In such an environment, measuring between 5 year averages centered on the peaks may give a less meaningful estimate of TFP advance than simply measuring between peaks. The averaging method would, in the above instance, give a result which is biased upward in the presence of procyclical TFP, because the initial period level would be brought down by the lower TFP on either side of the peak more than would the end period level. These issues of method and dating are, however, probably minor in terms of the larger argument of this paper. Whether TFP growth averaged closer to 1 percent or closer to 1.2 percent a year over the gilded age is in some sense beside the point, since both numbers reflect robust advance relative, for example, to growth at the end of the twentieth century.

[6] The identification of a peak can differ depending on the frequency of data examined. For monthly data, one would say May 1907; for quarterly data , 1907:2, but for annual data, 1906, because this is the year for which the estimates of the annual unemployment rate bottom out.

for 1941, but this characterization holds even without the adjustment (see footnote a to Table 1 and Field, 2007b).

Table 1
TFP Growth estimates, United States, Private Domestic Economy, 1869/78-2005

1869/78-1892[a]	1.23
1892-1906	1.24
1906-1919	.85
1919-1929	1.97
1929-1941[b]	2.66
1941-1948[b]	.84
1948-1973	2.13
1973-1989	.53
1989-2000	.93
2000-2005	1.83

a This estimate is based on a regression of logged values of TFP from 1869-78 though 1907 which yields a trend growth rate of 1.23 percent per year. Since the first two observations are averages for ten year periods, and assuming some procyclicality of TFP over this year, this is probably a slight overestimate, since the initial period included almost two complete peak to trough cycles (see text). A straight calculation for this period from the Kendrick data, centering 1869-78 on 1873.5, yields 1.59 percent per year, which may partly reflect some procyclicality in TFP or remaining recovery from the Civil War. The 1892-1906 calculation is defensible as peak to peak, since both years represented troughs in the annual unemployment series. The main conclusion is that TFP advance in the post Civil War decades prior to 1892 was not dissimilar to that experienced between 1892 and 1906.

b These growth rates are based on a cyclically adjusted TFP level for 1941. Unemployment in 1941 was still 9.9 percent, and TFP was strongly procyclical over the years 1929-41 (as it has been for more than a century – see Field 2000d), suggesting that its level would have been higher had the economy been closer to full employment in the last year before full scale war mobilization. The adjustment is made, using data from 1929 to 1941, by regressing the TFP growth rate from the previous year (difference in natural logs) on the change in the unemployment rate (percentage points), and then using the coefficient on change in unemployment to calculate what 1941 PDE TFP would have been had the economy been at potential output, defined as the 3.8 percent unemployment experienced in 1948. The regression results are:

$$\Delta TFP = .0270 - .0077^{*} \Delta UR$$
$$R^2 = .660 \quad (3.53) \quad (-4.41)$$

(t statistics in parentheses; data are for 1929-41; n = 12)

There is a 6.1 percentage point difference between actual 1941 unemployment (9.9 percent) and unemployment at potential output (the 3.8 percent of 1948); implying that 1941 TFP would have been 4.7 percent higher than in fact it was had the economy been fully employed. The unadjusted growth rates, calculated directly from Table A-XXII of Kendrick, are 2.27 percent per year for 1929-1941, and 1.51 percent per year for 1941-1948. For application of this methodology to data on the private nonfarm economy, see below and additional discussion in Field (2007b).

Source: 1869/78 - 1948: Kendrick, 1961, Table A-XXII. 1948-2000. www.bls.gov, accessed January 26, 2006; 2000-2005, www.bls.gov, accessed October 18, 2006.

From 1948 onward, data are from the BLS website. The logged values of TFP (MFP) levels from the BLS website from 1973 through 2005 are also plotted on chart 1. Peak to peak calculations for 1973-89 yield .53 percent per years, increasing to .93 percent per year from 1989 to 2000 and to 1.83 percent per year between 2000 and 2005. For the entire 1973-2005 period, the compound annual growth rate is .87 percent per year.

These data show that TFP growth rates in the last part of the nineteenth century were far stronger than the narrative we have come to accept suggests, and substantially higher than they were during corresponding years in the twentieth century. This comparison and reframing is important, because it offers the possibility of reconciling what has become a troubling disconnect in the teaching of U.S. economic history. How could it be that the build out of the transcontinental railway and telegraph networks and the development of modern business enterprise (Chandler 1977, Field, 1987), which both enabled and was in turn enabled by these new technologies, had so little imprint on the TFP data? How could it have been that the new technologies of the second industrial revolution, such as Bessemer and Siemens-Martin open hearth steel, the Bonsack cigarette making machine, or the disassembly line pioneered by Swift in meat packing, left so little trace on the data? Add to this David and Wright's argument that advance in mineral extraction was heavily dependent on a knowledge base developed and transmitted in universities, schools of mines, and professional associations (David and Wright, 1997), as well as the dependence of the growth of American agricultural output on biological innovation resulting from government sponsored R and D (Olmstead and Rhode, 2002), and there is a real puzzle.

Table 2
TFP Growth estimates, United States, Private Nonfarm Economy, 1869/78-2004

1869/78-1892[a]	1.95
1892-1906	1.11
1906-1919	1.12
1919-1929	2.02
1929-1941[b]	2.78
1941-1948[b]	.49
1948-1973	1.90
1973-1989	.34
1989-2000	.78
2000-2004	1.85

a This estimate is based on a regression of logged values of PNE TFP from 1869-78 though 1907 which yields a trend growth rate of 1.59 percent per year. One needs 1.95 percent per year TFP growth from 1873.5 to 1892 to make the trend growth rate through 1907 consistent with the peak to peak calculation for 1892-1906.

[b] These growth rates are based on a cyclically adjusted TFP level for 1941 (see note b to Table 1). The adjustment is made, using data from 1929 to 1941, by regressing the PNE TFP growth rate from the previous year (difference in natural logs) on the change in the unemployment rate (percentage points), and then using the coefficient on change in unemployment to calculate what 1941 PNE TFP would have been had the economy been at potential output, defined as the 3.8 percent unemployment experienced in 1948. The regression results are:

$$\Delta TFP = .0283 - .0092 * \Delta UR$$
$$R^2 = .647 \quad (3.02) \quad (-4.28)$$

(t statistics in parentheses; data are for 1929-41; n = 12)

The unadjusted growth rates, calculated directly from Table A-XXIII of Kendrick, are 2.31 percent per year for 1929-1941, and 1.29 percent per year for 1941-1948. For additional discussion, see Field (2007b).

Source: 1869/78 - 1948: Kendrick, 1961, Table A-XXIII. 1948-2000. www.bls.gov, accessed January 26, 2006, 2000-2004, accessed October 18, 2006.

How can one reconcile the influence of all these factors with the suggestion that TFP growth averaged just .5 percent a year from the end of the Civil War into the first decade of the twentieth century? This number obscures the relatively high post 1871 TFP growth rates by combining them with the period of falling TFP between 1855 and 1871. The commonly quoted generalization that TFP grew at about half a percent a year in the post Civil War nineteenth century is inconsistent with the post 1871 data and with what we know qualitatively and at the sectoral level about the evolution of the economy after the war.

Consider first the railroads and Fogel's 1964 study of their social saving. Fogel concluded that had saving flows been congealed in somewhat inferior capital investments (canals, river dredging), U.S. GDP would have been about 4 percent lower in 1890 than it was. Now, 4 percent is not a large number, but neither is it 0, and it can be translated into an increment to TFP growth. Over a 25 year period (1865 to 1890), a .15 percent per year increment to TFP growth, continuously compounded, yields a 4 percent boost to GNP in 1890. Suggesting that total TFP growth up through 1890 was in the range of .37 percent per year, as did Abramovitz and David, leaves only .22 percent per year for everything else. We should not, however, feel obliged to construct our narrative within such a tight TFP budget.

Consider next that the build out of the railway network combined with the construction of a transcontinental telegraph network gave rise to perhaps the greatest organizational innovation of the last two centuries: what Chandler (1977) called modern business enterprise. Is there any type of innovation that would be more likely to show up in the residual, a measure of disembodied change, than this? The new organizational form was critical for the operation of large railway and telegraph corporations. These technologies were also what allowed MBE to be extended from transport and communications to distribution and ultimately manufacturing (Field, 1987). The .15 percent per year does not account for the spillover effects of the railroad in using sectors, most particularly its enabling of MBE. It will therefore underestimate the railroad's overall contribution to TFP.

If we accept the traditional narrative, MBE had apparently little measurable impact on TFP growth prior to the First World War. When is it supposed to have had an impact? Data from Table 1 for the PDE show TFP growth falling off after 1906. Data from Table 2 (see below) for the private nonfarm economy show some deceleration in TFP comparing 1892-1906 with 1869-92, and Kendrick's incomplete data for manufacturing (see Table 3) show some retardation in that sector as one goes into the first years of the twentieth century. By the time we get to the extraordinary TFP growth in manufacturing of the 1920s (1919-1929), MBE is already well established, and the explanatory focus is less on organizational innovation. Rather it has been on the delayed effects of electrification, particularly the use of wires as a substitute for mechanical gears and shafts in distributing power internally within the factory (Devine, 1973; David and Wright, 2003; Field, 2007c). The 1920s manufacturing revolution, moreover, was an across the board phenomenon– evidenced in the uniformly high rates of TFP advance at the two digit level (see Field, 2006a). The impact of MBE in manufacturing prior to the First World War was far less uniform – quite important in a few key sectors, not so important elsewhere. The same was true for distribution – but not rail transportation, where one had to have it. The data show higher TFP growth in the private nonfarm economy in the period from the end of the Civil War up through 1892. This is the more relevant aggregate if one is interested in the likely effects of MBE, and the data are consistent with its having played a contributing role in robust TFP growth then. Again, this is where Abramovitz's 1993 pre World War I subperiod data shows the fastest TFP growth.

To what degree could the discrepancy between the low TFP rates associated with the conventional narrative and those in Table 1 have to do with differential accounting for the growth of land input? Kendrick does include land in his estimates of farm capital, which are derived from Tostlebe (1957). If Kendrick's numbers do not adequately account for the growth of land input in agriculture, then TFP growth estimates for the private domestic economy for the end of the nineteenth century might be too high. One way to explore this possibility is to examine trends in TFP growth rates for the private nonfarm economy, for which the growth of land inputs is presumably less directly relevant.

To estimate TFP growth rates for the private nonfarm economy from the end of the Civil War up to 1892 I employ a methodology similar to that used for the private domestic economy. First, run a time trend through the logged values of Kendrick's PNE data, centering 1869-78 on 1873.5 and 1879-1888 on 1883.5. This yields 1.59 percent per year, continuously compounded from 1873.5 through 1907. Second, do a relatively clean peak to peak measure between 1892 and 1906, which yields 1.11 percent per year. Third, ask what growth rate one would have needed between 1873.5 and 1892 to be consistent with the results of the first calculation. The answer is 1.95 percent per year. This suggests strong TFP growth in the private nonfarm economy before 1892, moderating thereafter. Keep in mind that 1.11 percent per year between 1892 and 1906 is still substantially higher than what was registered in the U.S. twentieth century economy from 1973 onward. Whereas the Abramovitz and David narrative proposes accelerating TFP after 1890 (.8 percent per year rather than .3 percent earlier), Table 2 suggest some deceleration for the private nonfarm economy comparing the years before and after 1892. Table 1 showed rough constancy for the private domestic economy; the differences have to with some acceleration in TFP growth in agriculture comparing 1892-1906 with the earlier period.[7] Neither Table 1 nor Table 2 is consistent, however, with notable acceleration after 1890. The Abramovitz and David suggestion of .3 percent up through 1890 and .8 percent from 1890 through 1905 is, again, potentially misleading, because the .3 (or .37 percent) from 1855 through 1890 is a productivity growth estimate dragged down by declining productivity across the Civil War period.

The data on sectoral productivity trends is less complete than that for the aggregate measures, but what is available help us flesh out the underpinnings of what we are picking up in Tables 1 and 2.

Table 3 shows rates of TFP growth in mining, manufacturing, and telephone and telegraphs. These data suggest that the biggest gains in manufacturing came in the 1880s, after which growth slowed before the huge acceleration after 1919. In mining, the 1890s appear to have been a particularly fertile period (see David and Wright, 1997), and we also see an acceleration for agriculture. Progress in communication remains relatively strong throughout.

Table 3
TFP Growth in Mining, Manufacturing, and Telephone and Telegraphs, 1869-1919

	Mining	Manufacturing	Tel. and Tel.
1869-79		.86	
1879-89	1.24	1.94	2.30
1889-99	2.49	1.12	1.27
1899-1909	.77	.72	3.98
1909-1919	1.39	.28	1.35

Source: Kendrick, 1961, Tables C-III, D-1, H-III.

The relatively strong gains in manufacturing during the 1880s likely reflect the contribution of modern business enterprise. The 1880s were a big decade for the expansion of such MBE intensive subsectors as steel, cigarettes, meatpacking, and

[7] TFP in agriculture grew at a rate of 1.57 percent per year between 1892 and 1906 as compared with .56 percent per year between 1869 and 1892 (Kendrick, 1961, Table B-1).

petroleum refining. Use of this organizational form required the availability of reliable railroad and telegraph service, and was necessary in manufacturing to exploit economies dependent not just upon scale per se but on ensuring high levels of capacity utilization and rates of inventory turnover.

Finally, the growth of total factor productivity in railroads was very strong throughout the post Civil War period – higher than the rate of growth in the economy-wide aggregates and thus a significant contributor to them. Much of this represented the consequence of a continuing process of technical change resulting in larger locomotives and rolling stock, air brakes, and automatic couplers (Fishlow, 1966). But much, including the economically successful exploitation of such improvements, reflected and depended upon the contribution of modern business enterprise – the organizational form that allowed the operation of private enterprises whose size and dominance in the economy had never been witnessed before and has never been seen since. MBE was an absolute requirement in the business of railroad transportation, especially on a largely single tracked system, whereas MBE was adopted only in portions of the distribution and manufacturing sectors (Field 1992). The high penetration within the railroad sector was unmatched elsewhere, with the possible exception of telephone and telegraphs, which also exhibited TFP growth above that registered in the economy wide aggregates (see Table 3).

Table 4 also includes data on the growth rates of labor and capital productivity (TFP growth rates are a weighted average of the two). Readers may be surprised by the relative rates of increase of labor and capital productivity as well the respective sectoral increases in capital and manhours associated with them. Although the capital output ratio for the economy rose (in other words, capital productivity went down), in part as the consequence of the enormous accumulation in railroads, the situation within the sector itself was quite different. The sector of the economy most thoroughly penetrated by MBE generated rates of increase of capital productivity averaging over 5 percent per year from 1873.5 through 1906. Aside from assuring that trains didn't collide, an event which is, one might say, capital using, advanced logistical control contributed to rises in capital productivity by enabling higher utilization rates on fixed capital and rolling stock. One can interpret this simply as a scale economy, but the ability of a system to generate low costs at high volume is beside the point if volume cannot be managed and sustained at those levels. This required increases in labor input even more rapid than those of capital.

Table 4
Productivity Growth in Railroads, 1873.5-1919

	TFP	Output/hour	Output/unit of capital
1873.5-1883.5	4.25	3.58	5.75
1883.5-1892	2.33	1.86	4.98
1892-1906	2.56	1.82	5.31
1906-1919	3.02	3.33	1.70

Source: Kendrick, 1961, Table G-III.

Whereas capital in railroads grew at 1.96 percent per year between 1873.5 and 1906, manhours rose at 4.92 percent per year (Kendrick, 1961, Table G-III, p. 543).[8] In other words, in railroad enterprises, capital shallowed at a rate of about 3 percent a year, one of the reasons capital productivity went up so much. In contrast, for the private domestic economy as a whole, capital grew at 3.76 percent per year and manhours at 2.75 percent per year between 1873.5 and 1906, so capital was deepening at a rate of about 1

[8] Fishlow (1966) is critical of Ulmer's data which underlie Kendrick's railroad capital stock indices. But even Fishlow's data indicate capital shallowing in railroads, although not to the same degree. Between 1870 and 1910, he has persons engaged growing at 5 percent per year, while capital grew at 4.5 percent per year. Fishlow, 1966, Table 10, p. 626.

percent per year (Kendrick, 1961, Table A-XXII).[9] The trends within the railroad sector are testimony to the degree to which modern business enterprise is a capital saving innovation. MBE uses labor and saves capital (Field, 1987), and this characteristic is especially evident in sectors where the organizational form had its deepest penetration.

The need to insure high volume flows is central to Chandler's emphasis on the importance of throughput, whether he is discussing transportation, communication, distribution, or manufacturing. Modern business enterprise, in the context of the new railroad and telegraph technologies, represented a decisive break with prior modes of business practice. There were no modern business enterprises in 1840. In The Visible Hand (1977) Chandler suggests that if a contemporary business manager were transported back to 1910 he would be pretty much at home in the organizational and management environment, but if he were transported back to 1840, he would be in a different world, and might as well go back to the fifteenth century.

Modern business enterprises employ a multidivisional structure, depend on management information systems, and are run by a cadre of professional managers. Nineteenth century MBEs used the telegraph to move information quickly, the typewriter to create and maintain administrative office records, and the vertical file to store them. The linotype machine and innovations in making cheap paper from wood pulp spelled dramatic reductions in the cost of mass media, which were in turn increasingly utilized by department stores, mail order houses, and manufacturers to stimulate demand for their products or services through advertising.

[9] For the private nonfarm economy, capital grew at 4.99 percent per year, manhours at 3.46 percent between 1873.5 and 1906, so capital deepened at more than 1.5 percent per year (Kendrick, 1961, Table A-XXIII.

MBE developed first in the railroads. The telegraph industry also faced an imperative to manage high speed traffic, and employed MBE as well. The organizational form then spread to wholesale and retail distribution, giving rise to such new institutions as the department store and the mail order house. Finally, it was adopted in a limited number of subsectors of the industrial sector – in such businesses as steel, cigarette manufacturing, petroleum refining, meatpacking, and sewing machines/typewriters. MBE made possible and in turn was technologically dependent on nationwide systems of telegraph communication and railroad transportation. You could not have MBE without the telegraph, and there was no rationale for it without the railroad.

The hypothesis that the diffusion of MBE is implicated in TFP increases is not simply speculative: it leads to testable predictions. The historical narrative is reasonably clear with respect to where the organizational form did and did not take root prior to World War I: almost 100 percent in railroads and telegraphs, in parts of distribution (department stores, mail order houses) and in part but by no means all of the manufacturing sector (steelmaking, cigarette manufacture, meatpacking, petroleum refining, sewing machines/typewriter/firearm assembly) (Chandler, 1977; Field, 1987). The hypothesis predicts that in sectors wholly or partially penetrated by MBE, one should see TFP growth stronger than in the economy as a whole. The data in Tables 3 and 4 are largely consistent with this hypothesis. TFP growth in railroads and telegraphs was above the economy wide average throughout the period in question. In manufacturing this was so in the 1880s and especially the 1890s. Data for the distribution sector are also consistent with this view (see Field, 1996).

Chandler's principal focus was on organizational innovation. In a somewhat similar vein, Vaclav Smil has recently explored the contributions of late nineteenth century scientific and technical advance to twentieth century growth. His main thesis, which bears similarities with Chandler's, is that the four decades prior to the first World War contributed to a decisive break with the past:

> …the fundamental means to realize nearly all of the 20th century accomplishments were put in place before the century began, mostly during the three closing decades of the 19th century and in the years preceding WW1. That period ranks as history's most remarkable discontinuity not only because of the extensive sweep of its innovations but also because of the rapidity of fundamental advances that were achieved during that time (Smil, 2005, pp. 5-6).

A good deal of what Smil goes on to describe represented larder stocking: the establishment of foundations upon which was predicated future progress. But much of the advance had an immediate impact: "Many pre WW1 innovations were patented, commercialized and ready to be diffused in a matter of months (telephone, lightbulbs) or a few years (gasoline powered cars, synthesis of ammonia) after their conceptualization or experimental demonstration" (Smil, 2005, p. 9). Thus TFP growth between the Civil and First World Wars can be interpreted as reflecting the influence of contemporaneous scientific and technical progress combined and sometimes interacting with the effect of evolutionary improvement of systems such as the railroad and the telegraph whose foundations had been established prior to the Civil War. Rapidly commercialized breakthroughs and progress building upon earlier foundations meant that scientific, technical, and organization advance during this period had an impact on the way people lived then, as well as on how they would live after the First World War

In language similar to Chandler's, Smil writes that: "The enormity of the post 1860 saltation was such that people alive in 1913 were further away from the world of their great-grandparents who lived in 1813 than those were from their ancestors in 1513". He makes a similar point about scientific progress, arguing that if one transported the distinguished French chemist Lavoisier forward to the early twentieth century, much of what he would have seen would have been incomprehensible to him. In contrast, transport Edison, Fessenden, Haber, or Parsons (developer of the turbogenerator) to the early twenty first century and they'd be on top of what they were seeing – indeed, they would have provided the scientific and technical foundations for much of it (Smil, 2005, pp. 28, 296).

TFP advance in any given period results from the exploitation of technical systems whose foundations have been laid earlier and from the rapid commercialization of new products and processes resulting from contemporaneous scientific and technical progress. Some of that progress will, however, not be immediately exploited, thus replenishing the cupboard for subsequent periods. One needs to acknowledge the importance of larder stocking without suggesting that scientific and technical progress had little influence on living standards or productivity growth rates prior to the First World War.[10]

Clearly, the mix of larder stocking and immediate impact varied across the different areas of advancement examined by Smil. For example, his exposition gives pride of place to electricity, and we can consider its impact in providing motive power in manufacturing. A small steam engine, he argued, could convert only about 4 percent of coal's energy into power, of which 60 percent was lost in the process of mechanical transmission to the work station via overhead shafts and belts. The transmission system, moreover, had to be shut down typically for about 10 percent of the time for

[10] Again, to be fair to Abramovitz and David, they never made this argument in precisely these terms. But they did argue that virtually all of the influence of technological advance on output per hour worked through a rate of profit/ interest rate mechanism, encouraging higher saving flows and faster rates of physical capital deepening. A corollary was that little of the influence of technological advance was evident in TFP growth.

maintenance. So we are dealing with energy efficiency of about 1.4 percent (.04*.4*.9) for steam generated power distributed mechanically within a factory.

In contrast, by the time of the First World War, electricity produced with a turbogenerator had an energy conversion efficiency of about 10 percent. Assuming 10 percent of this was lost in transmission, and the use of a direct drive electric motor with 85 percent efficiency, we have overall energy efficiency of almost 8 percent (.1*.9*.85) – a five fold improvement. Removing the straightjacket of mechanical distribution of power also allowed substantial savings on floor space and the possibility of moving to single story rather than multiple story installations.

The conventional narrative argues, however, probably correctly, that most of the gains from this source were not realized until the 1920s, and indeed underlay the fabulous – more than 5 percent per year – growth of TFP in the manufacturing sector between 1919 and 1929 (see Kendrick, 1961; Devine, 1983; David and Wright, 2003; Field, 2007c). So whereas it would be fair to say that prewar advances in systems of power generation laid the foundation for post World War I advance in manufacturing TFP, it is unlikely that a great deal of the prewar TFP growth can be attributed to the electrification of industry, at least with respect to motive power. Note that within manufacturing, the Kendrick data suggest the fastest gains in the 1880s, certainly well before any of this could have had much effect.

The situation is quite different, however, with respect to space lighting and traction. By 1900 there were over 1,000 central power stations in the U.S. Much of the demand these stations satisfied was residential, but some was also in commerce and manufacturing, particularly in industries such as textiles where electric lighting offered much lower probabilities of inducing explosions than did gas and facilitated expanded shift work. By absolute standards incandescent bulbs were and still are quite inefficient in turning energy into light, but in comparison to candles or gas, they represented a big improvement. Smil estimated that candles converted .01 percent of paraffin's chemical energy into light, and coal gas no more than .05 percent. By 1913 tungsten filaments converted 2 percent of electric energy into light. With 10 percent generation efficiency and 10 percent transmission losses, energy efficiency had risen to .18 percent (.1*.9*.02), still very low but more than three times that of coal gas. The efficiency of converting coal into electric power benefited from very rapid gains in the electricity generating sector, involving the switch from the use of steam engines to drive dynamos to the use of steam turbines linked inline with a generator or alternator. As the result of improvements in bulbs, and power generation, as well as reductions in loss due to transmission, the cost of household lighting fell 90 percent in just two decades between 1892 and 1912. Steam engines themselves underwent substantial improvements, with energy efficiency for new large stationary installations rising from 6 - 10 percent in the 1860s to 12-15 percent after 1900 (Smil, 2005, pp. 289-90).

If direct drive motors were slow to find their way into manufacturing, that was not true in traction. Edison's Pearl Street station opened in 1882. By 1893 14 out of 16 cities with population greater than 200,000 had electric traction streetcars as did 41 of 42 cities with population between 50,000 and 200,000 (Dyer and Martin, 1929, cited in Smil, 2005, p. 94).

A second area upon which Smil focused is materials. David Landes (1969, p. 259) noted that the real cost of steel fell 80- 90 percent between the early 1860s and the mid-1890s. Crude oil in the United States in 1910 cost 10 percent of what it had in real terms in the 1860s. With the invention of the Hall-Herout reduction process, the real cost of aluminum fell 90 percent between 1890 and 1913, although the use of this advanced material in the economy was still very small. (Smil, 2005, pp. 155, 292). These cost reductions are the duals of productivity advance in the respective sectors, and they are the consequence of more simply than the effects of capital deepening.

All of the foundational work on the gasoline powered internal combustion engine was done prior to the First World War. Although this was largely larder stocking, with most of the big productivity gains in the use of self propelled vehicles yet to come, some gains were already beginning to be reaped prior to the war. In 1913 the operating cost of a truck was 40 percent that of a horse drawn vehicle, garaging costs alone were barely 15 percent of the analogous space requirements for a horse (Perry, 1913, cited in Smil, 2005, p. 288). The same economics can be applied to the use of electric power for purposes of traction. Ultimately, the replacement of horsepower with the gasoline engine would free a substantial portion of American crop acreage for purposes other than producing feed for animals.

Similarly, although the scientific and technical foundations for radio and moving pictures were established prior to the war, much of the realization of gains associated with it took place subsequently.

Smil argued that most of the important scientific and technical foundations for twentieth century economic growth were established in the two generations prior to WWI. We can acknowledge that much of the impact on aggregate productivity was not felt until later in the twentieth century, particularly the interwar years (Field, 2006a,b, 2007a), and also recognize that much, such as Bessemer and Siemens-Martin steel, did have an immediate impact. We can also acknowledge that much productivity growth and living standard improvement in the years from 1871 through 1906 was influenced by spillovers from the build out of the railroad and telegraph networks, technologies whose foundations were laid pre Civil War, as well as rapid productivity growth within those sectors themselves.

Spillovers took the form of innovations in business organization that allowed new ways of doing business in using sectors. Some examples: the telegraph enabled the development of a system of stock trading after the Civil War that persisted in essentially unaltered form for almost a century – breaking down only in 1968 (Field 1998). The telegraph and the railroad were essential technical preconditions for the revolution in meat packing and distribution engineered by Swift and Co. and its competitors. Carnegie's steel making revolution depended on the railroad and telegraph for its logistical operation (and railroads played an important role in stimulating the demand for his product). The development of the American Tobacco Company and exploitation of the Bonsack cigarette making machine is inconceivable without the railroad and the telegraph, as is Rockefeller's success with Standard Oil. In all these cases: stock trading, beef and pork packing, steel, cigarettes, and petroleum products, we see very substantial declines in real prices.

In the two generations prior to the First World War scientific advance became increasingly important as an underpinning of economic growth. For the first time in history technical advance depended substantially on an understanding of scientific principles, including modern chemistry, which underlay the Haber-Bosch process for synthesizing ammonia, the laws of thermodynamics, which were critical in improvements in the efficiency of steam engines, as well as the development of steam turbines, and advances in understanding electromagnetism, which underlay breakthroughs in wireless communication as well as the development of improved electric motors. If modern business enterprise was the most important institutional innovation in this period, a good candidate for the second would be the industrial research laboratory, which played a role in all of the above developments. As Abramovitz acknowledged, once one looks at the subperiod calculations, there is no longer a disconnect between narratives such as Smil's and the aggregate data. Strong TFP advance after 1871 is consistent with the importance of "Knowledge Based Progress" in the last part of the nineteenth century, as it is with the major acceleration in per capita patenting rates in the United States after the Civil War (Khan and Sokoloff, 2001, p. 239).

Together, this qualitative and quantitative evidence makes implausible the suggestion that economic growth in the gilded age can almost entirely be explained as the consequence of the growth of inputs conventionally measured, or that labor productivity and living standard advance is virtually entirely to be attributed to capital deepening. The macro numbers don't show this, and such a conclusion is contrary to the impression of contemporary observes such as Byrn (1901) that they were living and had lived through an historically unique transition, a conclusion affirmed in the judgments of more recent writers such as Chandler and Smil.

Conclusion

Productivity advance in any period is the consequence of the exploitation of technical foundations which have been established earlier and breakthroughs that are rapidly commercialized and have their impact within the same epoch. The period 1871-1913 is no different in this regard. The technical foundations for the railroad and the telegraph were pre Civil War, although the proximately significant advances that allowed for the plummeting prices of steel and aluminum took place after the war. The rapid progress in scientific, technical and organizational knowledge during the two generations prior to the First World War laid the foundations for twentieth century advance, particularly that remarkable period between the two world wars. But it also underlay the qualitative and quantitative changes that characterized the epoch – the multifaceted improvements that in the minds of so many observers irrevocably separated the world of 1910 from that a half century earlier.

Perhaps Edward Byrn can be forgiven some millennial enthusiasm when he wrote in 1901 about the century just completed:

> The Philosophical mind is ever accustomed to regard all stages of growth as proceeding by slow and uniform processes of evolution, but in the field of invention the nineteenth century has been unique. It has been something more than a merely normal growth or natural development. It has been a gigantic tidal wave of human ingenuity and resource, so stupendous in its magnitude, so complex in its diversity, so profound in its thought, so fruitful in its wealth, so beneficent in its results, that the mind is strained and embarrassed in its effort to expand to a full appreciation of it. Indeed the period seems a grand climax of discovery, rather than an increment of growth (Byrn, 1901, p. 3).

Edward Bellamy, H.G. Wels, and Jules Verne would have agreed. Macroeconomic data are consistent with this interpretation. They do not support the view that the last part of the nineteenth century exhibited exceptionally low rates of increase in total factor productivity. TFP growth averaged, for the private domestic economy, above 1.2 percent per year from the early 1870s up through 1906. Such growth was substantially more robust than that experienced in the last part of the twentieth century. Revision in our macroeconomic narrative for the years between the Civil and First World Wars is necessary to reconcile it with these numbers and with what we know about organizational, scientific, and technological progress at the sectoral level during the same period.

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