THE UNIVERSITY OF WARWICK

Dec 2015 No.257

A Vision of the Growth Process in a Technologically Progressive Economy: the United States, 1899-1941.

Gerben Bakker, Nicholas Crafts and Pieter Woltjer

WORKING PAPER SERIES

Centre for Competitive Advantage in the Global Economy

Department of Economics

CAGE Competitive Advantage in the Global Economy

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

A Vision of the Growth Process in a Technologically Progressive Economy: the United States, 1899-1941.

Gerben Bakker

(London School of Economics)

Nicholas Crafts

(University of Warwick)

and

Pieter Woltjer

(Wageningen University)

December 2015

Abstract

We develop new aggregate and sectoral Total Factor Productivity (TFP) estimates for the United States between 1899 and 1941 through better coverage of sectors and better measured labor quality, and show TFP-growth was lower than previously thought, broadly based across sectors, strongly variant intertemporally, and consistent with many diverse sources of innovation. We then test and reject three prominent claims. *First*, the 1930s did *not* have the highest TFP-growth of the twentieth century. *Second*, TFP-growth was *not* predominantly caused by four leading sectors. *Third*, TFP-growth was *not* caused by a 'yeast process' originating in a dominant technology such as electricity.

JEL Classification: N11, N12, O47, O51.

Keywords: Harberger diagram; mushrooms; productivity growth; total factor productivity; yeast

Acknowledgements: We are grateful to Herman de Jong for making data available to us and to Reitze Gouma for help with the estimation of capital input. An earlier version was presented at seminars at the London School of Economics, Oxford University, UC Davis, Stanford University, and the University of Groningen, where we received a number of very helpful comments. We thank Stephen Broadberry, Herman de Jong, Alexander Field, and Nicholas Oulton for critical comments and advice on an earlier draft. Funding for a pilot project was provided by a seed grant from the Suntory and Toyota International Centres for Economics and Related Disciplines (STICERD) of the London School of Economics, as well as a grant from the Netherlands Organisation for Scientific Research (NWO Grant no.: 360–53–102). Morton Jerven provided excellent research assistance at this initial stage of the project. The usual disclaimer applies.

One of the most famous findings in growth economics is in Solow (1957), namely, that 7/8th of labor productivity growth in the United States in the years 1909 to 1949 came from technical change, or more precisely could not be attributed to capital deepening but was a residual. This was soon confirmed in the landmark study of Kendrick (1961) which estimated that during 1869 to 1953 and 1909 to 1948, the growth in total factor productivity (TFP) accounted for 80 and 88.5 per cent of labor productivity growth, respectively. Modern research basically confirms these findings and also shows that TFP growth was by far the predominant source of labor productivity growth even when refinements are made to allow for improvements in labor quality (cf. Table 1).

The context for these estimates is the episode of technological advance which is often called the 'second industrial revolution' which saw the United States overtake Britain as the world's leading economy and in the process achieve unprecedented rates of TFP growth.[1] During the early decades of the twentieth century, the United States was in the forefront of the development of the most important new technologies including aviation, the internal combustion engine, mass production, electricity, and petrochemicals (Mowery and Rosenberg, 2000). Electricity, whose impact peaked in the 1920s (David, 1991), is widely recognized as one of history's most important general purpose technologies (GPTs). Gordon (1999; 2000) described TFP growth in the period between 1891 and 1972 as 'one big wave' based on a few major technology clusters which delivered much more rapid advance than has been seen since or seems likely in future. Importantly, TFP growth continued to be rapid through the Great Depression and Field (2003) labeled the 1930s as the 'most technologically progressive decade' of the twentieth century.

Understanding how and why the United States was so successful in achieving rapid technological progress at this time is obviously important, all the more so given current fears about 'secular stagnation'. A key aspect of this is to decide on the most appropriate vision of the growth process, a challenge which was set by Harberger (1998) in his presidential address to the American Economic Association. Harberger contrasted the possibility of a 'yeast process' and a 'mushroom process' of TFP growth (or in his terminology 'real cost reduction'); the former would be based on a common source – perhaps a GPT with many spillovers - applying across many sectors, while the latter would entail multiple disparate sources.

Against this background, the main contribution of this paper is to develop a much improved and extended dataset which provides a much fuller description of the sectoral pattern of TFP growth across the American economy for the period 1899 to 1941 and sub-periods within those years. Compared with the estimates in Kendrick (1961), which still comprise the main source available to researchers, our growth accounting covers in detail about 80 per cent rather than 50 per cent of the private domestic economy (PDE), we provide detailed estimates for 1929 to 1941 rather than 1929 to 1937, we adjust TFP growth for labor quality improvement within occupations, we estimate the contribution of capital inputs on a capital-services basis where feasible, i.e., for 1929 to 1941, and we obtain a set of value-added weights which allow both the aggregation of sectoral TFP growth rates and also the construction of diagrams to illustrate the degree of inequality of sectoral contributions to total TFP growth. Overall, we find that contributions to TFP growth were spread widely across the American economy, so we perform an additional growth accounting exercise relating to the direct and indirect implications of TFP

[1] Not only was 2 per cent per year far in excess of what the United States itself had achieved during most of the nineteenth century, it was also well ahead of TFP growth in Britain during and after the Industrial Revolution which never exceeded 0.8 per cent per year (Abramovitz and David, 2001; Crafts, 2004a; Matthews et al., 1982).

growth in electrical capital in the 1920s when electricity had its maximum impact as a GPT. We use the results of these investigations to challenge, or at least to qualify, claims made by David (1991), Field (2011), Gordon (2000), and Harberger (1998).

To this end, we address several specific questions. First, we consider whether the growth process was 'mushrooms' (originating in multiple disparate sources), or 'yeast' (widespread and originating in one dominant source), or superficially yeast but actually mushrooms. Second, we quantify the impact of the technology clusters that are said to comprise the 'one big wave' of TFP growth. Third, we re-examine the issue of whether the 1930s really was the most technologically progressive decade of the twentieth century. Fourth, we review the magnitude and pervasiveness of TFP growth accruing from investment in electric motors in manufacturing during the 1920s to account for the role of electricity as a GPT.

In outline, our approach is as follows. We use conventional neoclassical growth accounting assumptions taking account of labor quality in measuring labor inputs. We start with the estimates in Kendrick (1961) for 1899-1929 and improve and extend them where possible. We are able to add 5 sectors – construction, distribution, FIRE (finance, insurance, and real estate), postal services, and spectator entertainment. We produce estimates for 1929 to 1941 using the *National Income and Product Accounts* (NIPA) to obtain nominal value added at the industry level (which are deflated using available price data) and employment. Capital inputs for 1929 to 1941 are constructed using a perpetual inventory method and investment data from the BEA's (2010) fixed assets tables. The capital stocks are then aggregated to the industry level on the basis of imputed rental prices. The result is a measure of capital services, which accurately captures the input flows derived from the capital in place. We replace Kendrick's pre-1929 indices of labor inputs and develop new industry level indices for 1929 to 1941, taking changes in the quality of labor into account. The big advantage of our method for estimating labor inputs compared with that of Kendrick (1961) is that it accounts for improvements in educational attainment within occupations. Moreover, since we now have both capital and labor inputs measured on a similar basis to that of the BLS our TFP estimates for 1929 to 1941 are comparable with the BLS estimates for the post-1948 period.

Having constructed these new growth accounting estimates at the sectoral level, we use them to examine the concentration and persistence of the industry origins of TFP growth. We examine both the rate of TFP growth and the intensive growth contribution (TFP growth multiplied by share of total value added) of each sector. This enables us to construct diagrams for the PDE in the style of Harberger (1998) and thus to see whether the resulting pictures look like 'mushrooms' or 'yeast'. We also compute rank correlations to examine inter-temporal persistence of productivity performance at the sectoral level. In order to pursue the issue of the role of electrification of factories in TFP growth in American manufacturing, we obtain estimates of TFP spillovers by replicating the regression analysis in David (1991) using our new TFP estimates and also develop estimates of electrical capital in use at the sectoral level. This permits both growth accounting with two types of capital (electrical and non-electrical) and also the construction of Harberger diagrams for electrical and non-electrical contributions to TFP growth in manufacturing for the 1920s.

The results of these analyses are quite different from those of earlier work in a number of important aspects. First, we estimate a much higher rate of growth of labor quality than did Kendrick (1961); for 1899-1941, our estimate is about 0.8 per cent per year while his was about 0.3 per cent per year. An immediate corollary is that we estimate a lower rate of TFP growth in the PDE at 1.3 per cent per year during 1899-1941 compared with Kendrick's estimate of 1.7 per cent per year. Second, we estimate that the technology clusters associated with Gordon's 'one big wave' accounted for just under 40 per cent of TFP growth in the PDE during 1899-1941. Their contribution rose steadily from 0.3 per cent per year in 1899-1909 to just under 0.75 per cent per year in 1929-41. This is impressive but possibly less overwhelming than a reader of Gordon (2000) might imagine. Third, we do not agree with Field (2003) (2011) that the 1930s was the most technologically progressive decade if the criterion is TFP growth in the PDE; we estimate that TFP growth was 1.87 per cent per year during 1929-41 compared with 2.00 percent per year during 1948-60 and 2.23 per cent per year during 1960-73. Fourth, we find that, including both own TFP growth and TFP spillovers, electrical capital contributed only 28 per cent of TFP growth in manufacturing during the 1920s and that this contribution varied more across sectors than did non-electrical TFP growth, so our findings do not support the idea of a yeast process based on electricity as a GPT as the best way to conceptualize technological progress in manufacturing at this time. Fifth, we find that intensive growth contributions were generally broadly-based whether at the level of the PDE or of manufacturing, with the exception of the period 1909-19. However, we also find that there is rather low persistence of TFP growth and intensive growth contributions between periods and the economic history literature reveals multiple sources of TFP growth. Together with our findings on electricity, this leads us to conclude that Harberger's vision that TFP growth is really a 'mushrooms' process is probably right even though, superficially, the appearance is 'yeast-like'.

Our results take on added significance in the context of the renewed interest in selective industrial policy that has emerged since the financial crisis of 2008 (Warwick, 2013). This might be thought of as intervening to encourage a shift of productive resources towards sectors with prospects of rapid TFP growth. Our investigation of TFP growth during 1899-1941 underlines the dangers of selective policies favoring 'technologically progressive' industries. In particular, our results suggest that TFP growth over time was highly unpredictable, that there were multiple sources of TFP growth rather than a few key technologies, and that large, unglamorous sectors like wholesale and retail trade, which can benefit from but do not originate technological progress, contributed much more to TFP growth than exciting new industries like electric machinery. This suggests that Harberger (1998) was right to argue that rather than to try to back winners, the key role for policy is to enable firms to respond effectively to changing circumstances and not to obstruct creative destruction.

1. Key Ideas and Literature Review

A natural starting point for considering the spread of productivity growth across sectors is the seminal paper by Harberger (1998). This paper introduced a graphical device similar to the Lorenz Curve to display the pattern of TFP growth contributions by industry when industries are ranked by their TFP growth rate from highest to lowest; this is reproduced in Figure 1. Here Figure 1a shows a case where all sectors contribute to TFP growth and no industry dominates the growth process while Figure 1b shows a case where TFP growth is negative in a significant number of sectors and relatively few industries account for most of the total.

Harberger used the terminology of a 'yeast process' and a 'mushroom process' to describe these patterns.[2] A 'yeast process' would be based on very broad and general externalities whereas a 'mushroom process' would result from TFP growth with a 1001 different causes. However, it is also possible, as Harberger acknowledged, that a 'yeast-like pattern' might be observed when disparate (unconnected) sources of TFP growth happen to be widespread and sectors with negative TFP growth

[2] The analogy comes from the fact that yeast causes bread to expand very evenly whereas mushrooms pop up unpredictably and spasmodically.

are absent or at least have little weight. Harberger's own view was that the 'mushroom' diagram represented the usual configuration and he produced estimates to illustrate this for the United States in the period 1948 to 1985 where the diagrams resembled Figure 1b rather than Figure 1a. Moreover, he argued that over time different industries dominated so that contributions were not only concentrated within each period but exhibited little persistence between periods. He thought this might be characteristic of a Schumpeterian process of 'creative destruction'. Harberger did not provide estimates for earlier in the twentieth century but he stated that he thought that the mushroom pattern prevailed then as well and that the 1920s was the decade of cars and rubber tires, the 1930s was the decade of refrigerators, and the 1940s was the decade of pharmaceuticals (1998, p. 5).

It may seem that a General Purpose Technology (GPT), i.e. one which comes to have many uses, to be widely used and to have many Hicksian and technological complementarities (Lipsey, 1998) would generate a yeast process for TFP growth similar to Figure 1. This need not be the case, however.

Consider a growth accounting formula of the type used to analyze the impact of ICT on labor productivity growth

$$\frac{\Delta\frac{Y}{L}}{\frac{Y}{L}} = \alpha\frac{\Delta\frac{K_O}{L}}{\frac{K_O}{L}} + \beta\frac{\Delta\frac{K_{ICT}}{L}}{\frac{K_{ICT}}{L}} + \eta\left(\frac{\Delta A}{A}\right)_{ICTM} + \phi\left(\frac{\Delta A}{A}\right)_{NICTM} \qquad (1)$$

This equation decomposes the sources of labor productivity growth into contributions from two types of capital, ICT capital and other capital each weighted by their income shares, β and α, and two types of TFP growth in the manufacture of ICT equipment and in the rest of the economy each weighted by their value-added shares, η and φ. When applied to the U.S. non-farm business sector in the period 1995-2004, the peak of the 'new economy' boom, this results in contributions from ICT capital and other capital of 0.78 and 0.44 percentage points per year, respectively, and from TFP growth in ICT production and other production of 0.72 percentage points and 0.90 percentage points, respectively (Byrne et al., 2013). Since ICT production was only a small sector, a Harberger diagram for TFP growth in this period would look quite 'mushroomy' even if (unremunerated) TFP spillovers comprised a significant part of TFP growth in other sectors.

If, however, a similar diagram were to be drawn for contributions to labor productivity growth, a yeast process would be more likely to emerge because investments in ICT capital have been spread across many sectors. Indeed, this is what David and Wright (1999) found prevailed during the heyday of an earlier GPT, electricity, where they displayed a flat curve for labor productivity growth between 1919 and 1929 in American manufacturing and also reported a strong correlation between TFP growth and growth of horsepower in electric motors which they attributed to TFP spillovers.[3] A similar labor productivity growth profile is reported for Swedish manufacturing for the period 1900-1912 when electrification diffused rapidly across many industries (Prado, 2014). Even so, as Prado himself points out, this would not always happen with a GPT since adoption of the technology across the economy as a whole might be subject to variable diffusion lags, as was the case with steam power (Crafts, 2004b).

[3] In their discussion of electricity as a GPT, David and Wright (1999) did not, however, present a Harberger diagram for TFP growth either for manufacturing or the private domestic economy. Nor did they explicitly quantify the sectoral contributions of this technology to demonstrate that it did indeed explain 'yeastiness'.

And in any case, the GPT may not be the only game in town since its emergence may come at a time when myriad other sources of productivity improvement are available.

Although the Harberger-type approach has generally been applied to manufacturing, this seems unduly restrictive especially given the important role that productivity growth in services played in the twentieth century United States. This is implicit in the well-known account of American economic growth given by Gordon (2000) who describes ‘one big wave’ in TFP growth between 1891 and 1972 with an acceleration peaking in 1928-1950. He argued that this was driven by four technology clusters: electricity, the internal combustion engine together with derivative inventions such as interstate highways and supermarkets, rearranging molecules (chemicals and pharmaceuticals), and the entertainment, communication and information sector. Surprisingly, Gordon did not attempt to quantify the growth contribution of these four technologies over time.

The most comprehensive recent description of the growth process which attempts a decomposition of sectoral contributions to productivity growth in the early twentieth century American economy is by Field (2011) who drew heavily on the work of Kendrick (1961). Field emphasized that there were big differences between the 1920s, in which TFP growth was dominated by manufacturing, and the 1930s when TFP growth was spread more widely across much of the economy. In the period 1919 to 1929, TFP growth in manufacturing was very rapid at 5.1 per cent per year and exceeded 2 per cent per year in all but one 2-digit manufacturing industry; prima facie this does not seem to match Harberger’s caricature and rapid electrification of factories at that time might seem to indicate that a ‘yeast process’ was at work. In the period 1929 to 1937, however, TFP growth in manufacturing fell to 1.9 per cent per year and the range of TFP growth across manufacturing industries was much greater.

An important innovation made by Field was to examine TFP growth for the period 1929 to 1941 whereas Kendrick (1961) based his disaggregated estimates on the period 1929 to 1937; it is the later end date which justifies the label ‘the most technologically progressive decade’. The rationale for replacing 1937 by 1941 is that this permits a view based on a year when economic recovery from the Depression was more complete.[4] Field (2011) provided a 4-sector breakdown of TFP growth contributions which suggests that even if TFP growth within manufacturing was ‘yeasty’ in the 1920s this may not be true for the economy as a whole. On the other hand, for the 1930s his emphasis on broadly-based TFP growth suggests that a ‘yeast-like pattern’ stemming from various sources may have prevailed in the economy if not manufacturing. However, to explore these points properly requires a

[4] As noted by Field (2011), 1941 was the first year since 1929 that unemployment averaged less than 10 per cent, making it far preferable to 1937 as a (peacetime) peak year. Still, 1941 is not ideal, as unemployment was higher (9.9 per cent) than in 1929 (3.2 per cent). Because of the pro-cyclical nature of productivity, Field argues that TFP would have been higher in 1941 had the economy operated at full capacity, mainly because of the effects of labor and capital hoarding. To address this, he suggests a one-off adjustment that raises the average annual growth of TFP between 1929 and 1941 from 2.31 to 2.78. Inklaar et al. (2011) provide a more comprehensive test of the cyclical nature of productivity in the interwar US economy. They find robust evidence of short-run increasing returns to scale, on the basis of which they calculate a ‘purified’ measure of technological change which confirms that “the hoarding of production factors was the dominant reason for the decline in measured Solow residual TFP in U.S. manufacturing between 1929 and 1933.” (Inklaar et al. 2011: 851) Between 1933 and 1937, however, TFP grew much faster than technology, resulting from a rapid expansion of the utilization of factor inputs. In the years leading up the Second World War the potential bias between TFP and technology had vanished. It should also be noted that, although unemployment in 1941 was above the 1929 level, the peacetime output gap may have already closed. It is widely accepted that the New Deal raised the NAIRU significantly; for example, Cole and Ohanian found that the unemployment rate was raised by 6 pecentage points while Hatton and Thomas (2010) estimated that the impact was probably even larger. Taken together, these points make the adjustment suggested by Field hard to justify and we prefer to use the raw data for 1941.

full decomposition based on appropriate weights and a finer breakdown than the broad sectors used by Field.

The bottom line is that the literature does not contain an adequate quantitative account of the industry origins of productivity growth during the early twentieth century and this implies that existing visions of the growth process are somewhat blurred. In particular, it is not really clear whether the process was always 'mushrooms', as Harberger would expect, or whether there was a phase with a 'yeast-like process' at least at the height of technological progressivity in the 1930s, as Field's account suggests. It is also unclear whether electricity as a GPT can be credited with promoting a 'yeast process' of TFP growth in manufacturing in the 1920s. We seek to clarify these issues.

In theoretical terms, then, we can subdivide the underlying growth process into two different types: generalized TFP-growth, in which one dominant source of TFP growth works with a large effect across a large number of industries (a yeast process); and specialized TFP growth in which, at the extreme, a source of TFP growth works just within one industry (a mushroom process).[5] In turn, specialized TFP growth can be divided into two cases: universal specialized TFP growth, in which a very large number of industries experience TFP growth from an industry-specific source; and sporadic specialized TFP-growth, in which only a limited number of industries experience TFP growth from an industry-specific source.

This means that the observation of a yeast pattern can reflect four different underlying processes: zero TFP growth (universal stagnation), universal specialized TFP growth only, generalized TFP growth only, and finally, a combination of generalized TFP growth and universal specialized TFP growth. In the context of a Harberger diagram, these processes would be observationally equivalent and further information would be required to discriminate between them. Of course, observing a mushroom pattern is not consistent with any of these four underlying processes.

Using the above terminology, it is clear that Harberger's narrative account of mushrooms mixes two different underlying *processes* that result in observing either a mushroom or a yeast *pattern*. When he mentions '1001 different causes' of TFP-growth, this appears very much to refer to a growth process of universal specialized TFP-growth (the vast majority of industries experience substantial industry-specific TFP-growth), which actually is likely to lead to observing a yeast pattern. When Harberger remarks that the 1920s were the decade of cars, the 1930s of household appliances and the 1940s of antibiotics, he appears to refer to a growth process of sporadic specialized TFP growth (a small number of industries experience substantial industry-specific TFP growth), which would lead us to expect a mushroom pattern.

2. Data and Methods

The definitive study on productivity growth at the industry level in the United States for the first half of the twentieth century is Kendrick (1961). Although Kendrick offered substantial detail, the estimates presented in his book fall some way short of what is required for a full empirical evaluation of the ideas of Field and Harberger. Kendrick provides estimates of average annual TFP growth for 1899 to 1953 and for sub-divisions of these years for the aggregate of the private domestic economy and for 5 sectors which in turn are divided into 33 industries. These sectors covered 54 per cent of the private domestic economy in 1953. TFP growth for the remaining 46 per cent (which includes construction, distribution,

[5] An intermediate type of growth would be a process in which a source of TFP growth has an effect on more than one industry, but the number of industries remains limited.

finance, and most of the rest of the services sector) was obtained arithmetically by comparing the total of the covered sector with the estimates for the whole private domestic economy; for 1899 to 1953, TFP in the covered sector was estimated at 2.1 per cent per year, for the total private domestic economy at 1.7 per cent and the residual sector was calculated as 1.3 per cent (Kendrick, 1961, p. 137).

Kendrick's concept of TFP growth is based on the growth rate of real value added minus the factor-share weighted sum of the rates of growth of capital and labor inputs as in equation (2)

$$\frac{\Delta A}{A} = \frac{\Delta Y}{Y} - \alpha \frac{\Delta K}{K} - (1-\alpha)\frac{\Delta L}{L} \qquad (2)$$

where α is the share of profits in value added. For the private domestic economy and for the 5 main sectors, labor inputs are based on man-hours weighted by average hourly earnings to capture increases in labor quality resulting from shifts of workers between differently-paid occupations and industries. Within sub-sectors, however, labor quality is assumed to remain unchanged. Kendrick reports TFP growth rates by sector and by sub-sector but does not provide estimates of value-added shares or of the productivity growth contribution of each industry (i.e., its TFP growth rate multiplied by its value-added weight).

We take Kendrick's study as a starting point but extend and improve upon his work. We provide estimates of TFP growth for a more complete set of industries and therefore have a much smaller residual sector. In particular, we add estimates for construction, distribution, the financial (FIRE) sector, spectator entertainment, and the post office. However, we were unable to find sources that would allow estimates for the health-care, hotels and restaurants, and waterworks sectors. Our extensions mean that coverage goes up from 55 per cent to 80 per cent of the private domestic economy on average in 1899-1941. We also provide a full set of value-added weights and productivity growth contributions at the industry level and we derive Harberger diagrams of productivity growth contributions both for manufacturing and for the private domestic economy. We also construct estimates for a 1929-41 sub-period rather than the years 1929-37 to address the issues raised by Field (2006) and we consider the implications of replacing Kendrick's periods 1909-19 and 1919-29 by 1909-21 and 1921-29. In making these estimates, we take fuller account of labor quality by allowing for the impact of the rapid increase in educational attainment in the first half of the twentieth century and we do so at the industry level basing our index of labor inputs on age, gender, and education of the workforce.

For the inclusion of the five hard-to-measure sectors – namely, finance, insurance and real estate (FIRE), construction, wholesale and retail distribution, spectator entertainment, and postal services – we estimated capital, labor, factor income shares and output for the start and end dates of our periods using a variety of sources that included censuses, the *National Income and Product Accounts* (NIPA), as well as a variety of secondary sources. From these estimates, TFP growth rates were calculated and weighted by value-added shares interpolated from the benchmark years, 1899, 1929, and 1939 to obtain estimates of each sector's intensive growth contribution; see Appendix B for full details.

The second difficult task is to develop industry level estimates that extend Kendrick's estimates for 1929-37 through 1941. Our approach here starts by obtaining industry-level estimates of nominal value added from NIPA and then deflating on the basis of wholesale prices from the U.S. Bureau of Labor Statistics, production prices from *Historical Statistics of the United States* (Carter et al., 2006), and, for some service sectors, relevant price indices from NIPA. Labor inputs are based on NIPA for employment adjusted for hours of work using Kendrick (1961) and *Historical Statistics* and for quality using the method detailed below. Capital inputs are estimated on the basis of capital services. We estimate the industry-level stock of capital for the private domestic economy between 1929 and 1941 using a Perpetual Inventory Method (PIM) and the investment and depreciation series taken from the BEA's *Fixed Assets* tables.[6] Rental prices of assets at the industry level are based on the imputed industry rate of return, the asset-specific rate of depreciation and capital gains and losses from changing asset prices. This allows the calculation of 'capital compensation' weights to aggregate the capital input.[7] We present full details in Appendix C.

Three features of the methods that we employ deserve some comment. These relate to the way in which industrial contributions to aggregate TFP growth are measured, to the way in which we measure labor quality, and to the summary statistic used to describe the 'yeastiness' of productivity growth.

Following Kendrick (1961), we employ a growth accounting technique based on value-added rather than gross output. This also mirrors the approaches to examining contributions to TFP growth adopted by Field (2011) and Harberger (1998). This implies that we take the contribution to TFP growth of industry j as $\omega_j(\Delta A_j/A_j)$ where ω_j is value added in industry j divided by GDP and we sum these individual contributions of all n industries to obtain TFP growth for the aggregate private domestic economy so that

$$\frac{\Delta A_{GDP}}{A_{GDP}} = \sum_{j=1}^{n} \omega_j \frac{\Delta A_j}{A_j} \qquad (3)$$

This approach can be interpreted as measuring an industry's capacity to contribute to economy wide productivity but the components of this aggregate are not an accurate measure of disembodied technical change (OECD, 2001).[8] An industry's intensive growth contribution (IGC) therefore depends not only on its rate of TFP growth but also on its size and it follows that intensive growth contributions by industry are not necessarily highly correlated with TFP growth rates.

Our approach to measuring labor quality improves on that of Kendrick, in particular, by taking account of the implications of the rapid increase in years of schooling on the quality of workers in each occupation over time but also by allowing for changes in gender composition and experience of the labor force. Our method also permits measurement of labor quality at the industry level. So for all industries we conduct growth accounting with measurement of labor input based on quality as well as hours worked. Not surprisingly, this method finds a higher rate of growth of labor quality; labor quality in the private domestic economy during 1899-1941 is estimated to have grown at 0.8 per cent per year compared with Kendrick's estimate of 0.3 per cent.

[6] Note that Gordon (2016) argues that the official investment and depreciation rates from the BEA severely underestimate the growth of capital inputs for the period between 1925 and 1945. In particular, he questions whether the depreciation rates, which are fixed over time, are representative for the Depression era. Appendix C explores the impact that the adjustment to the official depreciation rates, along the lines suggested by Gordon, would have on TFP growth between 1929 and 1941.

[7] It is not possible to use this method to replace Kendrick's estimates of capital inputs for the pre-1929 period which are obtained using a traditional capital stocks method. In particular, we lack asset-by-industry capital stocks and asset-specific depreciation rates. It should be noted that the differences in TFP growth between the two methods are generally fairly small; the implications are explored in Appendix C.

[8] An alternative which has this desirable property is to do growth accounting on a gross output basis where the use of intermediate inputs is explicitly taken into account and aggregation is based on Domar weights (cf. Hulten, 1978). This is too data demanding to be attempted here, given the available historical sources.

To construct an index of labor input for each individual industry, we assume that labor input (HK) for industry *j* be expressed as a translog function of its individual components. We form indices of labor input from data on employment by industry, cross-classified by gender, age and education. Dropping the industry subscript *j* for ease of notation, the growth of labor input for industry *j* can thus be represented as

$$\frac{\Delta HK}{HK} = \sum_{l=1}^{q} \bar{v}_l \frac{\Delta L_l}{L_l} \tag{4}$$

where L_l is employment at the industry level for a given set of *q* characteristics of the labor force *l* (gender, age and education) and $\bar{v}_l$ is the two-period average of this employment group's share in the total labor income at the industry level.

The share of labor income (v_l) is derived as the product of the average wage (p_l) and employment (L_l) for each combination of labor characteristic *l,* divided by the total wage sum

$$v_l = \frac{p_l \Delta L_l}{\sum_{l=1}^{q} p_l \Delta L_l} \tag{5}$$

So our measure of industry labor quality growth is the difference between the growth rates of the compensation-weighted index of labor input and total employment.

$$\frac{\Delta LQ}{LQ} = \sum_{l=1}^{q} \bar{v}_l \frac{\Delta L_l}{L_l} - \frac{\Delta L}{L} \tag{6}$$

We follow a three-tiered approach to the data preparation for the labor quality estimation. First, we estimate educational attainment for individual workers for the pre-1940 census samples on the basis of the 1940 returns. Second, we construct an employment matrix for the entire period that groups workers according to their (predicted) educational attainment, gender, age and by industry. Lastly, we derive the compensation matrix on the basis of average wages for each labor category taken from the 1940 census of population. These employment and compensation matrices can then be used to calculate labor quality on the basis of equation (6). Full details of our estimation method are reported in Appendix D.

We use Harberger diagrams along the lines of Figure 1 to address the question of 'yeast' versus 'mushrooms'. We follow Inklaar and Timmer (2007) in using a summary statistic, the 'Harberger coefficient', to describe the degree of concentration of industry contributions to total TFP growth.[9] This measures the area between the curve and the diagonal divided by the total area under the curve, that is

[9] We have coined the term 'Harberger coefficient' as an analogue to the Gini coefficient which describes the degree of inequality associated with a Lorenz Curve.

$V/(V + W)$ and will have a lower value the more equal are the industrial contributions to TFP growth. The Harberger coefficient can be expressed as

$$H = \frac{V}{V+W} = \frac{\int_0^1 f(x)dx - \int_0^1 xdx}{\int_0^1 f(x)dx} = \frac{\int_0^1 \left(f(x)dx\right) - \frac{1}{2}\frac{\Delta A}{A}}{\int_0^1 f(x)dx} \qquad (7)$$

where x is the cumulative share of value added when the intensive growth contributions are ranked from largest to smallest TFP growth rate, and $f(x)$ is the cumulative TFP growth contribution of this cumulative value added, and dA/A is TFP-growth for the whole economy, set at unity in this diagram.[10] So the numerator V in expression (7) is the area between the curve and the diagonal, and W is the triangle under the diagonal. V is calculated by subtracting the triangular area W from the total area under the curve. When TFP contributions are exactly proportional to value added, the Harberger curve lies along the diagonal, and V equals zero.

In order to evaluate the contribution of electricity to productivity growth in each manufacturing industry in the 1920s, we use an augmented version of an equation similar to (1) which is as follows:

$$\frac{\Delta\frac{Y}{L}}{\frac{Y}{L}} = \alpha\frac{\Delta\frac{K_O}{L}}{\frac{K_O}{L}} + \beta\frac{\Delta\frac{K_{ELEC}}{L}}{\frac{K_{ELEC}}{L}} + \eta\left(\frac{\Delta A}{A}\right)_{ELEC} + \phi\left(\frac{\Delta A}{A}\right)_O + (1-\alpha-\beta)\frac{\Delta\frac{HK}{L}}{\frac{HK}{L}} + \gamma\frac{\Delta\frac{K_{ELEC}}{L}}{\frac{K_{ELEC}}{L}} \qquad (8)$$

where the additional terms, $(1 - \alpha - \beta)\ \Delta(HK/L) / (HK/L)$ and $\gamma\ \Delta(K_{ELEC}/L) / (K_{ELEC}/L)$, represent the contributions of labor quality growth and of (unremunerated) TFP spillovers resulting from the growth of the electrical capital stock, respectively. These TFP spillovers are counted as part of total TFP growth rather than the capital-deepening contribution of electrical capital, and if no attempt is made to measure them they would accrue as part of $\varphi(\Delta A/A)_O$.

We calculate the rate of growth of horsepower in electric motors (both primary and secondary) based on the installed horsepower by industry reported by DuBoff (1979) as an estimate of the rate of growth of electrical capital and we obtain an estimate of β by assuming that the share of profits accruing to electrical capital corresponds to the share of electrical equipment capital in total capital. We calculated this share by estimating total capital per industry and electrical capital per industry using the NIPA and data on investment by asset type from the BEA for 1921 to 1929 and then taking the average of both over these years (see Appendix C).

It has been strongly argued by David (1991) that TFP spillovers were important in the 1920s when investment in secondary motors delivered unit drive on machinery and facilitated improvements in factory design. We follow David (1991) in estimating γ by a cross-section regression of the change in TFP growth (the TFP-growth for 1919-29 minus that for 1899-1919) against the average annual rate of growth of horsepower in secondary motors in each manufacturing industry during 1919-29. These estimates can then be used together with TFP growth in the electrical machinery sector to construct a Harberger diagram of total electrical TFP growth contributions. We also use equation (8) to construct

[10] In practice, the diagrams are not as smooth as in Figure 1, as we have a discrete number of industries. Instead they consist of piecewise linear plots.

Harberger-type diagrams of contributions to labor productivity growth following the lead of David and Wright (1999) but in addition distinguishing between electrical and non-electrical contributions. We calculate the equivalent of the Harberger coefficient (H^*) from a modified version of equation (7) which is

$$H = \frac{\int_0^1 f(x)dx - \int_0^1 x dx}{\int_0^1 f(x)dx} = \frac{\int_0^1 \left(f(x)dx \right) - \frac{1}{2}\frac{\Delta \frac{Y}{L}}{\frac{Y}{L}}}{\int_0^1 f(x)dx} \tag{9}$$

where on this occasion *f(x)* is the cumulative labor productivity growth contribution.

3. Results

This section reports our estimates of value added weights, growth of labor quality, and TFP growth at the industry level together with our estimates of intensive growth contributions by industry, i.e., the sectoral decomposition of TFP growth, which are derived from them. At the same time, we point out some noteworthy features of these data.

Value-added weights are reported in Table 2. It is apparent that wholesale & retail trade and FIRE, which have been added to the measured sector, are relatively large sectors – taken together in the interwar period they are nearly as large as manufacturing. At the same time, it is also striking that manufacturing accounts for only about a quarter of total value added throughout the period. This makes clear both that confining a discussion of productivity performance to that sector alone would be potentially quite misleading and also that strong productivity growth for the whole economy would normally require other sectors to make significant contributions. It is also worth noting that farming was still quite sizeable which suggests that, following Kendrick, it is appropriate to base an analysis of productivity in the market economy primarily on the performance of the private domestic economy (PDE) rather than the private non-farm domestic economy (PNE).

Table 3 reports estimates of labor quality growth by industry for each period. As was noted above, these estimates are more detailed than Kendrick's and they also show a faster rate of labor quality growth because they take account of improvements in labor quality within occupations and sectors which is important in an era of rapidly improving educational attainment. For example, Goldin and Katz (2008) report that while only 10.6 per cent of those aged 14 to 17 were enrolled in high school in 1900 by 1938 this had risen to 67.7 per cent. It is important to note that the much higher rate of growth of labor quality in the PDE than in the PNE is very largely explained by the impact of sectoral reallocation of labor, which mainly concerned workers moving out of agriculture, as well as by increased educational attainment, which provided the most important contribution. In addition, the increased average age of workers raised labor quality over the long run while an increase in the proportion of females from 18 per cent at the start of the period to 24 per cent at the end largely offset the age effect.[11]

[11] The large number of sectors with negative labor quality growth in 1899-1909 reflects tendencies of the workforce becoming younger and more female at a time when educational attainment was rising less quickly than in later decades.

Table 3 presents a picture not only of rapid labor quality growth on average but also one of substantial variation between sectors and over time. The highest figure (telephone in 1929-41) is 1.14 per cent per year while the lowest (leather products in 1899-1909) is -0.71 per cent per year. The range in successive sub-periods is 1.64, 1.20, 0.98, and 1.08, respectively. This implies that the correction factors for labor quality applied to crude TFP will be quite variable and that relative sectoral contributions to TFP after these adjustments are made will potentially look quite a bit different. Interestingly, and perhaps contrary to some priors, the correlations between labor quality growth and refined TFP growth (reported in Table 4) are quite low across our 37 sectors at 0.00, -0.03, 0.02, 0.18, respectively for each sub-period, and 0.10 for the whole period, 1899-1941. The fastest labor quality growth over the period as a whole is found in paper, rubber products, and textiles.

The rates of TFP growth reported in Table 4 are generally lower than those in Kendrick (1961) in particular because our adjustment for the growth of labor quality is larger than his; over 1899-1941 as a whole we estimate TFP growth in the PDE at 1.3 per cent per year compared with 1.7 per cent according to Kendrick. Obviously, this still represents a very strong performance relative either to the nineteenth century or rivals like the United Kingdom. The fastest TFP growth during these years was in 1929-41 for the PDE but not for manufacturing where TFP growth was much faster in the 1920s. It is clear that strong performance in the 1930s was relatively broadly based and involved much of the services sector, including our residual sector.

During 1899-1941, the top three sectors in terms of TFP growth were entertainment, electric utilities and transport equipment, all of which can be considered part of the 'second industrial revolution'. Each of these sectors made regular appearances in the top 5 throughout the period but a further 9 sectors featured at least once in the top 5. More generally, rank correlation coefficients for sectoral TFP performance between successive periods were quite low (0.4, 0.0, and 0.2). There are 24 observations (about 16 per cent) with negative TFP growth; 13 of these were for 1909-19 which may have been affected by World War I. It is noticeable that the 6 sectors whose TFP growth fell by at least 2.0 percentage points between 1899-1909 and 1909-19 showed an average improvement in TFP growth of 4.9 percentage points between 1909-19 and 1919-29.

Table 5 displays estimates of sectoral intensive growth contributions (IGC). It is noticeable that with the exception of 1909-19, the sum of negative IGC of measured sectors is very small – below 10 per cent of total TFP growth in each decade. The IGC depends both on TFP growth and also on a sector's size. Indeed, the sector with the fastest TFP growth rate never had the largest IGC in any period although rank correlations between TFP growth and IGC are reasonably high most of the time, namely, 0.6, 0.9, 0.4, and 0.8 in successive periods. To facilitate comparisons, Table 6 provides ranking of sectors by TFP growth and by IGC in each period.

The top 3 IGC sectors during 1899-1941 were wholesale and retail trade, railroads, and foods, none of which would be thought of as exciting new, technologically progressive industries.[12] Over the whole period 1899-1941, wholesale and retail trade (with a value-added weight of 13.5 per cent), which benefited from improvements in transport and communications and increased store sizes (Field, 2011) but was not at the heart of the second industrial revolution, provided the largest IGC but ranked only 24th in TFP growth. Likewise, farming was a large, unglamorous sector (with a value added of 10.1 per cent) which had low TFP-growth but ranked sixth in IGC over the whole period, and third in the 1930s,

[12] They were not identified by Mowery and Rosenberg (1989) as especially R & D intensive. The leaders in that respect were chemicals, petroleum, and electrical machinery.

at least partially by benefiting from second industrial revolution innovations such as pesticides, animal medicines, the combustion engine, and electricity, which was needed in vast quantities for the Haber-Bosch process to make artificial fertilizer (Olmstead and Rhode, 2008). Manufacturing's IGC dominated in 1919-29 when it accounted for about 70 per cent of all TFP growth but this was exceptional and its average contribution over 1899-1941 was 'only' about 40 per cent. This was, however, still well above its value-added weight of about a quarter of GDP. The four technologies that Gordon (2000) identified as driving his 'one big wave' of TFP growth contributed increasingly over the period, rising from 0.301 percentage points in 1899-1909 to 0.742 percentage points in 1929-41 with an average IGC over the whole period of 0.498 percentage points, almost as big as the contribution of the entire manufacturing sector (38 vs. 41 per cent).[13]

4. **The Most Technologically Progressive Decade?**

Field (2011) repeated his 2003 argument that the 1930s, defined as 1929-41, were the most technologically progressive decade of the twentieth century. This was based on that period having the fastest TFP growth in the private non-farm economy (PNE) and also that the 1930s saw unusually broadly-based TFP growth with the intensive growth contribution (IGC) of transport and utilities combined with wholesale and retail trade being roughly equal to that of manufacturing with each accounting for about 47 per cent of TFP growth in the PNE. In this section, we re-examine both these claims using the new estimates that we reported in section 3.

In Table 7, we report TFP growth rates for the private domestic economy (PDE) over the long twentieth century where, as in Field (2011), the post-1948 estimates are taken from the Bureau of Labor Statistics (2014). As remarked in section 3 above, we follow Kendrick rather than Field in basing our comparisons on the PDE rather than the PNE. We believe our estimates are comparable for 1899-1941 with those of the BLS for post-1948 in that capital and labor inputs are estimated on the same basis (but differently from Kendrick on whose estimates Field relied). It is clear from Table 7 that the 1930s did not have the fastest TFP growth but were below the TFP growth of the periods 1948 to 1960 and 1960 to 1973.[14] Rather than singling out the 1930s as having the highest TFP growth, it may be preferable to see TFP growth in the peacetime American economy steadily increasing from the 1920s through the 1960s (Gordon 2000).

In Table 8, we re-work Field's sectoral decomposition of TFP growth in the PNE which compares the 1930s with the 1920s. We use the estimates of TFP growth and value-added weights set out in section 3 and mid-period rather than end-period weights, partly because this is normal practice and partly because the manufacturing sector's weight increased appreciably as the American economy moved

[13] We take the 'big wave' sectors to be Chemicals, Petroleum & coal products, Rubber products, Electric machinery, Electric utilities, Transport equipment, Wholesale and retail trade, Local transit, Telephone, and Spectator entertainment. The latter has been added to the Kendrick big wave sectors and is largely based on Bakker (2012).

[14] If the period 1948 to 1973 is considered, as in Field (2011), the TFP growth rate for the PDE is 2.12 per cent per year which is also superior to 1929-41. If the variable retirement method proposed by Gordon (2016) is applied (see footnote 5 above and Appendix C, tables C5 and C6), then the PDE growth rate for 1929-1941 reduces from 1.9 to 1.7 percent per annum, even though it stays the same at 1.3 percent per annum for the whole period 1899-1941. Use of this method would undermine Field's claim that TFP growth in the 1930s was the fastest in the twentieth century. Also, with Gordon's method, the Harberger coefficient increases appreciably from 0.35 to 0.38 which would go against Field's view that the 1930s saw more broadly-based TFP growth than the 1920s, see section 5. However, it should be noted that no evidence is available to validate Gordon's assumptions about delayed retirement of capital.

towards war in 1941. In this case, our disagreement with Field (2011) is that he significantly understated the contrast between the two decades.[15] Our estimates show that, whereas the IGC for manufacturing in the 1920s accounted for 74.1 per cent of TFP growth in the PNE, in the 1930s this had fallen to 36.0 per cent as TFP growth in manufacturing almost halved. Indeed, during 1929 to 1941, we estimate that transport and public utilities together with wholesale and retail trade were not on a par with manufacturing but rather accounted for a much larger share of TFP growth in the PNE at 52.0 per cent.

However, in order to obtain a clearer picture the extent to which the sectoral pattern of TFP growth in the 1930s differed from what had gone before, it is important to develop a perspective based on a less coarse decomposition of intensive growth contributions and to take a longer-term view. This task is undertaken in the following section using the device of the Harberger diagram.

5. 'Yeast' or 'Mushrooms'?

The difference between 'yeasty' and 'mushroomy' patterns of intensive growth contributions (IGC) was reviewed in the context of Figure 1. In Figure 2, we present Harberger diagrams based on TFP growth contributions obtained from our dataset for the period 1899-1941. To our knowledge, this is the first time this has been attempted. In drawing these diagrams for the PDE, we base them on our aggregate measured sector, i.e., we have excluded the residual sector. We believe this is appropriate because the residual sector comprises an odd assortment of sectors which may well have experienced quite different rates of TFP growth. Combining them is likely to exaggerate the degree of yeastiness in 1929-41 when the residual sector's TFP growth was 1.4 per cent per year (Table 4).[16]

The picture that emerges from Figure 2 is that 1929-41 is quite like not only the 1920s but also the first decade of the twentieth century. In each case, the visual impression is relatively 'yeasty' and the Harberger coefficients are quite similar with 0.35 for 1929-41 being marginally lower than 0.37 for 1899-1909 but slightly higher than 0.33 for 1919-29. In each period there are few sectors with negative TFP growth and their value-added share in the measured sector is fairly small. In contrast, 1909-19, saw lower TFP growth than the other periods and has a Harberger coefficient of 0.71, looks very 'mushroomy' and is something of an outlier with negative TFP growth in many sectors. If the residual sector had been included as an addition to the Harberger diagram, this picture would essentially remain but the details would change with Harberger coefficients of 0.42, 0.59, 0.40, and 0.33 for the successive periods (and 0.30 for the entire period).

In fact, there seems to be a strong inverse correlation between the size of the Harberger coefficient and the aggregate rate of TFP growth as Inklaar and Timmer (2007) stress in their review of the evidence for the market sector in OECD economies around the turn of the 21st century. It seems that relatively rapid TFP growth is typically associated with a more balanced and broadly-based pattern across sectors. That said, it is worth noting that the Harberger coefficients for the American economy in the interwar period are a bit lower than any of those reported by Inklaar and Timmer (2007) including values for the United States of 0.65 and 0.52 in 1987-95 and 1995-2003, respectively.

The very similar Harberger coefficients for the 1920s and the 1930s suggest that is probably best to see the argument made by Field (2011) that the latter decade saw more broadly based TFP growth as a

[15] It should, however, also be noted that our estimate of TFP growth in the PNE at 1.82 per cent per year for 1929 to 1941 is below the BLS estimate of 1.88 per cent for the PNE in 1948 to 1973 reported in Table 1.
[16] The residual sector includes charities, healthcare, hotels & restaurants, waterworks and miscellaneous services.

comment on the dominance of manufacturing in the 1920s but not in the 1930s. This is further reinforced by the coefficients of variation reported in Table 5 which show a much bigger value for 1929-41 than for 1919-29.

In Figure 3, we draw Harberger diagrams for the manufacturing sector where coverage is virtually complete and the issue of a residual sector does not arise. Here the story is even more 'yeasty' with the same exception of the 1909-19 decade. However, a notable difference is that the most 'yeasty' decade in manufacturing is the 1920s, the same decade that experienced unusually rapid TFP growth in that sector. The Harberger coefficients for successive periods are 0.34, 0.72, 0.18, and 0.30.

The sectoral pattern of TFP growth for 1909-19 is very different from that of other periods. It seems possible that this reflects distortions from World War I and its aftermath. To check on this we have investigated the implications of using a revised periodization based on 1921 as the break year. For industries within manufacturing we obtained labor input and value added data for 1909, 1921, and 1929 from the Census of Manufactures and capital stock estimates from the dataset constructed by Inklaar et al. (2011). We then estimated capital stock for 1909 by combining Kendrick's index of real capital stock for that year based on 1929 = 100 with the Inklaar et al. data which are in 1929 dollars (full details of data sources can be found in Appendix A). The pattern that we see confirms the findings for the original periodization. The Harberger coefficients are 0.57 for 1909-21 and 0.22 for 1921-29.

Overall, this is clearly not what would be expected on the basis of Harberger (1998) which pointed readers towards a sporadic specialized TFP growth process for manufacturing (which would look like Figure 1b) in the interwar period. Why was the picture actually quite 'yeasty' (like Figure 1a rather than Figure 1b) for manufacturing and also for the PDE? The answer seems to be that several factors sustained a 'yeast-like pattern' for IGC by maintaining positive TFP growth in the vast majority of sectors rather than that there was a 'yeast process' at work. Consider the 1930s. In that decade, TFP growth represents a combination of technological progress and cost reductions associated with exit and rationalization. For example, TFP advance on the railroads was promoted by track closures in the face of financial pressure (Field, 2011, ch. 12) while the severe downturn of the early 1930s led to the permanent exit of many low productivity automobile plants (Bresnahan and Raff, 1991). The large IGC made by wholesale and retail trade was based on the development of national chain stores, self-service supermarkets, and investment in larger stores on new sites which replaced earlier outlets (Bernstein, 1987). Technological progress was underpinned by several strong but different clusters including electricity, the internal combustion engine, and chemicals (Mowery and Rosenberg, 2000). It is fair to say that this was an era when industrial research laboratories and applied science and engineering in universities were becoming more important but R&D was concentrated in relatively few sectors, notably, chemicals, electrical machinery, rubber, and petroleum. Also, the US was a big technology importer in some of these sectors. In chemicals, for example, it obtained a lot of patents at the end of the First World War because of wartime expropriations, leading to a 20 percent 'spillover' increase in domestic invention (Moser and Voena 2012) and in the 1920s a lot of patents were bought from abroad. Standard Oil of New Jersey, for example, paid the unprecedented sum of $35 million (three percent of the chemical industry's 1929 value added and about $390 million in dollars of 2013) for licensing the entire oil patent portfolio of IG Farben, the German chemicals cartel (Bakker 2013: 1801-2; Enos 1962). During the 1930s, many top German scientists fled to the United States and also generated important knowledge spillovers resulting in a further 31 percent increase in U.S. invention in the scientists' respective disciplines (Moser, Voena and Waldinger, 2014).

Prima facie, this review points in the direction of a universal specialized TFP growth process underpinning for the yeast pattern that is observed. On the other hand, the experience of the 1920s, which was, of course, the heyday of the electrification of American factories, might seem to point to the impact of electricity as a GPT as a 'yeast process' that dominated TFP growth in manufacturing during that decade. The following section investigates this hypothesis, which is the strongest candidate for a yeast process.

6. The Impact of Electric Motors on 1920s' Manufacturing Productivity Growth

The case for electricity as a GPT being responsible for a broadly-based ('yeasty') pattern of intensive growth contributions in American manufacturing in the 1920s is based on TFP spillovers. Devine (1983) noted several reasons why such spillovers might flow from changes in the design of factories facilitated by the shift to machinery with unit drive including enhanced flexibility of configuration, improved materials handling, greater feasibility of single-storey plants, and lighter factory buildings all of which were capital-saving. Horsepower in secondary motors in manufacturing grew rapidly averaging 6.19 per cent per year between 1919 and 1929 and 2.87 percent per year between 1929 and 1939 (DuBoff, 1979).

To estimate the size of these TFP spillovers we run similar cross-section regressions to David (1991) which look at the relationship between accelerations in TFP growth and growth of secondary motors per labor input, but use our estimates of TFP growth and a larger sample of manufacturing industries.[17] The results are reported in Table 9. We find evidence in favor of TFP spillovers for the 1920s but cannot reject the null hypothesis for the 1930s.[18] This is perhaps not surprising since the literature has singled out the 1920s as the period when these spillovers were substantial. Our results for the 1920s are somewhat similar to earlier estimates but imply that spillovers were smaller and accounted for a lower proportion of the TFP growth acceleration during the 1920s. For the manufacturing sector as a whole, the impact of growth in horsepower in secondary motors per labor input was 6.19 x 0.203 = 1.26 percentage points or about a third of the increase in TFP growth compared with nearly one half according to David (1991).

A decomposition of contributions to labor productivity growth in manufacturing in the 1920s based on equation (8) is reported in Table 10. Contributions from electrical capital deepening are reported in column 4 and contributions from electricity to TFP growth are reported in column 5; the latter is based on TFP spillovers, as estimated above, plus own TFP growth in the case of electrical machinery. The sum of these two components of the impact of electricity is recorded in column 8.

Three points stand out from the data reported in Table 10. First, it is apparent that electrical contributions generally account for a relatively small share of labor productivity growth, on average just under a quarter. Second, and similarly, TFP growth attributable to electricity amounts to less than 30 percent of all TFP growth while at the same time the coefficient of variation of electrical TFP growth is higher than that of non-electrical TFP growth. Third, it therefore seems difficult to understand the overall 'yeastiness' of manufacturing productivity growth in the 1920s as primarily a reflection of the impact of electricity as a GPT.

---

[17] This is quite similar in essence to the approach of Stiroh (2002) to investigating TFP spillovers from ICT capital accumulation in the late twentieth century.

[18] This rejects the hypothesis of electrification as a yeast process for TFP growth in the 1930s.

This conclusion is reinforced by the Harberger and Harberger-type diagrams displayed in Figure 4 and the associated Harberger coefficients summarized in Table 11. These are 0.30 for both electrical TFP growth and electrical contributions to labor productivity growth, respectively, compared with 0.18 and 0.17 for total TFP growth and overall labor productivity growth, respectively. Table 11 shows that these low Harberger coefficients for manufacturing productivity growth do not stem from a 'yeasty' impact of electricity per se but are more the result of broadly-based non-electrical contributions and a lack of correlation between these two types of contributions. Although, as noted in section 1, in some circumstances there may be reasons to belief that Harberger coefficients for a GPT could be smaller for labor productivity growth contributions than for TFP growth contributions, this does not really apply to electricity in the 1920s where the electrical labor productivity growth contribution had a yeastiness similar to that of the electrical TFP growth contribution.

In sum, this analysis points to a rather different interpretation of the 'yeasty' Harberger and Harberger-type diagrams for manufacturing in the 1920s from that which a reader of David and Wright (1999) would have been led to expect. Manufacturing productivity growth does not appear to have been completely dominated by the pervasive impact of electricity. The possibility remains open that TFP growth was largely sustained by a vigorous advance from a multiplicity of unconnected sources in many sectors such that it can be seen as a combination of generalized TFP growth and universal specialized TFP growth. In other words, we observe a 'yeast-like pattern' rather than a dominant yeast process in which one technology only drove widespread TFP advance across industries. The coincidence of very 'yeasty' productivity contributions and the electricity revolution may be just that.[19]

7. Conclusions

The research reported in this paper provides a significantly improved account of TFP growth in the United States between 1899 and 1941. We have developed the seminal work of Kendrick (1961) by covering more sectors in detail, by taking better account of labor quality, by extending the analysis from 1937 to a more suitable endpoint at 1941, and by calculating intensive growth contributions by sector. This last extension, which weights TFP growth by value-added share, also allows us to examine the nature of the growth process in the style of Harberger (1998).

Our growth accounting estimates find that TFP growth in the PDE averaged 1.3 per cent per year during the years from 1899 to 1941. This compares with Kendrick's (1961) estimate of 1.7 per cent per year. The difference results mainly from the adjustment made to crude TFP for labor quality. We estimate that labor quality grew at 0.8 per cent per year which is considerably higher than the 0.3 per cent estimated by Kendrick (1961). The main reason for this difference is that we take explicit account of improvements in educational attainment within occupations which was quite significant at a time when years of schooling were rising steadily.

Our method of correcting TFP for improvements in labor quality is similar to that employed by the BLS for the postwar period which means that inter-temporal comparisons can be made more accurately than hitherto, especially for 1929 to 1941 where we have also been able to estimate capital inputs on a capital-services basis. This leads us to the conclusion that, despite the claims of Field (2003), the 1930s was not the 'most technologically progressive decade of the twentieth century' since TFP growth in the

[19] A similar remark may be applicable to the suggestion by Prado (2014) that the rapid diffusion of electricity-based technology was responsible for a 'yeasty' Harberger-type diagram in pre-World War I Sweden given that the impact of electricity is not quantified.

PDE was below that achieved in both 1948-1960 and 1960 to 1973. Nevertheless, it is still true that there was a strong productivity performance during 1929 to 1941; our estimate is that TFP growth in the PDE averaged about 1.9 per cent per annum in these years.

We provide a detailed account of sectoral contributions to overall TFP growth which shows that TFP growth was broadly based during most of the period 1899 to 1941. This means that although the sectors which Gordon (2000) identified as comprising the core of the 'one big wave' of technological progress made a substantial contribution averaging just under 40 per cent of TFP growth they did not comprise a dominant component of TFP growth. Electrification, generally thought to have been one of the most important general purpose technologies in history, accounted for only 28 per cent of TFP growth in American manufacturing in the 1920s when its impact peaked. It appears that TFP growth accrued across the economy from multiple disparate sources.

This leads us to reject the hypothesis of a yeast process at the heart of American TFP growth. Nevertheless, if Harberger diagrams are constructed, with the exception of 1909 to 1919, we observe 'yeast-like patterns' as the Harberger curves are rather flat and close to the diagonal. This is explained by the relative absence of sectors with significant negative TFP growth contributions compared with the postwar periods for which Harberger (1998) constructed his characteristic 'mushrooms' diagrams. We observe something quite close to universal, rather than sporadic, specialized TFP growth.

The vision of the growth process in the American economy during the early twentieth century that emerges from our research has some important implications. It was characterized by vigorous technological progress that stemmed from many different sources and which, by the 1930s, promoted strong TFP growth in a wide range of sectors going well beyond the sectors usually highlighted in accounts of the 'second industrial revolution', such as electrical machinery and automobiles, to distribution and entertainment. It seems reasonable to see this as the outcome of institutional and policy settings that were generally conducive to investment, innovation, and creative destruction. Some of the star performers were unlikely to have been promoted by the selective industrial policies of an interventionist government and would certainly not have been priority sectors under central planning. The message is that strong growth potential in the United States was underpinned by good horizontal industrial policies which ensured that TFP growth was resilient even in the traumatic decade of the 1930s.

References

Abramovitz, Moses and Paul A. David. 2001. "Two Centuries of American Macroeconomic Growth: from Exploitation of Resource Abundance to Knowledge-Driven Development." Stanford Institute for Economic Policy Research Discussion Paper No. 01-05.

Bakker, Gerben. 2012. "How Motion Pictures Industrialized Entertainment." *Journal of Economic History*, 72 (4): 1036-1063.

Bakker, Gerben. 2013. "Money for Nothing: How Firms Have Financed R&D-Projects since the Industrial Revolution." *Research Policy*, 42(10): 1793-1814.

Bernstein, Michael A. 1987. "The Response of American Manufacturing Industries to the Great Depression." *History and Technology*: 3(3): 225-248.

Bresnahan, Timothy F. and Daniel M. G. Raff. 1991. "Intra-Industry Heterogeneity and the Great Depression: the American Motor Vehicles Industry, 1929-1935." *Journal of Economic History* 51(2): 317-331.

Broadberry, Stephen N. 1998. "How did the United States and Germany Overtake Britain? A Sectoral Analysis of Comparative Productivity Levels." *Journal of Economic History* 58(2): 375-407.

Bureau of Economic Analysis. 1999. *Fixed Reproducible Tangible Wealth in the United States, 1925-1994*. Washington DC: Government Printing Office.

Bureau of Labor Statistics, "Historical Multifactor Productivity Measures", http://www.bls.gov/mfp/home.htm (October 2014).

Byrne, David M., Stephen D. Oliner, and Daniel E. Sichel. 2013. "Is the Information Technology Revolution Over?" *International Productivity Monitor* 25 (Spring): 20-36.

Cole, Harold 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.

Carter, Susan B., Scott S. Gartner, Michael R. Haines, Alan L. Olmstead, Richard Sutch, and Gavin Wright (Eds.). 2006. *Historical Statistics of the United States: Earliest Times to the Present*. Cambridge: Cambridge University Press.

Crafts, Nicholas. 2004a. "Productivity Growth in the Industrial Revolution: a New Growth Accounting Perspective." *Journal of Economic History* 64(2): 521-535.

Crafts, Nicholas. 2004b. "Steam as a General Purpose Technology: a Growth Accounting Perspective." *Economic Journal* 114(495): 338-351.

David, Paul A. 1991. "Computer and Dynamo: the Modern Productivity Paradox in a Not-Too-Distant Mirror." In OECD, *Technology and Productivity: the Challenge for Economic Policy*, 315-347. Paris: OECD.

David, Paul A. and Gavin Wright. 1999. "Early Twentieth Century Productivity Growth Dynamics: an Inquiry into the Economic History of 'Our Ignorance'." University of Oxford Discussion Paper in Economic and Social History No. 33.

Devine, Warren D. 1983. "From Shafts to Wires: Historical Perspective on Electrification." *Journal of Economic History* 43(2): 347-372.

DuBoff, Richard B. 1979. *Electric Power in American Manufacturing, 1889-1959*. New York: Arno Press.

Enos, John L. 1962. *Petroleum Progress and Profits: A History of Process Innovation*. Cambridge, Mass.: MIT Press.

Field, Alexander J. 2003. "The Most Technologically Progressive Decade of the Century." *American Economic Review* 93(4): 1399-1413.

Field, Alexander J. 2011. *A Great Leap Forward: 1930s Depression and U.S. Economic Growth*. New Haven: Yale University Press.

Goldin, Claudia and Lawrence F. Katz. 2008. *The Race Between Education and Technology*. Cambridge, Mass.: Harvard University Press.

Gordon, Robert J. 1999. "U.S. Economic Growth since 1870: One Big Wave?" *American Economic Review*, 89(2): 123-128.

Gordon, Robert J. 2000. "Interpreting the 'One Big Wave' in U. S. Long-Term Productivity Growth." In *Productivity, Technology and Economic Growth,* edited by Bart van Ark, Simon Kuipers and Gerard Kuper, 19-65. Dordrecht: Kluwer Publishers.

Gordon, Robert J. 2016. *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War*. Princeton, NJ.: Princeton University Press.

Harberger, Arnold C. 1998. "A Vision of the Growth Process." *American Economic Review* 88(1): 1-32.

Hatton, Timothy J. and Mark Thomas. 2010. "Labour Markets in the Interwar Period and Recovery in the UK and the USA." *Oxford Review of Economic Policy* 26: 463-485.

Hulten, Charles R. 1978. "Growth Accounting with Intermediate Inputs." *Review of Economic Studies* 45(3): 511-518.

Inklaar, Robert, de Jong, Herman, and Gouma, Reitze. 2011. "Did Technology Shocks Drive the Great Depression? Explaining Cyclical Movements in U. S. Manufacturing." *Journal of Economic History*, 71(4): 827-858.

Inklaar, Robert and Timmer, Marcel P. 2007. "Of Yeast and Mushrooms: Patterns of Industry-Level Productivity Growth." *German Economic Review* 8(2): 174-187.

Kendrick, John W. 1961. *Productivity Trends in the United States*. Princeton, NJ.: Princeton University Press.

Lipsey, Richard G., Clifford T.Bekar, and Kenneth I. Carlaw. 1998. "What Requires Explanation?" In *General Purpose Technologies and Economic Growth,* edited by Elhanan Helpman, 15-54. Cambridge, Mass.: MIT Press.

Matthews, Robin C. O., Charles H. Feinstein, and John C. Odling Smee. 1982. *British Economic Growth, 1856-1973*. Stanford, CA.: Stanford University Press.

Moser, Petra, and Alessandra Voena. 2012. "Compulsory Licensing: Evidence from Trading with the Enemy Act." *American Economic Review*, 102(1): 396-427.

Moser, Petra, Alessandra Voena and Fabian Waldinger. 2014. "German Jewish Emigres and US Invention." *American Economic Review*, 104(10): 322-355.

Mowery, David C. and Rosenberg, N. 1989. *Technology and the Pursuit of Economic Growth*. Cambridge: Cambridge University Press.

Mowery, David C. and Nathan Rosenberg. 2000. "Twentieth Century Technological Change." In *The Cambridge Economic History of the United States*, vol. 3., edited by Stanley L. Engerman and Robert E. Gallmann, 803-925. Cambridge: Cambridge University Press.

OECD. 2001. *Measuring Productivity*. Paris: OECD.

Olmstead, Alan L. and Paul W. Rhode. 2008. *Creating Abundance: Biological Innovation and American Agricultural Development.* New York: Cambridge University Press.

Prado, Svante. 2014. "Yeast or Mushrooms? Productivity Growth Patterns across Swedish Manufacturing Industries, 1869-1912." *Economic History Review* 67(2): 382-408.

Solow, Robert M. 1957. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39(3): 312-320.

Stiroh, Kevin J. 2002. "Are ICT Spillovers Driving the New Economy?", *Review of Income and Wealth*, 48(1), 33-58.

Warwick, Kenneth (2013), 'Beyond Industrial Policy', *OECD STI Policy Paper* No. 2.

Table 1. Recent Estimates of Contributions to Labor Productivity Growth in the United States, 1901-2007 (% per year).

Period	*K/L*	*Crude TFP*	*Refined TFP*	*Y/L*
1901-1919	0.44	1.27	1.08	1.71
1919-1929	0.30	1.97	2.02	2.27
1929-1941	-0.06	2.41	2.31	2.35
1941-1948	0.21	1.50	1.29	1.71
1948-1973	0.76	1.99	1.88	2.75
1973-1989	0.70	0.58	0.36	1.28
1989-2000	0.78	1.29	0.79	2.07
2000-2007	0.87	1.72	1.38	2.59

Notes: 'refined TFP' corrects 'crude TFP for labor quality. Estimates are for the private nonfarm economy (PNE).

Source: derived from Field (2011, Table 2.1); post-1948 is based on data from Bureau of Labor Statistics, "Historical Multifactor Productivity Measures", http://www.bls.gov/mfp/home.htm (October 2014).

Table 2. Industry Value Added as percentage of GDP, United States, 1899-1941.

Industry	*Value added (percentage of GDP)*				
	1899-1919	1909-1919	1919-1929	1929-1941	1899-1941
Farming	12.8	11.1	9.4	7.7	10.1
Metals	0.6	0.6	0.6	0.5	0.6
Anthracite Coal	0.3	0.3	0.3	0.2	0.3
Bituminous Coal	0.7	0.7	0.7	0.6	0.7
Oil and Gas	0.4	0.5	0.7	0.8	0.6
Non-metals	0.4	0.3	0.3	0.2	0.3
Foods	4.3	4.5	4.6	5.6	4.8
Tobacco	0.9	0.9	0.9	1.1	0.9
Textiles	1.8	1.8	1.9	1.7	1.8
Apparel	1.6	1.5	1.3	1.2	1.4
Leather Products	0.9	0.8	0.6	0.5	0.7
Lumber Products	2.3	1.7	1.2	0.8	1.5
Paper	0.4	0.5	0.6	0.7	0.6
Printing Publishing	1.4	1.6	1.7	1.6	1.6
Chemicals	0.9	1.0	1.1	1.3	1.1
Petroleum, Coal Products	0.6	0.9	1.3	1.2	1.0
Rubber Products	0.2	0.3	0.4	0.4	0.3
Stone, clay, glass	0.7	0.8	0.8	0.8	0.8
Primary Metals	2.6	2.5	2.4	2.2	2.4
Fabricated Metals	1.0	1.2	1.5	1.5	1.3
Machinery Non-Electric	2.3	2.2	2.0	1.9	2.1
Electric Machinery	0.4	0.6	0.9	1.0	0.7
Transport Equipment	1.0	1.4	1.8	2.0	1.6
Furniture	0.5	0.6	0.6	0.6	0.6
Miscellaneous	0.9	0.8	0.7	0.6	0.7
Electric Utilities	0.5	1.1	1.7	2.0	1.4
Manufactured Gas	0.1	0.1	0.2	0.2	0.2
Natural Gas	0.1	0.2	0.2	0.3	0.2
Construction*	5.4	4.8	4.2	3.2	4.3
Wholesale & retail trade*	13.6	13.5	13.4	13.6	13.5
Railroads	6.2	5.9	5.5	4.4	5.4
Local Transit	1.1	1.1	1.0	0.8	1.0
Residual Transport	1.1	1.2	1.3	1.7	1.3
Telephone	0.3	0.5	0.7	0.8	0.6
Telegraph	0.1	0.1	0.1	0.1	0.1
Post Office*	0.4	0.5	0.5	0.6	0.5
FIRE*	4.5	7.9	11.3	10.9	8.8
Spectator Entertainment*	0.4	0.4	0.5	0.5	0.5
Manufacturing	24.6	25.5	26.4	26.8	25.8
Aggregate measured sectors	73.6	76.4	79.2	76.0	76.3
Government sector	3.4	4.0	4.7	7.7	5.1
Residual sector	23.0	19.6	16.2	16.3	18.7

Note: benchmark estimates were made for 1899, 1929 and 1939 based on original sources. The period values

were then estimated by linear adjacent-year weighting using mid-interval years, for example: 1899-1909 is 25/30 of the 1899 weight and 5/30 of the 1929 weight; 1909-1919 is the average
of the 1899 and 1929 weights, and 1919-1929 is 5/30 of the 1899 weight and 25/30 of the 1929 weight.
* = sector measured in this paper but not by Kendrick.
FIRE = financed, insurance, real estate & business services.
Source: see Appendix A for details.

Table 3. Growth in Labor Quality by Industry, United States, 1899-1941.

Industry	*Growth in labor quality (percent per annum)*				
	1899-1909	1909-1919	1919-1929	1929-1941	1899-1941
Farming	0.00	0.73	0.31	0.48	0.38
Metals	0.16	0.54	0.54	0.44	0.42
Anthracite Coal	0.19	0.49	0.56	0.51	0.44
Bituminous Coal	0.19	0.49	0.56	0.51	0.44
Oil and Gas	-0.05	-0.22	0.73	0.65	0.30
Non-metals	0.13	0.55	0.14	0.54	0.35
Foods	-0.01	0.20	0.36	0.41	0.25
Tobacco	-0.38	0.10	0.20	0.65	0.17
Textiles	0.52	0.67	0.66	0.71	0.64
Apparel	0.24	0.63	0.40	0.06	0.32
Leather Products	-0.71	0.23	0.26	0.31	0.04
Lumber Products	-0.06	0.47	0.46	0.45	0.33
Paper	0.93	0.63	0.67	0.60	0.70
Printing Publishing	0.07	0.42	0.39	0.47	0.34
Chemicals	-0.09	0.51	0.43	0.62	0.38
Petroleum, Coal Products	0.19	0.61	0.50	0.84	0.55
Rubber Products	0.48	0.75	0.56	0.76	0.65
Stone, clay, glass	-0.03	0.37	0.57	0.44	0.34
Primary Metals	0.05	0.57	0.61	0.47	0.43
Fabricated Metals	-0.02	0.45	0.56	0.42	0.35
Machinery Non-Electric	0.02	0.40	0.75	0.54	0.43
Electric Machinery	0.84	0.48	0.51	0.51	0.58
Transport Equipment	-0.20	0.15	0.60	0.60	0.30
Furniture	-0.36	0.45	0.23	0.32	0.17
Miscellaneous	0.00	0.44	0.71	0.43	0.40
Electric Utilities	0.13	0.39	0.40	0.98	0.50
Manufactured Gas	-0.19	0.14	0.45	0.71	0.30
Natural Gas	-0.19	0.14	0.45	0.71	0.30
Construction*	-0.14	0.49	0.15	0.13	0.16
Wholesale & retail trade*	-0.04	0.40	0.19	0.09	0.16
Railroads	-0.08	0.53	0.75	0.76	0.50
Local Transit	0.14	0.60	0.60	0.57	0.48
Residual Transport	0.14	0.12	0.55	0.49	0.33
Telephone	0.18	0.00	0.80	1.14	0.56
Telegraph	-0.06	0.17	-0.19	0.84	0.22
Post Office*	0.30	0.35	0.46	0.44	0.39
FIRE*	-0.06	0.99	0.52	0.27	0.42
Spectator Entertainment*	0.21	0.77	0.30	0.23	0.37

Manufacturing average	0.04	0.42	0.50	0.50	0.37
PDE	0.85	1.12	0.65	0.59	0.79
Memorandum:					
Kendrick PDE	0.50	0.41	0.17	0.20	0.32
Minimum	-0.71	-0.22	-0.19	0.06	0.04
Maximum	0.93	0.99	0.80	1.14	0.70
Range	1.64	1.20	0.98	1.08	0.67

Notes:

* = sector measured in this paper but not by Kendrick.

Source: own calculations, see the text and Appendix D.

Table 4. Growth in Total Factor Productivity (TFP) by Industry, United States, 1899-1941.

Industry	*TFP-growth (percent per annum)*				
	1899-1909	1909-1919	1919-1929	1929-1941	1899-1941
Farming	-0.2	-0.7	1.0	2.5	0.7
Metals	1.0	1.8	3.4	0.6	1.7
Anthracite Coal	-0.5	0.2	-0.4	0.3	-0.1
Bituminous Coal	1.1	1.5	2.0	1.8	1.6
Oil and Gas	1.3	1.1	5.0	2.1	2.3
Non-metals	1.5	0.0	5.8	3.6	2.8
Foods	0.5	-1.5	4.5	3.7	1.9
Tobacco	1.5	4.8	4.2	5.8	4.2
Textiles	0.7	0.4	2.4	3.3	1.8
Apparel	0.5	2.2	3.7	-0.4	1.4
Leather Products	0.6	0.3	2.7	-0.1	0.9
Lumber Products	-0.4	-1.6	2.1	-1.8	-0.4
Paper	1.7	-0.2	4.2	1.1	1.7
Printing Publishing	3.8	2.7	3.4	0.3	2.5
Chemicals	0.8	-1.1	7.1	2.1	2.2
Petroleum, Coal Products	0.6	-1.5	8.2	-1.1	1.4
Rubber Products	1.9	6.8	7.3	1.5	4.2
Stone, clay, glass	2.2	0.4	5.3	1.7	2.4
Primary Metals	2.7	-0.9	5.0	2.4	2.3
Fabricated Metals	2.3	1.5	4.2	1.3	2.3
Machinery Non-Electric	1.0	0.4	2.3	2.1	1.5
Electric Machinery	0.0	-0.1	3.1	4.6	2.0
Transport Equipment	1.3	6.9	7.9	3.5	4.8
Furniture	-0.5	-0.8	4.0	1.4	1.0
Miscellaneous	0.8	-0.9	4.1	1.5	1.4
Electric Utilities	5.1	8.0	2.3	5.1	5.1
Manufactured Gas	4.2	4.9	2.9	1.8	3.4
Natural Gas	0.1	1.0	0.0	3.7	1.3
Construction*	4.4	-1.6	0.8	0.7	1.1
Wholesale & retail trade*	1.5	0.0	0.9	3.4	1.6
Railroads	1.9	3.0	1.3	2.6	2.2
Local Transit	1.0	2.2	3.6	0.4	1.7
Residual Transport	-1.3	1.4	7.0	5.8	3.3
Telephone	4.7	1.9	1.1	1.4	2.2
Telegraph	1.5	-1.3	4.4	0.7	1.3
Post Office*	1.4	2.5	0.1	0.4	1.1
FIRE*	0.5	-0.6	0.2	-1.3	-0.4
Spectator Entertainment*	4.0	10.8	3.2	4.4	5.5

Manufacturing	1.1	0.5	4.5	2.3	2.2
Aggregate measured sectors	1.2	0.4	2.2	1.9	1.5
Residual sector	-0.0	1.8	-0.8	1.8	0.7
PDE	0.9	0.7	1.7	1.9	1.3
Memorandum:					
Kendrick's aggregate measured sectors	0.7	0.8	3.7	(2.5)	(1.9)
Kendrick's residual sector	1.7	1.5	-0.1	(2.0)	(1.4)
Kendrick PDE	1.2	1.1	2.0	2.3	1.7
Minimum	-1.3	-1.6	-0.4	-1.8	-0.4
Maximum	5.1	10.8	8.2	5.8	5.5
Range	6.4	12.4	8.6	7.6	6.0

Notes: Kendrick's aggregate measured sector comprises Farming, Mining, Manufacturing, Transportation, Communication & Public Utilities)

* = sector measured in this paper but not by Kendrick.

For 1929-1941 and 1899-1941 the TFP-growth of Kendrick's measured and residual sectors was estimated using our data for Kendrick's measured sectors for 1929-41 and the relationship between measured, residual and aggregate TFP growth in Kendrick’s numbers for his 4 sub-periods during 1899 through 1937.

TFP here is refined TFP, i.e. after correcting crude TFP for the growth of labor quality (see text).

Source: Kendrick 1961, pp. 136-7; own calculations, see the text and Appendices B and C (industry data) and Appendix D (labor quality data).

Table 5. Intensive Growth Contribution (IGC) by Industry, United States, 1899-1941.

Industry	*IGC = (VAShare*TFP growth)*				
	1899-1909	1909-1919	1919-1929	1929-1941	1899-1941
Farming	-0.025	-0.079	0.097	0.193	0.075
Metals	0.006	0.011	0.019	0.003	0.009
Anthracite Coal	-0.002	0.001	-0.001	0.001	0.000
Bituminous Coal	0.007	0.010	0.014	0.012	0.010
Oil and Gas	0.005	0.005	0.033	0.017	0.015
Non-metals	0.006	0.000	0.015	0.007	0.007
Foods	0.022	-0.068	0.211	0.206	0.096
Tobacco	0.013	0.042	0.037	0.062	0.041
Textiles	0.013	0.007	0.044	0.058	0.031
Apparel	0.008	0.032	0.049	-0.005	0.019
Leather Products	0.006	0.002	0.017	0.000	0.005
Lumber Products	-0.008	-0.027	0.026	-0.013	-0.006
Paper	0.008	-0.001	0.024	0.007	0.010
Printing Publishing	0.054	0.042	0.058	0.005	0.038
Chemicals	0.007	-0.011	0.080	0.028	0.026
Petroleum, Coal Products	0.003	-0.013	0.103	-0.013	0.015
Rubber Products	0.004	0.020	0.028	0.006	0.015
Stone, clay, glass	0.016	0.003	0.044	0.015	0.019
Primary Metals	0.069	-0.023	0.121	0.052	0.054
Fabricated Metals	0.022	0.018	0.064	0.020	0.030
Machinery Non-Electric	0.022	0.008	0.047	0.039	0.030
Electric Machinery	0.000	0.000	0.028	0.046	0.016
Transport Equipment	0.013	0.096	0.142	0.071	0.081
Furniture	-0.002	-0.005	0.026	0.009	0.006
Miscellaneous	0.007	-0.007	0.027	0.010	0.010
Electric Utilities	0.024	0.088	0.040	0.103	0.077
Manufactured Gas	0.005	0.007	0.005	0.003	0.006
Natural Gas	0.000	0.002	0.000	0.012	0.003
Construction*	0.238	-0.075	0.035	0.023	0.043
Wholesale & retail trade*	0.209	-0.001	0.123	0.462	0.211
Railroads	0.116	0.175	0.072	0.111	0.111
Local Transit	0.011	0.024	0.036	0.003	0.016
Residual Transport	-0.014	0.017	0.094	0.096	0.048
Telephone	0.014	0.010	0.008	0.012	0.015
Telegraph	0.002	-0.002	0.007	0.001	0.002
Post Office*	0.006	0.012	0.001	0.002	0.006
FIRE*	0.023	-0.049	0.023	-0.145	-0.032
Spectator Entertainment*	0.015	0.048	0.016	0.023	0.026
Manufacturing	0.277	0.115	1.176	0.603	0.537
Aggregate measured sectors	0.922	0.319	1.812	1.542	1.186
Residual sector	-0.003	0.358	-0.128	0.323	0.128
PDE	0.920	0.677	1.685	1.866	1.314
Mean	0.024	0.008	0.048	0.041	0.031
Coefficient of variation	2.156	5.2833	0.944	2.211	1.328

Notes:
* = sector measured in this paper but not by Kendrick : *Source*: derived from Tables 3 and 5.

Table 6. Industries Ranked by TFP-growth and IGC, United States, 1899-1941.

	1899-1909		***1909-1919***		***1919-1929***		***1929-1941***		***1899-1941***	
	TFP	***IGC***	***TFP***	***IGC***	***TFP***	***IGC***	***TFP***	***IGC***	***TFP***	***IGC***
1	Electric Utilities	Construction	Spectator entertainment	Railroads	Petroleum, Coal Products	Foods	Residual Transport	Wholesale and retail trade	Spectator entertainment	Wholesale and retail trade
2	Telephone	Wholesale and retail trade	Electric Utilities	Transport Equipment	Transport Equipment	Transport Equipment	Tobacco	Foods	Electric Utilities	Railroads
3	Construction	Railroads	Transport Equipment	Electric Utilities	Rubber Products	Wholesale and retail trade	Electric Utilities	Farming	Transport Equipment	Foods
4	Manufactured Gas	Primary Metals	Rubber Products	Spectator entertainment	Chemicals	Primary Metals	Electric Machinery	Railroads	Rubber Products	Transport Equipment
5	Spectator entertainment	Printing Publishing	Manufactured Gas	Tobacco	Residual Transport	Petroleum, Coal Products	Spectator entertainment	Electric Utilities	Tobacco	Electric Utilities
6	Printing Publishing	Electric Utilities	Tobacco	Printing Publishing	Nonmetals	Farming	Foods	Residual Transport	Manufactured Gas	Farming
7	Primary Metals	Finance and Services	Railroads	Apparel	Stone, clay, glass	Residual Transport	Natural Gas	Transport Equipment	Residual Transport	Primary Metals
8	Fabricated Metals	Fabricated Metals	Printing Publishing	Local Transit	Primary Metals	Chemicals	Nonmetals	Tobacco	Nonmetals	Residual Transport
9	Stone, clay, glass	Machinery NonElectric	Post office	Rubber Products	Oil and Gas	Railroads	Transport Equipment	Textiles	Printing Publishing	Construction
10	Rubber Products	Foods	Local Transit	Fabricated Metals	Foods	Fabricated Metals	Wholesale and retail trade	Primary Metals	Stone, clay, glass	Tobacco
11	Railroads	Stone, clay, glass	Apparel	Residual Transport	Telegraph	Printing Publishing	Textiles	Electric Machinery	Oil and Gas	Printing Publishing
12	Paper	Spectator entertainment	Telephone	Post office	Tobacco	Apparel	Railroads	Machinery NonElectric	Primary Metals	Textiles
13	Telegraph	Telephone	Metals	Metals	Paper	Machinery NonElectric	Farming	Chemicals	Fabricated Metals	Fabricated Metals

14	Wholesale and retail trade	Tobacco	Bituminous Coal	Bituminous Coal	Fabricated Metals	Textiles	Primary Metals	Construction	Telephone	Machinery NonElectric
15	Nonmetals	Transport Equipment	Fabricated Metals	Telephone	Miscellaneous	Stone, clay, glass	Chemicals	Spectator entertainment	Chemicals	Chemicals
16	Tobacco	Textiles	Residual Transport	Machinery NonElectric	Furniture	Electric Utilities	Machinery NonElectric	Fabricated Metals	Railroads	Spectator entertainment
17	Post office	Local Transit	Oil and Gas	Manufactured Gas	Apparel	Tobacco	Oil and Gas	Oil and Gas	Electric Machinery	Stone, clay, glass
18	Oil and Gas	Apparel	Natural Gas	Textiles	Local Transit	Local Transit	Bituminous Coal	Stone, clay, glass	Foods	Apparel
19	Transport Equipment	Paper	Stone, clay, glass	Oil and Gas	Metals	Construction	Manufactured Gas	Telephone	Textiles	Local Transit
20	Bituminous Coal	Chemicals	Machinery NonElectric	Stone, clay, glass	Printing Publishing	Oil and Gas	Stone, clay, glass	Bituminous Coal	Local Transit	Electric Machinery
21	Local Transit	Miscellaneous	Textiles	Leather Products	Spectator entertainment	Electric Machinery	Miscellaneous	Natural Gas	Paper	Oil and Gas
22	Metals	Bituminous Coal	Leather Products	Natural Gas	Electric Machinery	Rubber Products	Rubber Products	Miscellaneous	Metals	Telephone
23	Machinery NonElectric	Post office	Anthracite Coal	Anthracite Coal	Manufactured Gas	Miscellaneous	Furniture	Furniture	Bituminous Coal	Rubber Products
24	Miscellaneous	Metals	Nonmetals	Nonmetals	Leather Products	Lumber Products	Telephone	Paper	Wholesale and retail trade	Petroleum, Coal Products
25	Chemicals	Leather Products	Wholesale and retail trade	Electric Machinery	Textiles	Furniture	Fabricated Metals	Nonmetals	Machinery NonElectric	Bituminous Coal
26	Textiles	Nonmetals	Electric Machinery	Wholesale and retail trade	Machinery NonElectric	Paper	Paper	Rubber Products	Petroleum, Coal Products	Paper
27	Leather Products	Manufactured Gas	Paper	Paper	Electric Utilities	Finance and Services	Construction	Printing Publishing	Apparel	Miscellaneous
28	Petroleum, Coal Products	Oil and Gas	Finance and Services	Telegraph	Lumber Products	Metals	Telegraph	Manufactured Gas	Miscellaneous	Metals
29	Apparel	Rubber Products	Farming	Furniture	Bituminous Coal	Leather Products	Metals	Local Transit	Telegraph	Nonmetals
30	Finance and Services	Petroleum, Coal Products	Furniture	Miscellaneous	Railroads	Spectator entertainment	Post office	Metals	Natural Gas	Furniture
31	Foods	Telegraph	Miscellaneous	Chemicals	Telephone	Nonmetals	Local Transit	Post office	Construction	Post Office

32	Natural Gas	Natural Gas	Primary Metals	Petroleum, Coal Products	Farming	Bituminous Coal	Anthracite Coal	Telegraph	Post office	Manufactured Gas
33	Electric Machinery	Electric Machinery	Chemicals	Primary Metals	Wholesale and retail trade	Telephone	Printing Publishing	Anthracite Coal	Furniture	Leather Products
34	Farming	Anthracite Coal	Telegraph	Lumber Products	Construction	Telegraph	Leather Products	Leather Products	Leather Products	Natural Gas
35	Lumber Products	Furniture	Petroleum, Coal Products	Finance and Services	Finance and Services	Manufactured Gas	Apparel	Apparel	Farming	Telegraph
36	Furniture	Lumber Products	Foods	Foods	Post office	Post office	Petroleum, Coal Products	Petroleum, Coal Products	Anthracite Coal	Anthracite Coal
37	Anthracite Coal	Residual Transport	Lumber Products	Construction	Natural Gas	Natural Gas	Finance and Services	Lumber Products	Finance and Services	Lumber Products
38	Residual Transport	Farming	Construction	Farming	Anthracite Coal	Anthracite Coal	Lumber Products	Finance and Services	Lumber Products	Finance and Services
Rank order correlations TFP-IGC:										
	0.6		0.9		0.4		0.8		0.5	

Source: Tables 4 and 5.

Table 7. TFP Growth in the Private Domestic Economy, United States, 1899-2007 (% per year).

Period	*TFP-growth*
1899-1909	0.92
1909-1919	0.68
1919-1929	1.68
1929-1941	1.87
1948-1960	2.00
1960-1973	2.23
1973-1989	0.48
1989-2000	0.98
2000-2007	1.45

Note: the post-war break points are chosen on the basis of NBER business cycle peaks.

Sources: Table 5 and Bureau of Labor Statistics, “Historical Multifactor Productivity Measures”, http://www.bls.gov/mfp/home.htm (October 2014); National Bureau of Economic Research, “US Business Cycle Expansions and Contractions,” http://www.nber.org/cycles.html (accessed 28 November 2015).

Table 8. Decomposition of TFP Growth in the United States Private Non-Farm Economy (PNE), 1919-1941.

	Panel A: 1919-1929					
	Field (2011)			***This study***		
	1929 Weight (%)	***TFP Growth (% p.a.)***	***IGC (% p.a.)***	***Midperiod Weight (%)***	***TFP Growth (% p.a.)***	***IGC (% p.a.)***
Manufacturing	32.93	5.12	1.69	30.73	4.45	1.37
Transport and Public Utilities	14.10	1.86	0.26	12.66	2.41	0.30
Wholesale and Retail Trade	20.30	0.50	0.10	15.66	0.91	0.14
Mining				2.90	3.20	0.09
Other	32.67	-0.09	-0.03	38.05	-0.39	-0.15
Total PNE		2.02			1.76	
	Panel B: 1929-1941					
	Field (2011)			***This study***		
	1941 Weight (%)	***TFP Growth (% p.a.)***	***IGC (% p.a.)***	***Midperiod Weight (%)***	***TFP Growth (% p.a.)***	***IGC (% p.a.)***
Manufacturing	42.42	2.60	1.10	31.61	2.25	0.71
Transport and Public Utilities	12.28	4.60	0.57	12.22	3.30	0.40
Wholesale and Retail Trade	22.23	2.39	0.53	16.10	3.39	0.55
Mining				2.82	1.66	0.05
Other	23.07	0.48	0.11	37.26	0.31	0.12
Total PNE		2.31			1.82	

Notes: Other is obtained as a residual and mining is part of other for Field (2006); weights are % PNE. May not sum to total due to rounding.

Sources: Field (2011, Tables 2.5 and 2.10); derived from Tables 4 and 5.

Table 9. Regressions of TFP Spillovers from Electricity Adoption for a Cross-Section of all Manufacturing Industries, United States, 1919-1941.

	1919-1929	*1929-1941*
Constant	2.465***	-2.662*
	(4.02)	(-2.42)
HP Growth	0.203*	-0.022
	(2.25)	(-0.12)
Adjusted R^2	0.18	-0.06
N	19	19

Notes: The dependent variables are (TFP growth 1919-29 – TFP growth 1899-19) and (TFP growth 1929-41 – TFP growth 1919-29) derived from Table 4; the independent variables are the average annual rates of growth of horsepower in secondary electric motors in 1919-29 and 1929-39 from DuBoff (1979).

t-statistics in parentheses.

* = significant at 5 % level

*** = significant at 0.1 % level

Source: own calculations.

Table 10. Contributions to Labor Productivity Growth in Manufacturing, United States, 1919-1929 (% per year).

	Labor Quality Growth	Non-Electrical K/L Growth	Non-Electrical TFP Growth	Electrical K/L Growth	Electrical TFP Growth	Labor Productivity Growth	Sum of Non-Electrical Contributions	Sum of Electrical Contributions
Foods	0.2743	0.1501	3.8161	0.0059	0.7222	4.9685	4.2404	0.7281
Tobacco	0.1508	2.7989	2.4167	0.0011	1.8325	7.2000	5.3664	1.8336
Textiles	0.5037	-0.5083	1.7981	0.0083	0.5982	2.4000	1.7935	0.6065
Apparel	0.3042	-0.0020	4.2331	0.0020	-0.5374	4.0000	4.5354	-0.5354
Leather Products	0.1975	-0.4174	2.3706	0.0174	0.3319	2.5000	2.1507	0.3493
Lumber Products	0.3539	0.4586	-0.2918	0.0414	2.4380	3.0000	0.5207	2.4793
Paper	0.5157	0.3666	2.0307	0.0334	2.1536	5.1000	2.9130	2.1870
Printing Publishing	0.2969	-0.0064	3.4031	0.0064	0.0000	3.7000	3.6936	0.0064
Chemicals	0.3338	0.7873	5.6429	0.0127	1.4234	8.2000	6.7639	1.4361
Petroleum etc.	0.3870	0.3871	6.2074	0.0129	2.0056	9.0000	6.9815	2.0185
Rubber Products	0.4335	0.6518	6.0884	0.0482	1.1781	8.4000	7.1736	1.2264
Stone, clay, glass	0.4411	0.5778	3.3937	0.0222	1.8653	6.3000	4.4126	1.8874
Primary Metals	0.4690	0.2777	3.4594	0.0223	1.5716	5.8000	4.2061	1.5939
Fabricated Metals	0.4293	0.4910	3.9341	0.0090	0.2366	5.1000	4.8544	0.2456
Non-Elec Mach.	0.5763	-0.0099	1.8364	0.1099	0.4872	3.0000	2.4028	0.5972
Electric Machinery	0.3953	0.4960	0.0000	0.0040	3.1047	4.0000	0.8913	3.1087
Transport Eqpmt.	0.4580	0.6882	6.4228	0.0118	1.5192	9.1000	7.5691	1.5309
Furniture	0.1783	0.0644	2.7529	0.0356	1.2688	4.3000	2.9956	1.3044
Miscellaneous	0.5472	0.8893	2.5470	0.0107	1.5059	5.5000	3.9834	1.5166
Standard deviation	0.1207	0.6691	1.8545	0.0247	0.8928	2.1147	2.0167	0.8929
Mean	0.3813	0.4285	3.2664	0.0218	1.2477	5.3457	4.0762	1.2695
Coeff. of variation	0.3164	1.5617	0.5677	1.1290	0.7156	0.3956	0.4948	0.7033

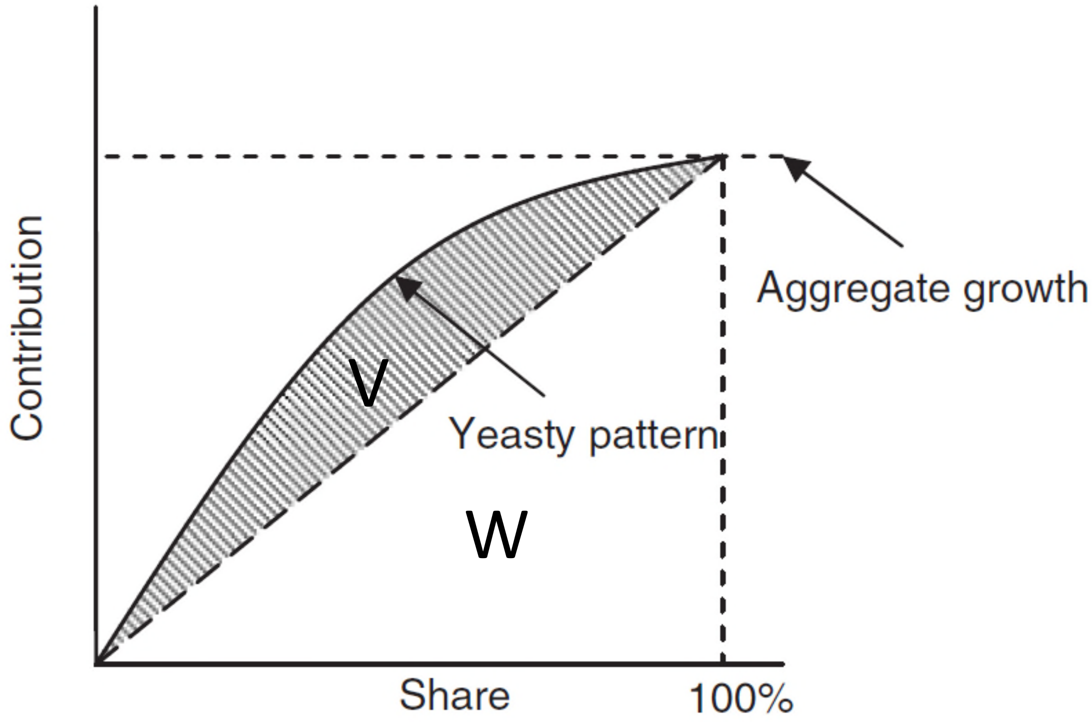
Notes: Col 8 = Col 4 + Col 5; Col 7 = sum of Cols 2 through 6; Col 6 = TFP spillovers except for electrical machinery which includes own TFP growth as well.
Source: own calculations based on implementing equation (8)

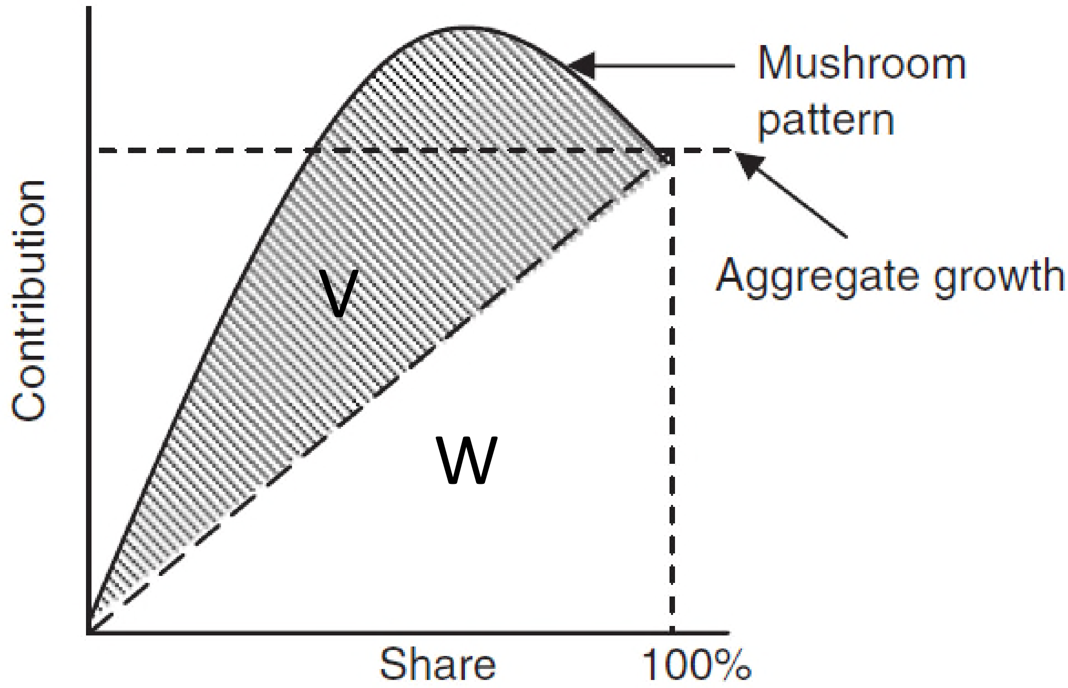
Table 11. Harberger Coefficients for Contributions to Productivity Growth in the Manufacturing Sector, United States, 1919-1929.

	TFP Growth	***Labor Productivity Growth***
Electrical	0.30	0.30
Non-Electrical	0.22	0.20
Total	0.18	0.17

Notes: Harberger coefficients are defined as in equations (7) and (9), respectively.

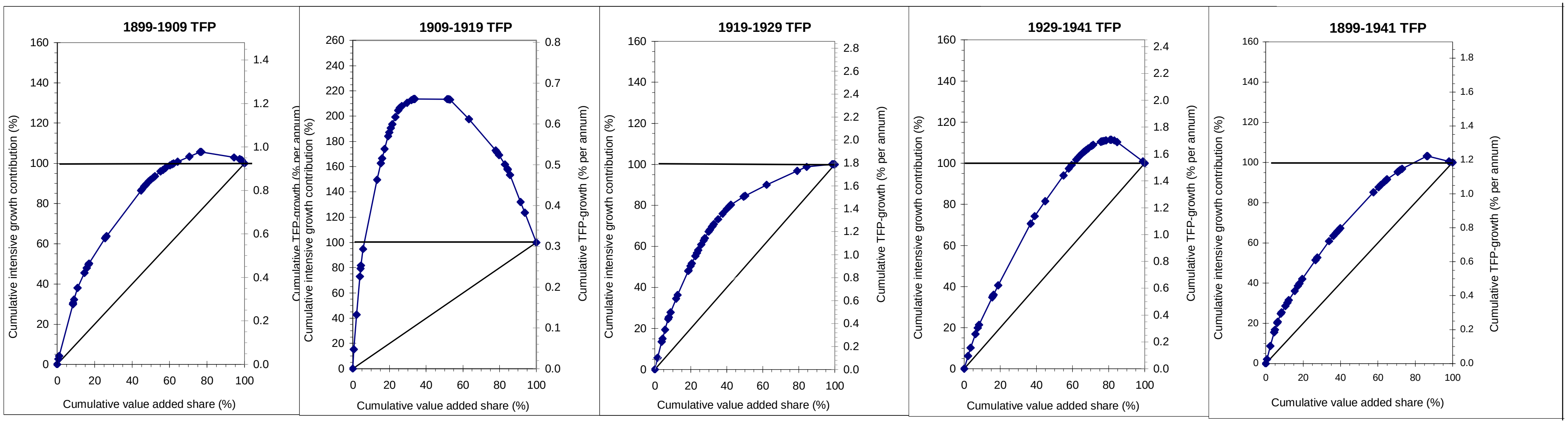
Source: own calculations.





Figures 1a and 1b. *Diagrammatic illustration of two hypothetical distributions of intensive growth contributions by industry versus the industry's value-added share in GDP, ranked by industry TFP-growth rate.*

Source: these two images are taken from Inklaar and Timmer (2007), and are based on the diagram developed in Harberger (1998).

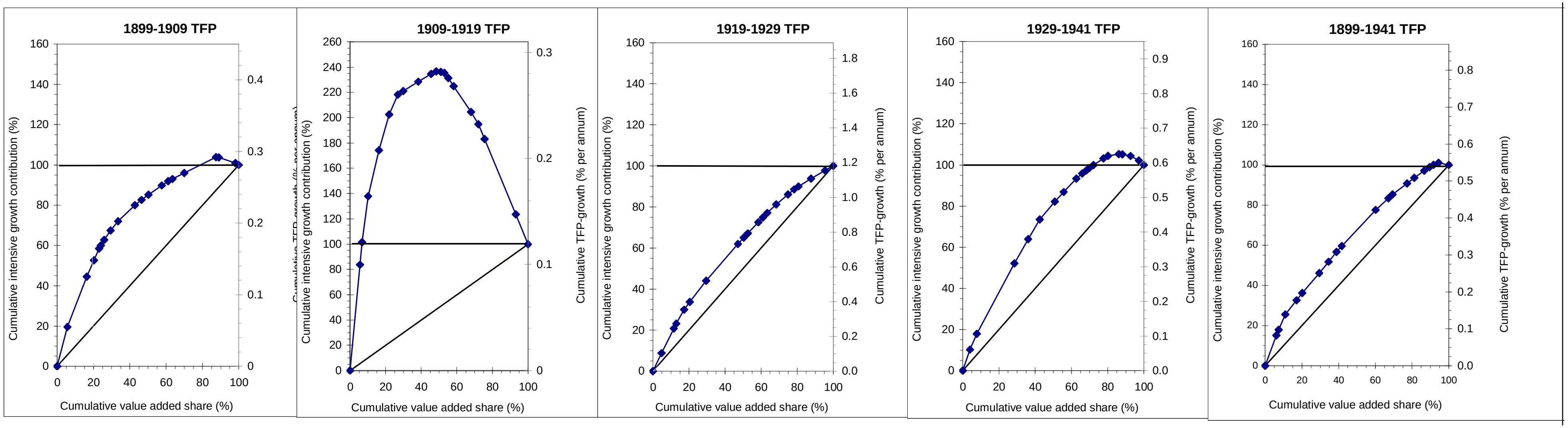


Harberger-coefficient: 0.37 0.71 0.33 0.35 0.30

Figure 2. Cumulative Distribution of the Intensive Growth Contribution Relative to the Cumulative Distribution of the Value-Added Share for Measured Sectors, United States, 1899-1941.

Note: the intensive growth contribution is after correction for growth in labor quality

Sources: see text, Table 5 and Appendices A, B and C.



Harberger-coefficient: 0.34 0.72 0.18 0.30 0.22

Figure 3. Cumulative Distribution of the Intensive Growth Contribution Relative to the Cumulative Distribution of the Value-Added Share for Manufacturing, United States, 1899-1941.

Note: the intensive growth contribution is after correction for labor quality.

Sources: see text, Table 5 and appendices A, B, and C.

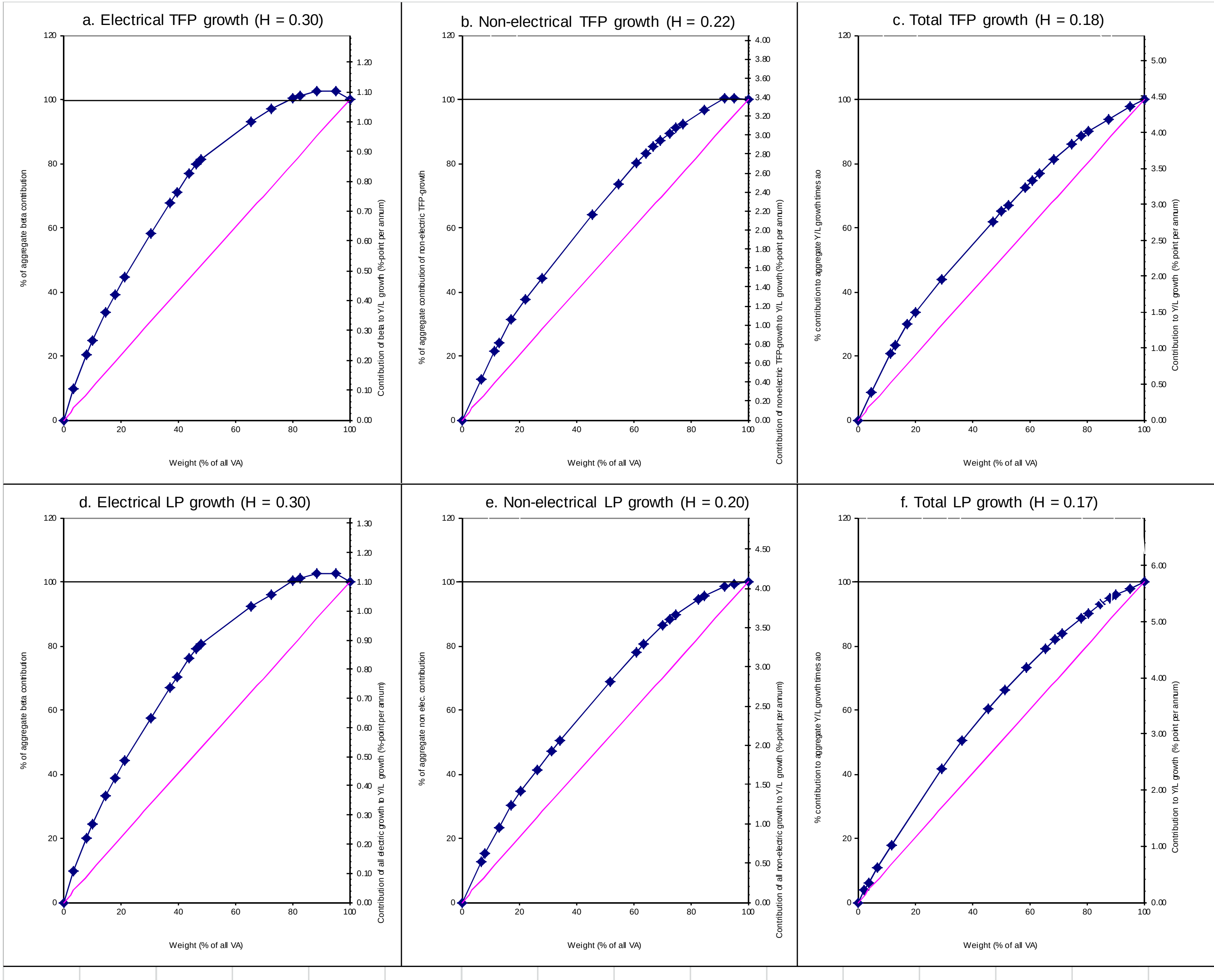


Figure 4. TFP and labour productivity electrical and non-electrical growth contributions to the U.S. manufacturing sector, 1919-1929.

Appendix A: Sources for Value Added Weights

Three benchmark years have been chosen to calculate value added weights: 1899, 1929, and 1939. From these benchmarks, mid-period weights have been calculated using linear interpolation. Below we discuss the sources for each set of benchmark estimates in detail.

A1. Value Added Weights for 1899

Estimates of value added for electric utilities, farming, metals, mining, non-metals, oil & gas, and manufacturing industries other than those specified below have been taken from Whitney (1968). Value added in foods is the aggregate of 'processed foods' and 'grain mill products' in Whitney (1968). Within manufacturing for tobacco, non-electric machinery, electric machinery, transport equipment, furniture, and 'miscellaneous' estimates have been taken from the *Census of Manufactures*. Estimates of value added in wholesale & retail trade and in FIRE have been taken from Carter et al. (2006, series Dh1 and Dh2), and estimates of value added in local transit and in railroads from Gallman and Weiss (1969, p.310).

Other sectors all entailed some computation which was implemented as follows:

Anthracite coal and bituminous coal has been estimated using Whitney's (1968) value added for coal mining and the U.S. Bureau of the Census (1960), series M 13-37, p. 350 to apportion the shares of anthracite and bituminous coal mining.

Manufactured gas and natural gas have been estimated using the gross output data in Gould (1946, Table A17), and then using the ratios of value added to gross output for 1919 from Kuznets (1941, p. 659, 661) to arrive at a value added estimate for 1899.

Construction has been arrived at by calculating gross output from Abramovitz (1964) and then using the average gross output/value added ratio for 1919-1924 from Kuznets (1941, pp. 641-2) to estimate value added.

Residual transport comprised water transportation, pipelines and transportation services. Water transport value added has been taken from Gallman and Weiss (1969, p. 316). For pipelines a rough bench mark estimate has been made for 1885 based on Chandler (1990, p. 74, 94), who stated that Standard Oil's pipeline network was about 4,000 miles. It is assumed that total installed length was double this, i.e., 8,000 miles. This benchmark is then linked to the time series reported in Carter et al. (2006, series Df1246) for 1921-1939 using geometric interpolation, and an estimate for 1899 is made. Real gross output in 1929 from Kendrick (1961, p. 463) relative to pipeline length is then used to estimate real gross output for 1899. The ratio between the 1929 value added of 'Pipelines except natural gas' reported in the *National Income and Product Accounts*, and 1929 gross output for pipelines in Kendrick (1961) is then used to estimate value added for 1899. Value added for transport services has been estimated using the ratio of this to all other transport sectors in 1929, and applying this ratio to the value added of all other transport sectors in 1899.

Telephone is based on the value added of the Bell system companies for 1899, as reported in U.S. Bureau of the Census (1961, p. 481, series R 14-27), multiplied by the inverse of its estimated share in all telephone value added. The latter has been estimated by taking the shares (weighted by local-exchange and long-distance calls) of the Bell companies and the independent companies in 1900, and backprojecting this ratio to 1899 taking into account the differential growth rate of the number of telephones for the two systems.

Telegraph value added comprises the 'International telegraph industry' and the 'domestic telegraph industry'. The former has been estimated taking operating revenues from Carter et al. (2006, series Dg18), and using the 1907 value added/ revenue ratio to estimate 1899 value added. For the latter, 1899 Western Union revenues were taken from Carter et al. (2006, series Dg 16). To arrive at non – Western Union revenues the growth of this category relative to Western Union growth has been calculated for 1902-1907. This ratio has been used to extrapolate 1902 non-Western Union revenues back to 1899. The ratio between gross income and value added in the telephone industry for 1902, as reported in Department of Commerce and Labor, Bureau of the Census, Bulletin 17, *Telephones and Telegraphs*, *1902* (1905, p. 31), has then been used to arrive at an estimate for 1899 value added.

Post Office value added is taken as the sum of wages and capital income. The ratio of 1909 wages as reported in King (1930, p. 364) to total revenue as reported in Carter et al. (2006, series Dg 181-9) has been used to estimate 1899 wages based on 1899 revenue from Carter et al. (2006, series Dg 181-9). It has then been assumed that income of remunerated capital was about 0.1 from 1899 revenue.

Value added for spectator entertainment has been calculated by extrapolating the benchmark estimate for 1900 gross output from Bakker (2012), using the growth rate of output over the population growth rate between 1900 and 1909, and multiplying by the average fraction of value added over gross output for live entertainment between 1929 and 1941. The latter has been estimated from the NIPA by using the share of live entertainment expenditure in all 'Amusements and recreation except motion pictures' expenditure.

A2. Value Added Weights for 1929

Value added for most sectors has been obtained directly from the National Income and Product Accounts as reported in Appendix C. Below we discuss the sectors for which value added could not be obtained directly from this source.

FIRE and wholesale & retail trade have been taken from Carter et al. (2006, series Dh2 and Dh25-6). Construction has been calculated from Abramovitz (1964). Manufactured gas has been calculated from Kuznets (1941, pp. 659-676).

The weight of electric utilities starts from the quantity of electricity sold and its price as reported in Bureau of the Census (1960, series S80-1) to arrive at the value of gross output for 1929. This value was then multiplied by the value added / gross output ratio calculated for 'electric light & power and manufactured gas' for 1929 from Kuznets (1941, pp. 659-676).

Natural gas is based on gross output from Gould (1946) multiplied by the ratio of value added to gross output for petroleum and natural gas together for 1929 from Leontief (1953).

Telephone value added has been calculated from Kuznets (1941, pp. 659-670). A second estimate has been made by using the method for calculating telephone value added outlined for 1939 in section 1.3 below. This estimate was slightly less reliable as for the 'Independent Telephone Companies' the geometric interpolation of 'wages and salaries' versus the use of relative factor incomes to estimate 'wages and salaries' yielded estimates for value added for 'Independent Telephone Companies' that were 33 percent apart. Using the average of these two estimates yields a total estimate of value added for the entire telephone industry that is only one percent higher than the Kuznets estimate. The latter value has therefore been taken.

For the 'Domestic Telegraph Industry' the value of intermediate inputs has been calculated by subtracting 'wages and salaries' from 'operating expenses' taken from Bureau of the Census (1960, p. 484-5, series R53-67). These 'operating expenses' do not include 'net income' and 'federal income tax', so must be approximately the sum of wages and salaries plus intermediate inputs. Capital income is then taken to be 'operating revenues' minus 'operating expenses'. A similar estimate has been made for the ''International Telegraph Industry' from Bureau of the Census (1960, p. 485-6, series R72-85).

A second estimate for Telegraph was made based on gross output for the domestic and international telegraph industries from the Bureau of the Census (1961, p. 484) multiplied by the ratio of value added to gross output from Kuznets (1941, pp. 659-670). This estimate yields a value that is 2.7 percent higher. As the former estimate is more precise, that estimate has been taken.

Post Office value added is taken as the sum of wages and capital income. Wages were estimated by taking the ratio of the compensation of postmasters as reported in the *Annual Report of the Postmaster General* (1970, pp. 138-141) to all wages as reported in King (1930, p. 364) for 1925, and establishing that this ratio was fairly stable for 1923-25 (fluctuating between 10.0 and 11.1 percent of all wages), and then using this ratio to estimate all wages for 1929 based on postmasters' compensation in 1929. It has then been assumed that income of remunerated capital was about 0.1 from 1929 revenue.

For Spectator Entertainment the value added of motion pictures is taken directly from the National Income and Product Accounts. The value added of live entertainment has been estimated by using the share of live entertainment expenditure in all 'Amusement and recreation, except motion pictures' expenditure.

A3. Value Added Weights for 1939

Value added for most sectors has been obtained directly from the National Income and Product Accounts as reported in Appendix C. Below we discuss the sectors for which the value added could not be obtained directly from this source.

FIRE and wholesale & retail trade have been taken from Carter et al. (2006, series Dh27 and Dh25-6). Construction value added has been calculated from Abramovitz (1964).

The weight of electric utilities starts from the quantity of electricity sold and its price as reported in Bureau of the Census (1960, series S80-1) to arrive at the value of gross output. This value was then multiplied by the value added / gross output ratio calculated for 'electric light & power and manufactured gas' for 1939 from Kuznets (1941, pp. 659-676).

Manufactured gas is based the estimate for 1938 in Kuznets (1941) extrapolated to 1939.

Natural gas is based on gross output taken from Gould (1946) multiplied by the ratio of value added to gross output for petroleum and natural gas together for 1939 from Leontief (1953).

For the Bell Telephone Companies the value of intermediate inputs has been calculated by subtracting 'wages and salaries' from 'operating expenses' taken from Bureau of the Census (1960, p. 481, series R14-27). These 'operating expenses' do not include 'interest expenses' and 'federal income tax', so must be approximately the sum of wages and salaries plus intermediate inputs. Capital income is then taken to be ‘operating revenues’ minus ‘operating expenses’ plus ‘income from Western Electric Co.’, which equals the sum of ‘interest expenses’, ‘federal income tax’ and ‘net income’ (Bureau of the Census 1960: 481, series R14-27). A similar estimate has been made for the ‘Independent Telephone Companies’ from Bureau of the Census (1960, p. 483, series R28-42), with the difference that ‘wages and salaries’ are not available for 1939 and had to be estimated. We made two estimates: one using the growth rate of ‘wages and salaries’ between 1934 and 1941 and estimating a 1939 value by geometric interpolation, and one by using the ratio of the factor incomes for the Bell Telephone Companies for 1939. The estimates for value added using these two different ‘wages and salaries’ estimates differ by only 1.2 percent, and the average has been taken. Total value added is then the sum of these estimates.

A second estimate has been made using the value added estimate in Kuznets (1941, pp. 659-676) for 1938 and multiplying it by the growth rate of operating revenue between 1938 and 1939 for Bell and independent telephone companies taken from Bureau of the Census (1960, p. 481-3, series R14-27 and R28-42). This yields a value added that is 4.8 percent lower than the above estimate. As the second estimate is an extrapolation and based on less information from the actual year (1939), the first estimate has been taken.

For the ‘Domestic Telegraph Industry’ the value of intermediate inputs has been calculated by subtracting ‘wages and salaries’ from ‘operating expenses’ taken from Bureau of the Census (1960, p. 484-5, series R53-67). These ‘operating expenses’ do not include ‘net income’ and ‘federal income tax’, so must be approximately the sum of wages and salaries plus intermediate inputs. Capital income is then taken to be ‘operating revenues’ minus ‘operating expenses’. A similar estimate has been made for the ‘‘International Telegraph Industry’ from Bureau of the Census (1960, p. 485-6, series R72-85).

A second estimate was made with the second method used for ‘Telephone’, using the weighted growth rate of operating revenues of the domestic telegraph industry and the international telegraph industry between 1938 and 1939 from Bureau of the Census (1960, p. 484) to extrapolate Kuznets’s value added from 1938 to 1939.Both estimates are very close: the first estimate is only 2.6 percent higher than the second. Given that this first estimate is based on data from the year itself and not on extrapolations, this first estimate has been taken.

Post Office value added is taken as the sum of wages and capital income. Wages were estimated by taking the ratio of the compensation of postmasters as reported in the *Annual Report of the Postmaster General* (1970, pp. 138-141) to all wages as reported in King (1930, p. 364) for 1925, and establishing that this ratio was fairly stable for 1923-25 (fluctuating between 10.0 and 11.1 percent of all wages), and then using this ratio to estimate all wages for 1939 based on postmasters’ compensation in 1939. It has then been assumed that income of remunerated capital was about 0.1 from 1939 revenue.

Spectator Entertainment value added has been estimated using the same method and sources as for 1929.

Appendix B. Estimates of TFP Growth for Hard-to-Measure Sectors, 1899-1929

B.1. Construction

Kendrick (1961, pp. 489-498) found that capital was a very small production factor in the construction sector, and therefore he only provided labor productivity estimates. From 1970, precise capital incomes shares of the U.S. construction sector are available from the EU KLEMS dataset (*EUKLEMS database*, November 2009 release, revised June 2010) which report a very small capital income share of 0.1 of value added in 1970. Abramovitz (1964) also suggests that capital was relatively unimportant in this period. Accordingly, for 1899-1929, we have taken labor productivity growth rates from Kendrick (1961, p. 498) to proxy crude TFP growth for 1899-1909, 1909-1919, and 1919-1929. Crude TFP for the periods to 1929 is adjusted by subtracting labor quality growth (see Table 3 in the main text and Appendix D) to arrive at refined TFP growth.

We have checked this estimate using indices of construction output from Abramovitz (1964, pp. 142-4, Table A1, series 6 for 1899-1915 and series 3 for the period after) and indices of labor input (Ibid., p. 125) to calculate output per man hour growth (and thus TFP growth) for the period 1899-1929. The resulting growth rate for the 30-year period from 1899-1929 is virtually the same as is obtained from Kendrick's growth rates for the three sub periods (1899-1909, 1909-1919 and 1919-1929).

B2. Wholesale and Retail Trade

Kendrick (1961, pp. 499-506) found that capital was also a very small production factor in wholesale and retail trade sector and therefore he only provided labor productivity growth estimates prior to 1929. He estimated that the capital income share was about 0.13 in both 1937-1948 and 1948-1953, and considerably less than 0.13 in 1929-1937 (Kendrick 1961, p. 505). Kendrick also estimated that about half of all capital stock in 1929 consisted of inventories (1961, p. 504). Accordingly, for 1899-1929, we have taken the labor productivity growth rates from Kendrick (1961, p. 506) to proxy crude TFP growth for 1899-1909, 1909-1919 and 1919-1929. Crude TFP is then adjusted by subtracting labor quality growth (see Table 3 in the main text and Appendix D) to arrive at refined TFP growth.

B3. Post Office

The growth rates of output and man-hours have been calculated from Kendrick (1961, p. 611). The growth rate of capital is based on the number of first, second, and third class post offices in existence at the benchmark years, taken from the *Reports of the Postmaster General* (Washington, D.C., various years). Given that between 1909 and 1925 the share of wages in total revenues ranged between 0.62 and 0.80, as reported in King (1930, p. 364), and given that a substantial part of the capital used consisted of the use of government buildings, the income share of total capital (remunerated capital and unremunerated use of government buildings) has been set at 0.4. Using these assumptions, TFP growth rates have been estimated for 1899-1909, 1909-1919 and 1919-1929. Crude TFP is then adjusted by subtracting the labor quality growth rates for the Post Office reported in Table 3 and Appendix B to arrive at refined TFP growth.

B4. Finance, Insurance, Real Estate, and Business Services (FIRE)

Crude TFP growth has been estimated for 1899-1909, 1909-1919, and 1919-1929 as follows. The growth rate of output has been estimated by creating an index consisting of one quarter of the output growth of financial intermediation, one quarter of the growth of life insurance policies, and one half of the growth of rent. These weights follow those reported for the FIRE sector in Central Statistical Office (1956, pp. 364-5).

The output growth of financial intermediation has been taken from Philippon (2014, appendix). The index used consists of the weighted average of Philippon's level index and 8.48 times Philippon's flow index, using Philippon's scaling factor (8.48) to make the two components comparable. Philippon's series have been taken from the file 'Data Series' for his article published on his website http://pages.stern.nyu.edu/~tphilipp/research.htm (accessed on 8 December 2014).

The value of life policies has been taken from Carter et al. (2006), series Cj715, deflated to real values by using the Bureau of Labor Statistics based Consumer Price Index as reported in Carter et al. (2006), series Cc1. Consumer expenditure on rent was taken from Lebergott (1996), Table A2 and deflated to real values using the residential rents index reported in Carter et al. (2006), series Cc4. The growth rate of labor inputs is based on the number of man-hours reported for 'finance, insurance, real estate' by Kendrick (1961, p. 314). The growth rate of the capital stock is based on FIRE tangible assets in 'Banking, 'Insurance' and 'Miscellaneous' reported in Goldsmith (1958), Tables A1, A7 and A15. Factor shares were estimated from Goldsmith (1958) based on 'employee compensation' and 'non-farm proprietors' compensation' for labor and on 'corporate profits, pre-Tax' and 'net interest' for capital, resulting in a 0.5 share for both factors. Using the EU KLEMS data for 1970 for labor and capital compensation in financial institutions and in real estate (*EUKLEMS database*, November 2009 release, revised June 2010), and weighing each sector by a half, also yields factor incomes of 0.5 each. These rates of crude TFP-growth have then been adjusted by subtracting the labor quality growth rates for the FIRE sector reported in Table 3 and Appendix D to arrive at refined TFP growth.

B5. Spectator entertainment

TFP-growth for spectator entertainment has been estimated following the methods and sources set out in Bakker (2012) for 1900 and 1938, extending the estimates to 1899 and 1941, and now including the three intermediate benchmark years, 1909, 1919 and 1929. The output estimates are based on the consumer expenditure series from Carter et al. (2006, series Dh311 and Dh312), the National Income and Product Accounts, the Bureau of Labor Statistics Admission Price Index, and several other price studies for the period before 1929. The labor estimates are based on the census using the same method as outlined for 1900 in Bakker (2012). Labor quality has been estimated using the method outlined in Appendix D. The capital estimates are based on Bakker (2012), extrapolating the 1900 estimate by one year using a composite growth index of capital proxies to arrive at an 1899 estimate, using the method outlined in Bakker (2012) for 1900 to arrive at the 1909 estimate, and for 1938 to arrive at a 1941 estimate. For motion pictures the annual investments in new cinemas have been used to make an estimate for 1929 based on the 1941 estimate. The 1919 estimate has been interpolated from the 1909 and 1929 estimates using the growth in aggregate cinema seating capacity and the capital per seat deflated by Kuznets' (1961) capital goods deflator. Live capital for 1929, and for 1926 (a year before talking pictures arrived) has been estimated assuming capital grew at one fourth the rate of output (given the small share of live capital by this time, the findings are not very sensitive to this assumption). Live capital for 1919 has been estimated by geometrically interpolating the 1909 and 1926 values. For

1929-1941 the resulting stock-based capital growth rate has been modified to a capital services-based capital growth rate by multiplying by the weighted difference between stock- and service-based capital growth estimates of the 'Motion picture and sound recording industries' and 'Performing arts, spectator sports, museums, and related activities' from the Bureau of Economic Analysis' fixed assets table (see Appendix C). A detailed statistical survey from 1909 of all Boston entertainment venues, reported by Jowett (1974), was used to assess the relative importance of live and filmed entertainment at that time.

Appendix C. Measurement and Sources for Output and Input, 1929-41

As emphasized by Field (2003), the assessment of productivity trends during the 1930s is highly sensitive to the choice of beginning- and end-point. In order to prevent cyclical effects from influencing the measurement of productivity growth it is best to choose business-cycle peaks as reference years. Kendrick's (1961) choice of comparing the depressed American economy in 1937 to the peak-year of 1929 conflicts with this principle. Field (2003: 1403) argues instead that 1941, with an unemployment rate of 9.9 percent, compares much more favorably to the fully employed economy of 1929 than the year 1937 (14.3 percent unemployment). Regrettably, little productivity data is available – at least not beyond the total economy trends – for the early 1940s. This led Field (2006) to restrict his analysis of technological change between 1929 and 1941 to a 4-sector breakdown of TFP growth. As noted in section 1, however, we require a much finer breakdown in order to fully decompose the sectoral contribution to TFP and labor productivity growth. This appendix describes the methods and sources which we use to develop new, industry level estimates extending beyond Kendrick's original 1929-37 figures. These new estimates allow us to measure productivity growth over the period suggested by Field, 1929-41, while matching the full sectoral detail realized by Kendrick.

Output

Instead of estimating value added on the basis of industry output less purchases of materials and services, we obtain nominal gross value added by summing over total compensation, gross operating surplus, and taxes on production less subsidies. The components of value added at the industry level are compiled by the U.S. Bureau of Economic Analysis (BEA, 2009) and listed in the *National Income and Product Accounts* (NIPA). Table C.1 provides an overview of the relevant variables, the exact source-tables, the number of industries differentiated, as well as the share of value added covered by each respective variable in the year 1947.

The NIPA tables provide annual data at the industry level, allowing us to estimate net output for a set of 35 (disaggregate) industries, completely covering the domestic economy. As illustrated in table C.1, the NIPA provides full industry coverage for the most influential variables which, together, make up over 80 percent of gross value added. For the remaining variables the BEA supplies data at a higher level of aggregation, distinguishing between either 12 separate industries (e.g. proprietors' income) or listing the total-economy value only (e.g. taxes on production less subsidies). For these variables, we use the detailed industry-level data for the components of value added in 1947 – taken from the BEA's (2011) *Historical Industry Accounts Data* – to distribute the aggregate figures over our complete list of industries.

To obtain real value added we deflate the nominal output figures for agricultural, mining, manufacturing, utilities and wholesale trade on the basis of wholesale prices compiled by the U.S. Bureau of Labor Statistics (1943: 4; 1949: 6; 1958: 26, 34) supplemented with the production prices listed in the *Historical Statistics of the United States* (HSUS 1975: 582-6) and the price index of electrical equipment compiled by the BEA (2010). For the remaining service sectors we apply the relevant price indices for personal consumption expenditure from the NIPA (BEA 1966: table 8.6; BEA 2009: table 1.5.4) and Kendrick (1961: 543-5, 556, 583-4). We aggregate the price deflators over industries on the basis of an annually chained Fisher index, where nominal gross value added, previously discussed, serves as weights.

Table C.1: components of value added by industry, United States, 1929-1941.

Variable	Description	Source [a]	Cov. [b]	Shr. [c]
VA	Value added, by industry	…	…	100%
…COMP	Compensation of employees, by industry	NIPA, table 6.2A	35	54%
…TXPIXS	Taxes on production and imports less subsidies	NIPA, table 1.7.5 line 18	1	7%
…GOS	Gross operating surplus, by industry	…	…	
……NINT	Net interest, by industry	NIPA, table 6.15A	12	1%
……PROINC	Proprietors' income, by industry (nonfarm)	NIPA, table 6.12A	12	9%
……FRMINC	Proprietors' income, farm (with IVA and CCadj)	NIPA, table 2.1 line 10	1	6%
……PBT	Corporate profits before tax, by industry	NIPA, table 6.17A	35	13%
……CCCA	Corporate capital consumption allowance, by industry	NIPA, table 6.22A	35	3%
……NCCA	Non-corporate capital consumption allowance, by industry	NIPA, table 6.13A	12	3%
……BCTP	Business current transfer payments	NIPA, table 7.7 line 1	1	0%
……IVA	Inventory valuation adjustment, by industry (nonfarm)	NIPA, table 6.14A	12	-3%
……CCadj	Capital consumption adjustment, by industry (nonfarm)	NIPA, table 7.6	1	0%
……GCFC	Consumption of fixed capital, government	NIPA, table 7.5 line 21	1	4%
……RIP	Rental income of persons, FIRE	NIPA, table 2.1 line 11	1	3%

[a] Source: BEA (2009).
[b] Number of separate industries distinguished in the original source. Note that full coverage corresponds to 35.
[c] Share of total economy value added covered in 1947. Source: BEA (2011).

Labor input

For labor input we rely on estimates of total employment by industry, fully compensated for changes in the average annual hours of work and the growth in the quality of labor. The sources for total employment and the average hours of work are discussed below. The adjustment for labor quality is dealt with in appendix D.

In correspondence with Kendrick (1961: 47-9), we define total employment as the sum of the number of employees, converted to a full-time equivalent basis, and self-employed persons. From 1929 onwards, the NIPA (BEA 2009: table 6.8A) lists this statistic as the total Persons Engaged in Production (PEP) at the detailed industry level.

Estimates for the average annual hours of work between 1929 and 1941 for the majority of industries are based on Kendrick (1961: 310, 360-2, 397-8, 543-7, 556, 583-4, 590-8, 611). For construction, other transportation and trade we rely on the HSUS (1975: 170-3) estimates of changes in the weekly hours of work. In addition, we accounted for differences in the average hours of work in durable and nondurable manufacturing based on data from the HSUS (1975: 169-70), normalized to fit Kendrick's (1961: 465-6) total manufacturing estimates. Our final measure of labor input is then derived by multiplying total employment (PEP) by both the index for the change in the average annual hours of work as well as the index for labor quality.

Capital input

For the period 1929 to 1941 we estimate the capital input on the basis of capital services. As opposed to capital stocks, which measure the total value, or wealth of all capital equipment and structures in place, our measure captures the capital service *flows* derived from these capital assets. The difference between both these methods is that capital services weight the growth of capital assets by their respective rental prices, whereas capital stocks weight assets by their asset price. As noted by Jorgenson et al. (2008: 109), "[c]apital input takes the form of services of the capital stock in the same way that labor input involves the services of the work force", making the resulting capital service indices strictly comparable to the measure of labor input discussed above.

In comparison to the stock measure, the capital service flows will allocate greater weight to assets that have shorter asset lifetimes and/or rapidly falling asset prices, as both of these characteristics will drive up the cost a user would have to pay to hire the asset for a given period. In the 1930s, prime examples of assets that are underweighted by the traditional capital stock measure are: communication equipment, office and accounting equipment and trucks.

Our capital services differ from the measure of capital adopted by Kendrick (1961), but is consistent with the post-war estimates of capital input by the BLS. This thus allows us to directly compare the 1929-1941 residual in our growth accounting exercise to the official TFP estimates for the decades following the war.

The construction of the indices of capital services proceeds in two phases. First, we estimate the industry-level stock of capital for the private domestic economy between 1929 and 1941 using a Perpetual Inventory Method (PIM) and the investment series taken from the BEA's *Fixed Assets* tables. Second, we estimate the rental price of assets at the industry level based on the imputed industry rate of return, the asset-specific rate of depreciation and capital gains and losses resulting from changing asset prices. Multiplying the stock of an asset by its rental price yields so called 'capital compensation', which in turn can be used as weights to aggregate the capital stocks to the industry and ultimately the total economy level.

For the construction of the capital stocks, we follow the approach set out by the BEA (2003: M-7), where the real investment ($I_{i,k}$) for asset *k* during year *i* is assumed to contribute $N_{i,k,t}$ to the real net stock of capital at the end of year *t*.

$$N_{i,k,t} = I_{i,k}\left(1-\frac{\delta_k}{2}\right)(1-\delta_k)^{t-i} \quad \text{, where } t \geq i \tag{C.1}$$

All investments are expected to have been made during the middle of the calendar year, and are depreciated at an annual geometric rate of depreciation δ_k. By summing the contributions over all investments up to and including year *t*, the real net stock of capital ($N_{k,t}$) for asset *k* at the end of year *t* can be derived.

$$N_{k,t} = \sum_{i=1}^{t} N_{i,k,t} \tag{C.2}$$

From 1901 onwards, the BEA's (2010) detailed *Fixed Assets* tables provide annual industry-by-asset investment series for private nonresidential capital. To reliably estimate the starting stock of capital in 1900, we supplement this data with the asset-specific constant-cost investment series for the period 1832-1900, listed in the BEA's (1993: 374-81) *Fixed Reproducible Tangible Wealth* report. Unfortunately, the pre-1901 investment series is only available at the total private economy level. We thus distribute the nineteenth century investment data for each of the 37 assets over our entire industries-list on the basis of the average investment shares for the first decade in the twentieth century – for which we have detailed industry-by-asset data. The geometric rates of depreciation for all our assets, with the exception of automobiles, are taken from Fraumeni (1997). The rate of depreciation for autos was derived implicitly from the standard *Fixed Assets* tables (BEA 2010, tables 2.2, 2.8).

On the basis of these investment series, depreciation estimates and equation (C.2) we compile the real net stock of capital between 1929 and 1941 for all assets and industries distinguished by the BEA (with the exception of the government sector). Capital services (*K*) for industry *j* can then be derived by weighting the growth of capital stocks for all *m* assets by its relative share in total industries capital compensations (*v*). Dropping the industry subscript *j* for ease of notation, the growth of capital services can be represented as

$$\ln\left(\frac{K_t}{K_{t-1}}\right) = \sum_{k=1}^{m} \bar{v}_k^K \ln\left(\frac{N_{k,t}}{N_{k,t-1}}\right) \tag{C.3}$$

Where $\bar{v}_k^K$ is the average share of capital compensation in year *t* and *t-1* for asset *k*

$$\bar{v}_k^K = \frac{v_{k,t}^K + v_{k,t-1}^K}{2} \tag{C.4}$$

As noted previously, capital compensation is the product of the rental price ($p_{k,t}^K$) and the real stock ($N_{k,t}$) of this asset. The share ($v_{k,t}^K$) is then calculated by dividing the assets capital compensation by the total industry's capital compensation. Note that industry *j*'s capital compensation can be obtained from the national accounts as value added minus the compensation of labor (see table C.1).

$$v_{k,t}^K = \frac{p_{k,t}^K N_{k,t}}{\sum_{k=1}^{m} p_{k,t}^K N_{k,t}} \tag{C.5}$$

The calculation of the rental price reflects the fact that in equilibrium, an investor is indifferent between two alternatives: either buying a unit of capital at time *t*-1, collecting a rental fee and then selling the depreciated asset in the next period, or earning a nominal rate of return on a different investment opportunity. The capital services thus depend on the asset-specific depreciation rates (δ_k), the (industry-specific) rate of return (i_t) and the capital gains or losses from price changes in $p_{k,t}^I$.[20]

$$p_{k,t}^K = p_{k,t-1}^I i_t + p_{k,t}^I \delta_k - 0.5\left[\ln\left(\frac{p_{k,t-1}^I}{p_{k,t-2}^I}\right) + \ln\left(\frac{p_{k,t}^I}{p_{k,t-1}^I}\right)\right] p_{k,t-1}^I \tag{C.6}$$

For the calculation of the industry rate of return we follow the ex-post procedure preferred by the BLS to make our capital service estimates comparable to the post-war figures. The rate of return is the sum of total capital compensation and the total capital gains from changes in investment prices, minus total depreciation, divided by the capital stock in prices of year *t-1*.

$$i_t = \frac{\sum_{k=1}^{m} p_{k,t}^K N_{k,t} + \sum_{k=1}^{m} 0.5\left[\ln\left(\frac{p_{k,t-1}^I}{p_{k,t-2}^I}\right) + \ln\left(\frac{p_{k,t}^I}{p_{k,t-1}^I}\right)\right] p_{k,t-1}^I N_{k,t} - \sum_{k=1}^{m} p_{k,t}^I \delta_k N_{k,t}}{\sum_{k=1}^{m} p_{k,t-1}^I N_{k,t}} \tag{C.7}$$

For the estimation of the rental prices we again rely on Fraumeni's (1997) depreciation rates, the BEA's (2010) price index of investment and the industry-level capital compensation from the NIPA tables (BEA 2009).

Table C.2 shows the difference between Kendrick's original capital input measures, the average annual growth of the capital stock measured using the BEA's investment series and the growth in capital services. Kendrick's estimates are very similar to the growth figures for the capital stocks, but differ substantially from the estimates based on capital services. As previously noted, capital service flows will

[20] Note that in equations (C.6) and (C.7) we rely on the two-period average change in the asset-specific investment prices to smooth out incidental price shocks.

allocate greater weight to assets that have shorter asset lifetimes (i.e. equipment and machinery), the stock of which expanded more rapidly than for long-lived assets (i.e. structures) during the 1930s. This explains why the growth figures for capital services exceed the capital stock based measures for both the PDE and PNE as well as most of the underlying industries during the years 1929-1941.

Table C.2: average annual rates of growth of capital input, United States, 1929-1941 (%).

Private domestic economy (PDE)	*Annual growth (%)*
Kendrick	-0.08
Capital stocks	-0.09
Capital services	0.37
Private domestic nonfarm economy (PNE)	*Annual growth (%)*
Kendrick	-0.13
Capital stocks	-0.05
Capital services	0.48

Source: Kendrick (1961), pp. 333-335; 338-340

Table C.3 shows the impact that the different measures of capital input have on total factor productivity. With the exception of Residual transport, for all industries capital-service based TFP-growth was lower or equal than the stock-based estimates (first three columns). The difference in TFP-growth ranged from minus 0.5 percentage points for metal mining, to plus 0.3 percentage points for Residual transport. Of the aggregate growth rates, only the residual sector (minus 0.4 percentage points), and the PDE-growth rate (minus 0.1 percentage points) were affected. The mean industry TFP-growth decreased by 0.1 percentage point. The coefficient of variation and the range only increased marginally.

The capital services-based intensive growth contribution (IGC) showed a similar pattern (Table C4, first three columns), with only Residual transport having a positive difference, of 0.005 percent per annum, and the minimum value being -0.014 percent per annum for Wholesale & retail trade. In the aggregate, the manufacturing IGC decreased with 0.006 percent, the aggregate measured sectors' IGC with minus 0.030 percent, the residual sector with minus 0.077 percent, and the PDE with 0.107 percent. The mean and coefficient of variation decreased marginally, and the range decreased by 0.013 percent. The Harberger coefficient only increased marginally, with 0.004, but because of rounding, with 2 decimals it went up from 0.34 to 0.35. Overall, the use of capital-services based TFP-growth and IGC showed a small but not insignificant difference with capital-stock based TFP growth.

For the whole period 1899-1941, using stock-based estimates for 1899-1929 and service-based estimates for 1929-1941, the differences in TFP-growth were very small, and differed in only six sectors from 0.0, ranging from minus 0.1 to 0.1. Likewise, for the IGC there were only significant differences (in the third decimal) for six industries.[21]

Variable retirement

Gordon (2016: 659-663) argues that the official investment and depreciation rates from the BEA severely underestimate the growth in capital input for the period between 1925 and 1945. In particular, he questions whether the depreciation rates, which are fixed over time, are representative for the Depression era. As investment collapsed, Gordon would expect equipment and structures to be scrapped and depreciated at a slower rate; i.e. he proposes that the expected life-time of all assets

[21] The tabulated results are available upon request from the authors.

should increase substantially during the 1930s. This lower rate of depreciation would lead to a greater increase in the capital stock than the estimates by the BEA would suggest.

As a crude proxy for these varying rates of depreciation, Gordon suggests comparing the ratio of investment to the official capital stock for each year with the average for 1925-1972. A low ratio, as was the case for 1933, would indicate an increase in the asset lifetime, whereas a relatively high ratio would indicate a reduction in the time producers hold on to their ageing capital assets.

As a robustness check to our capital input estimates, we apply the same procedure. We estimated the ratio of investment to stock separately for equipment capital and structures. The data was taken from the BEA's (2010) *Fixed Assets*, basic tables 2.1, 2.2, 2.7 and 2.8, lines 3 and 37. The official depreciation rates discussed in the previous section were multiplied by the ratio of investment to capital in the respective year, relative to the average of the period 1925-1972. On the basis of these depreciation rates we re-estimated the capital stocks and capital services. Tables C.3 and C.4 show the resulting TFP and IGC based on these revised capital inputs.

The effect of the adjustment on industry TFP-growth for 1929-1941 was negligible or significantly negative for all industries. It varied substantially, from 0.0 percentage-points for Coal Mining, Electric Machinery and Furniture, to minus 0.7 percentage-points for Oil & Gas mining and minus 0.5 percentage-points for both Metal Mining, and Petroleum & Coal products. The overall effect on the TFP-growth rate of the PDE was substantial, minus 0.2 percentage-points, which constitutes a ten percent downward adjustment. The impact on the intensive growth contribution (IGC) was small but significant for many industries, as only 7 industries had no difference at three decimals, and the change in the IGC was substantial for Farming, Foods, Wholesale & Retail trade and FIRE—all large sectors. For both TFP and IGC, the mean decreased and the coefficient of variation increased by about ten percent. The Harberger coefficient increased appreciably, from 0.35 to 0.38.

For the whole period 1899-1941, using standard depreciation based estimates for 1899-1929 and variable retirement based estimates for 1929-1941, the differences in TFP-growth were very small, minus 0.1 or 0.0 in most sectors and minus 0.2 in only one sector, Oil & Gas. Likewise, for the IGC there were only marginally significant differences (in the third decimal) for 19 industries, no significant differences in 17 industries, and no significant difference in the Harberger coefficient.[22]

Electrical equipment

To estimate the share of electrical equipment assets in the total stock of equipment – used to measure the impact of the installed electrical horsepower in manufacturing in section 6 – we also compile an annual series of the nominal net stock of capital for electrical equipment and total equipment. We apply the methods described above but focus on the period 1921 to 1929 instead.[23] The nominal net stock of electrical equipment is the aggregate of the nominal value of the BEA (2010) assets EI60 (electrical transmissions, distribution and industrial apparatus) and EO70 (electrical equipment not elsewhere classified). Total equipment includes electrical equipment in addition to transportation equipment, instruments and non-electrical equipment. We estimate the share of electrical equipment assets by dividing the nominal stock of electrical equipment by the total stock of equipment for the years 1921 and 1929 and then taking the average over both these years.

[22] The tabulated results are available upon request from the authors.

[23] Note that the shorter asset lifetimes for machinery and equipment allows us to safely estimate the real and nominal stocks for these assets beginning in 1921. The greater rate of depreciation reduces the sensitivity of these assets to the assumptions made regarding the pre-1900 rate of investment by individual industries.

Table C3. Comparative growth in Total Factor Productivity (TFP) by industry, using capital stock vs. capital services and standard depreciation vs. variable retirement, United States, 1929-1941.

Industry	*TFP-growth (percent per annum)*					
	Effect capital services			Effect variable retirement		
	Stock	Serv.	Diff.	SD	VR	Diff.
Farming	2.6	2.5	-0.1	2.5	2.2	-0.3
Metals	1.1	0.6	-0.5	0.6	0.1	-0.5
Anthracite Coal	0.4	0.3	0.0	0.3	0.3	0.0
Bituminous Coal	1.9	1.8	-0.1	1.8	1.8	0.0
Oil and Gas	2.1	2.1	0.0	2.1	1.3	-0.7
Non-metals	3.9	3.6	-0.3	3.6	3.3	-0.3
Foods	3.7	3.7	0.0	3.7	3.5	-0.2
Tobacco	5.8	5.8	-0.1	5.8	5.3	-0.5
Textiles	3.4	3.3	-0.1	3.3	3.1	-0.2
Apparel	-0.4	-0.4	0.0	-0.4	-0.6	-0.2
Leather Products	-0.1	-0.1	0.0	-0.1	-0.2	-0.2
Lumber Products	-1.7	-1.8	0.0	-1.8	-1.9	-0.1
Paper	1.2	1.1	-0.1	1.1	1.0	-0.1
Printing Publishing	0.3	0.3	0.0	0.3	0.2	-0.1
Chemicals	2.2	2.1	0.0	2.1	1.9	-0.3
Petroleum, Coal Products	-1.2	-1.1	0.1	-1.1	-1.6	-0.5
Rubber Products	1.6	1.5	-0.1	1.5	1.4	-0.1
Stone, clay, glass	1.9	1.7	-0.1	1.7	1.5	-0.2
Primary Metals	2.3	2.4	0.1	2.4	2.0	-0.3
Fabricated Metals	1.3	1.3	0.0	1.3	1.2	-0.2
Machinery Non-Electric	2.1	2.1	0.0	2.1	2.0	-0.1
Electric Machinery	4.6	4.6	0.0	4.6	4.6	0.0
Transport Equipment	3.6	3.5	0.0	3.5	3.3	-0.2
Furniture	1.4	1.4	0.0	1.4	1.4	0.0
Miscellaneous	1.9	1.5	-0.3	1.5	1.3	-0.2
Electric Utilities	5.1	5.1	0.0	5.1	4.7	-0.4
Manufactured Gas	2.0	1.8	-0.2	1.8	1.5	-0.3
Natural Gas	3.7	3.7	-0.1	3.7	3.3	-0.4
Construction*	0.8	0.7	-0.1	0.7	0.4	-0.3
Wholesale & retail trade*	3.5	3.4	-0.1	3.4	3.3	-0.1
Railroads	2.5	2.6	0.0	2.6	2.4	-0.1
Local Transit	0.5	0.4	-0.1	0.4	0.2	-0.1
Residual Transport	5.5	5.8	0.3	5.8	5.6	-0.2
Telephone	1.4	1.4	0.0	1.4	1.2	-0.2
Telegraph	0.8	0.7	-0.1	0.7	0.6	-0.1
Post Office*	0.5	0.4	-0.1	0.4	0.3	-0.1
FIRE*	-1.3	-1.3	0.0	-1.3	-1.6	-0.3
Spectator Entertainment*	4.4	4.4	0.0	4.4	4.3	-0.1

Manufacturing	2.3	2.3	0.0	2.3	2.0	-0.2
Aggregate measured sectors	1.9	1.9	0.0	1.9	1.7	-0.2
Residual sector	2.3	1.8	-0.4	1.8	1.7	-0.1
PDE	2.0	1.9	-0.1	1.9	1.7	-0.2
Memorandum:						
Kendrick's aggregate measured sectors	2.5	2.5		2.5	2.5	
Kendrick's residual sector	2.0	2.0		2.0	2.0	
Kendrick PDE	2.3	2.3		2.3	2.3	
Minimum	-1.7	-1.8	0.0	-0.4	-0.4	0.0
Maximum	5.8	5.8	0.0	5.5	5.5	0.0
Range	7.5	7.6	0.0	6.0	6.0	0.0

Notes: Stock = TFP-growth rate is calculated from input data that include stock-based estimates of capital.

Serv. = TFP-growth rate is calculated from input data that include service-based estimates of capital.

Diff. = the difference between the rates in the two preceding columns

SD = TFP-growth rate is calculated from input data based on the standard depreciation method using capital services set out in this appendix.

VR = TFP-growth rate is calculated from input data based on using both capital services (as set out in this appendix) and the variable retirement of capital method introduced by Gordon (2016).

Kendrick's aggregate measured sector comprises Farming, Mining, Manufacturing, Transportation, Communication & Public Utilities)

* = sector measured in this paper but not by Kendrick.

For 1929-1941 and 1899-1941 the TFP-growth of Kendrick's measured and residual sectors was estimated using our data for Kendrick's measured sectors for 1929-41 and the relationship between measured, residual and aggregate TFP growth in Kendrick’s numbers for his 4 sub-periods during 1899 through 1937.

TFP here is refined TFP, i.e. after correcting crude TFP for the growth of labor quality (see text).

Source: Kendrick 1961, pp. 136-7; own calculations, see the text and Appendices B and C (industry data) and Appendix D (labor quality data).

Table C4. Comparative intensive growth contribution by industry, using capital stock vs. capital services and standard depreciation vs. variable retirement, United States, 1929-1941.

Industry	***IGC = (VAShare*TFP growth)***					
	Effect capital services			Effect variable retirement		
	Stock	Serv.	Diff.	SD	VR	Diff.
Farming	0.198	0.193	-0.006	0.193	0.168	-0.025
Metals	0.006	0.003	-0.002	0.003	0.001	-0.002
Anthracite Coal	0.001	0.001	0.000	0.001	0.001	0.000
Bituminous Coal	0.012	0.012	0.000	0.012	0.012	0.000
Oil and Gas	0.017	0.017	0.000	0.017	0.011	-0.006
Non-metals	0.008	0.007	-0.001	0.007	0.007	-0.001
Foods	0.208	0.206	-0.002	0.206	0.194	-0.012
Tobacco	0.063	0.062	-0.001	0.062	0.057	-0.005
Textiles	0.059	0.058	-0.001	0.058	0.054	-0.003
Apparel	-0.005	-0.005	0.000	-0.005	-0.007	-0.002
Leather Products	0.000	0.000	0.000	0.000	-0.001	-0.001
Lumber Products	-0.013	-0.013	0.000	-0.013	-0.014	-0.001
Paper	0.008	0.007	0.000	0.007	0.007	-0.001
Printing Publishing	0.005	0.005	0.000	0.005	0.003	-0.002
Chemicals	0.029	0.028	0.000	0.028	0.025	-0.003
Petroleum, Coal Products	-0.014	-0.013	0.001	-0.013	-0.019	-0.006
Rubber Products	0.007	0.006	0.000	0.006	0.006	0.000
Stone, clay, glass	0.016	0.015	-0.001	0.015	0.013	-0.002
Primary Metals	0.051	0.052	0.002	0.052	0.045	-0.007
Fabricated Metals	0.020	0.020	0.000	0.020	0.017	-0.003
Machinery Non-Electric	0.039	0.039	0.000	0.039	0.037	-0.002
Electric Machinery	0.046	0.046	0.000	0.046	0.046	0.000
Transport Equipment	0.072	0.071	-0.001	0.071	0.067	-0.004
Furniture	0.009	0.009	0.000	0.009	0.009	0.000
Miscellaneous	0.012	0.010	-0.002	0.010	0.008	-0.001
Electric Utilities	0.104	0.103	-0.001	0.103	0.094	-0.009
Manufactured Gas	0.004	0.003	0.000	0.003	0.003	0.000
Natural Gas	0.012	0.012	0.000	0.012	0.011	-0.001
Construction*	0.026	0.023	-0.002	0.023	0.014	-0.009
Wholesale & retail trade*	0.476	0.462	-0.014	0.462	0.451	-0.011
Railroads	0.111	0.111	0.000	0.111	0.105	-0.006
Local Transit	0.004	0.003	-0.001	0.003	0.002	-0.001
Residual Transport	0.091	0.096	0.005	0.096	0.092	-0.004
Telephone	0.012	0.012	0.000	0.012	0.010	-0.002
Telegraph	0.001	0.001	0.000	0.001	0.001	0.000
Post Office*	0.003	0.002	-0.001	0.002	0.002	-0.001
FIRE*	-0.143	-0.145	-0.001	-0.145	-0.172	-0.027
Spectator Entertainment*	0.023	0.023	0.000	0.023	0.023	0.000

Manufacturing	0.609	0.603	-0.006	0.603	0.546	-0.056
Aggregate measured sectors	1.573	1.542	-0.030	1.542	1.380	-0.162
Residual sector	0.400	0.323	-0.077	0.323	0.299	-0.025
PDE	1.972	1.866	-0.107	1.866	1.679	-0.187
Mean	0.041	0.041	-0.001	0.041	0.036	-0.004
Coefficient of variation	2.213	2.211	-0.003	2.211	2.431	0.220
Minimum	-0.143	-0.145	-0.001	-0.145	-0.172	-0.027
Maximum	0.476	0.462	-0.014	0.462	0.451	-0.011
Range	0.619	0.607	-0.013	0.607	0.623	0.016
Harberger coefficient	0.345	0.349	0.004	0.349	0.377	0.028

Notes: Stock = intensive growth contribution (IGC) calculated from input data that include stock-based estimates of capital.

Serv. = IGC calculated from input data that include service-based estimates of capital.

Diff. = the difference between the IGCs in the two preceding columns

SD = IGC calculated from input data based on the standard depreciation method using capital services set out in this appendix.

VR = IGC calculated from input data based on using both capital services (as set out in this appendix) and the variable retirement of capital method introduced by Gordon (2016).

Kendrick's aggregate measured sector comprises Farming, Mining, Manufacturing, Transportation, Communication & Public Utilities)

* = sector measured in this paper but not by Kendrick.

For 1929-1941 and 1899-1941 the TFP-growth of Kendrick's measured and residual sectors was estimated using our data for Kendrick's measured sectors for 1929-41 and the relationship between measured, residual and aggregate TFP growth in Kendrick's numbers for his 4 sub-periods during 1899 through 1937.

TFP here is refined TFP, i.e. after correcting crude TFP for the growth of labor quality (see text).

Source: Kendrick 1961, pp. 136-7; own calculations, see the text and Appendices B and C (industry data) and Appendix D (labor quality data).

Appendix D. Labor Quality

D1. Discussion of the Kendrick Labor Quality Estimates

Kendrick (1961: 31-34) assessed the effect of skill changes on the composition of the labor force between 1869 and 1957. Instead of measuring changes in education attainment, gender and experience directly, however, he measured the changes in the occupational structure. He adjusted labor input by weighting the man-hours of work in separate occupations and industries by their average hourly earnings for a given base year. Kendrick's measure of labor quality thus captures two effects: (1) the relative shifts of workers between occupations, and (2) the relocation of employment between industries. The first effect, the shift of workers from low-paying positions (e.g. laborers) to better-paying jobs (e.g. operatives or clerical staff), reflects a change in the potential output per worker. The higher earnings (measured in terms of base-period compensation) imply a rise in the marginal productivity of that worker and thus a rise in the quality of the labor force – in line with the Jorgenson approach discussed below. Likewise, the shift of workers to better-paying industries also show up as an increase in labor quality.

Kendrick assumes under (1) that labor quality will only change over time if a worker transfers from one occupation to another or if an individual joins (or leaves) the labor force in an occupation that is better (worse) paid than the national average. Kendrick (1961: 33) surmises that "the inherent average physical and mental capacity of the person employed in each occupation is constant over time." The rapid increase in educational attainment during the late nineteenth and early twentieth century casts serious doubt on this assumption, however. The average years of schooling for cohorts born between 1880 and 1950 nearly doubled, increasing from approximately 8 to 14 years (Goldin and Katz, 2008: 20; 113; 170). Part of this increase in skill translated into a shift of employees between occupations and industries, but part also translated into a rise of the labor quality *within* occupations. For instance, the likelihood for a blue collar worker born around 1885 to have attended high school was substantially greater than it was for its counterpart born only 10 years prior, around 1875. The high-school education gave the blue-collar worker basic knowledge of chemistry, electricity and algebra, allowed him to read manuals and blueprints and made it much easier for him to effectively converse with managers and other professionals, raising his marginal productivity in the process. In addition to undervaluing the impact of the rapid increases in education attainment during the late nineteenth and early twentieth century, Kendrick's method ignores other demographic changes as well which thus biases his labor quality figures downwards compared to our own (see table D.1). Changes in the educational attainment, average age, or experience of the workforce and shifts in the gender composition are generally considered to be determining factors in the quality of labor, as we will illustrate below.

Table D.1: average annual rates of growth of labor quality, United States, 1899-1941 (%).

	Kendrick	This study
Private domestic economy (PDE)	*0.32*	*0.79*
1899-1929	0.36	0.87
1929-1941	0.20	0.59
Private domestic nonfarm economy (PNE)	*0.15*	*0.36*
1899-1929	0.16	0.40
1929-1941	0.14	0.27

Source: Kendrick (1961), pp. 333-335; 338-340

D2. Discussion of the Labor Quality Estimates in this Paper

In order to fully assess the impact of the substantial investments in schooling as well as the structural changes in the gender and age composition of the American workforce during the early twentieth century, we turn to an approach developed by Dale Jorgenson and Zvi Griliches (1967). The key innovation in their work was to adjust the traditional measure of labor input – i.e. total hours of work or employment – for improvements in quality. The main principle behind the labor quality adjustment is the distinction among several different types of labor inputs characterized by one or more quantifiable factors that affect the productivity potential of the worker (e.g. educational attainment, age, gender). By then assigning weights to these categories – usually in the form of average wages and earnings – one can measure the change in the productivity 'potential' of the workforce. The rationale for this procedure is that differences in average earnings between the labor categories can be thought of as reflecting differences in their marginal productivity. When this new measure of labor input is used in a growth accounting framework, output growth as a result of better educated and trained workers is ascribed to input growth, rather than productivity or technology growth (Jorgenson et al., 2008). Previous studies have shown that this quality adjusted measure can account for a substantial part of the residual or Total Factor Productivity (TFP) growth within traditional growth accounting studies (Denison, 1962; Griliches, 1963; Denison and Poullier, 1967; Gordon, 2010). Therefore, the labor quality adjustment allows for a purer measure of both labor input as well as technical change within a growth accounting framework.

Methodology

To construct an index of labor input for each individual sector, we assume that labor input (HK_{jt}) for industry *j* at time *t* can be expressed as a translog function of its individual components (Jorgenson et al., 1999: 92-3). We form indices of labor input from data on employment by industry, cross-classified by gender, age and education.[24] Dropping the industry subscript *j* for ease of notation, the growth of labor input for industry *j* can thus be represented as

$$\ln\left(\frac{HK_t}{HK_{t-1}}\right) = \sum_{l=1}^{q} \bar{v}_l^L \ln\left(\frac{L_{l,t}}{L_{l,t-1}}\right) \quad \text{(D.1)}$$

[24] Note that age, in our estimate for labor input, serves as a proxy for (work) experience. We thus assume that an individual has held a job his entire life since leaving high-school or college; depending on his educational attainment.

Where L_l is employment at the industry level for a given set of *q* characteristics of the labor force *l* (gender, age and education) and $\bar{v}_l^L$ is the average of this employment group's share in the total labor income

$$\bar{v}_l^L = \frac{v_{l,t}^L + v_{l,t-1}^L}{2} \tag{D.2}$$

The share of labor income ($v_{l,t}^L$) at time *t* is derived as the product of the average wage (p_l^L) and employment ($L_{l,t}$) for each combination of labor characteristic *l,* divided by the total wage sum

$$v_{l,t}^L = \frac{p_l^L L_{i,t}}{\sum_{l=1}^{n} p_l^L L_{l,t}} \tag{D.3}$$

Alternatively, the index of labor input can also be expressed as the product of employment (*L*) and an index of labor quality (*LQ*) or, in growth terms, as

$$\ln\left(\frac{HK_t}{HK_{t-1}}\right) = \ln\left(\frac{L_t}{L_{t-1}}\right) + \ln\left(\frac{LQ_t}{LQ_{t-1}}\right) \tag{D.4}$$

Rearranging terms in equation (B.4) and substituting the index for labor input by (D.1) we arrive at a direct measure of sectoral labor quality growth

$$\ln\left(\frac{LQ_t}{LQ_{t-1}}\right) = \sum_{l=1}^{q} \bar{v}_l^L \ln\left(\frac{L_{l,t}}{L_{l,t-1}}\right) - \ln\left(\frac{L_t}{L_{t-1}}\right) \tag{D.5}$$

The change in labor quality thus reflects the difference between the growth rates of the compensation-weighted index of labor input and sectoral employment.

The drawback of this approach is that it requires highly disaggregate data on employment and compensation, generally not available in the published census reports or secondary sources for the early twentieth century. Fortunately, the Integrated Public Use Microdata Series (IPUMS) has made samples from the decennial population censuses publicly available, providing detailed records for nearly 10 million individuals between 1900 and 1950 (Ruggles et al, 2010). We utilize the microdata from this source to construct our measure of labor quality.

Unfortunately, however, the 1900-1930 American population censuses did not inquire into either the educational attainment of the general population or the compensation of workers and employees. To overcome these data issues, we follow a three-tiered approach to the data preparation for the labor quality estimation. First, we estimate educational attainment at the micro level for the pre-1940 census samples on the basis of the 1940 returns. Second, we construct an employment matrix for the entire period that groups workers according to their (predicted) educational attainment, gender, age and by industry. Lastly, we derive the compensation matrix on the basis of average wages for each labor category taken from the 1940 census of population.[25] These employment and compensation matrices can then be used to calculate labor quality on the basis of equation (D.5).

Educational attainment

[25] The 1940 census was the first census of its kind to ask about schooling, labor compensation and working hours to all citizens surveyed. In the wake of the depression the 1940 population census dedicated a substantial part of its inquiry into the issue of employment and productivity.

For the first stage, we estimate the educational attainment *y* for an individual *i* on the basis of his or her occupation, gender, age and place of residence x_i. On the basis of this approach we take both the long-run changes in the average years of schooling as well as the effects of changes in the occupational structure and the gender/age composition of the workforce into account. We define four education categories (see table D.2) and we predict the likelihood that an individual *i* belongs to each of these specific educational categories (e.g. $Pr\{y_i = 1\}$). This probability should be bounded by 0 and 1, continuous and nonlinear; conditions which are all met by an (ordered) logit model

$$\Pr\{y_i \le k | x_i\} = \frac{e^{x_i'}}{1+e^{x_i'\beta}} \qquad , k = 1, 2, 3 \qquad \textbf{(D.6)}$$

The right-hand side of equation (D.6) is a cumulative distribution function with mean 0 and standard deviation 1. The coefficients are estimated using maximum likelihood, which is the optimal parametric estimator in this context (Long and Freese 2006).[26]

Table D.2: categorical variables logit and labor quality models.

Logit model	Labor quality model
Education:	*Education:*
See labor quality model	(1) 1-4 years grade school
	(2) 5-8 years grade school
Gender:	(3) 1-4 years high school
See labor quality model	(4) 1 or more years college
Occupation:	*Gender:*
(1) professional, technical	(1) male
(2) farmers (owners and managers)	(2) female
(3) managers, officials, and proprietors	
(4) clerical staff	*Age:*
(5) sales workers	(1) 16-17 years
(6) craftsmen	(2) 18-24 years
(7) operatives	(3) 25-34 years
(8) service workers (household)	(4) 35-44 years
(9) service workers (other)	(5) 45 years and over
(10) laborers	
(11) unemployed/retired	*Industry:*
	See main text
Region:	
(1) South	
(2) Midwest	
(3) West	
(4) Northeast	

Data

For the estimation of the logit model we rely exclusively on the 1940 1-percent sample included in the IPUMS dataset. This sample is limited to include only those citizens aged 16 years and above, leaving approximately 975,000 observations for the logistic regression. The dataset includes a measure of the highest year of schooling or degree completed. As illustrated in table D.2, we reclassify this variable to encompass four distinct educational attainment classes. The reason we reclassify the education variable is twofold. First, by treating it as a categorical variable as opposed to a continuous variable (e.g. years of education), we avoid the assumption that the distances between classes are equal; i.e. that an

[26] Note that we estimate the cumulative probability for the first three educational categories, since all individuals that are not part of either the first, second or third category will be part of the fourth category. The fourth category can thus be implicitly derived and should be excluded from the model.

additional year of grade school is identical to one additional year in college. Second, we limit the number of classes to 4 to ensure that each class is covered by a sufficient number of observations. This is important not just for the estimation of educational attainment, but also for the construction of the compensation matrix.[27] For the independent variables, we follow the literature on US labor quality and mark four variables as important predictors of educational attainment, namely: occupation, birth cohort, gender and region.

Individuals are classified into one of eleven main occupational groups which differ markedly in terms of their average educational attainment. For instance, the probability of a professional (e.g. engineers, economists) having attended high school was substantially greater than was the case for the average laborer. The importance of gender and year of birth is illustrated by Goldin and Katz (2008: 18-22; 170). They observe a rapid increase in the average years of schooling throughout the late nineteenth and early twentieth century. Each successive cohort spent a substantially greater number of years in school compared to the previous generation. In addition, Goldin and Katz (2008: 19) show that women generally attended school for longer than men did throughout most of the early twentieth century. The gender variable was taken directly from the IPUMS dataset while the year of birth was rounded off to the nearest decade. The log of the relative distance in decades to 1930 was then taken as the birth cohort measure. Lastly, the literature points to widespread differences in state support for education and shows that the rise in both high school graduation rates as well as college enrollment rates for states in the North and West of the country were considerably more impressive than for the rest of the nation (Goldin and Katz, 2008: 271-7). We incorporate a variable in the model that differentiates between the four main regions of the country (see table D.2).

For the second stage of the labor quality estimation, the construction of the employment matrix, we rely on the IPUMS 1-percent census samples for the decades between 1900 and 1950. To estimate educational attainment we include the occupation, birth cohort, gender and region variables discussed earlier, supplemented by data on the age of the individual and industry in which the subject is engaged. The employment sample is limited to include only those citizens between the ages of 16 and 84, who are part of the labor force. For the employment-matrix our dataset includes roughly 3,135,000 individual observations.

In the third stage of the data preparation we again rely on the 1940 sample to estimate relative compensation per labor category. Here we limit the sample to include only those citizens between the ages of 16 and 84 having worked at least 48 weeks in the previous year and earning an income greater than 0 (Goldin and Katz, 2008). These individuals are allocated to the cells of the matrix cross-classified by gender, age, education and industry as summarized in table D.2. Compensation is reported in the census as the respondent's total pre-tax wage and salary income for the previous year, expressed in current dollars. To obtain total personal income, which also includes non-wage income, we multiplied the 1940 compensation figures by the industry specific ratio between wage and salary income and total personal income taken from the 1950 census returns. Nonwage income generally represented only a small part of total personal income, with the notable exception of the agricultural sector. The samples for the logistic regression, the compensation matrix and the employment matrix are all weighted by the IPUMS `person weight' variable.

Robustness

Ideally, we would like to allow the weights for our labor quality index to vary over time, reflecting potential changes in relative compensation between the labor categories. Unfortunately, the censuses prior to 1940 did not inquire into either wages or earnings, impeding the accurate measurement of labor compensation for these earlier decades. Reassuringly, Goldin and Katz (2008: 53-63) demonstrate that the wage structure observed in 1940 was fairly typical for the prewar period. Although they do observe a gradual compression of the wage distribution for production workers between 1890 and

[27] Limiting the number of classes for the education variable allows us, for instance, to test the 'parallel regression assumption'; meaning that for each education class (grade-school, high-school, college, etc.) the coefficients for the independent variables (beta) are identical. As it turns out the assumption is violated. Hence we effectively estimate separate regressions for all education classes, obtaining different betas for each.

1940, Goldin and Katz conclude that the gap in the skilled/unskilled wage level for 1920 was virtually identical in comparison to 1940.

On the basis of Goldin and Katz's (2010) data for the state of Iowa we can perform a more conclusive sensitivity check of our labor quality figures. The *Iowa State Census Project* provides detailed compensation data, cross-classified by most of the categories that make-up labor input for the year 1915. Below we will compare the results from the third stage of the data preparation – the estimation of the compensation matrix – for the 1915 Iowa data and the original 1940 census data. We will then use these new estimates to provide an alternative estimate of labor quality for the first half of the twentieth century and decompose these estimates to trace the sources of divergence. In addition, we perform the same sensitivity check based on comprehensive income data for 1950, taken from the IPUMS dataset. Overall, on the basis of this evidence presented here we feel confident using solely the 1940 compensation figures as weights for the construction of our labor quality index.

Table D.3. Labor income estimates for Iowa and the United States, 1915, 1940 and 1950.
Dependent variable: log of income

	US 1940 (1)	US 1940 (2)	Iowa 1940 (3)	Iowa 1915 (4)	US 1950 (5)
Intercept	6.82***	6.90***	6.64***	6.48***	7.54***
	(0.005)	(0.003)	(0.029)	(0.012)	(0.009)
Female dummy	-0.70***	-0.53***	-0.52***	-0.65***	-0.52***
	(0.008)	(0.007)	(0.071)	(0.033)	(0.014)
Age 16-17 dummy	-0.81***	-1.23	-1.21***	-0.96***	-1.30***
	(0.019)	(0.021)	(0.155)	(0.043)	(0.036)
Age 18-24 dummy	-0.35***	-0.44***	-0.53***	-0.54***	-0.29***
	(0.004)	(0.005)	(0.039)	(0.017)	(0.008)
Age 35-44 dummy	0.24***	0.29***	0.28***	0.10***	0.15***
	(0.003)	(0.004)	(0.034)	(0.017)	(0.006)
Age 45+ dummy	0.28***	0.35***	0.35***	0.13***	0.16***
	(0.003)	(0.004)	(0.032)	(0.016)	(0.006)
1-4 yrs. grade school dummy	-0.34***	-0.46***	-0.28***	-0.30***	-0.22***
	(0.006)	(0.006)	(0.100)	(0.025)	(0.009)
1-4 yrs. high school dummy	0.20***	0.27***	0.33***	0.30***	0.20***
	(0.003)	(0.003)	(0.028)	(0.017)	(0.005)
1+ yrs. college dummy	0.47***	0.55***	0.54***	0.52***	0.38***
	(0.004)	(0.004)	(0.038)	(0.021)	(0.007)
Industry dummies	YES	NO	NO	NO	YES
Interaction terms	YES	YES	YES	YES	YES
Observations	207,436	207,436	3,456	14,403	88,071
Adjusted R-squared	0.50	0.37	0.31	0.26	0.35

Robust standard errors in brackets; * significant at 10%, ** significant at 5%, *** significant at 1%.
Reference category: male worker, aged 25 to 34, 5 to 8 years of grade school.

Table D.3 above provides a summary of the relative compensation in 1915, 1940 and 1950. The log of total compensation is regressed against a set of dummies for gender, age and education. We controlled for the full range of industries in our sample and included a set of interactions terms between gender and our main explanatory variables. We included samples from 1940 and 1950 for the whole of the US as well as the state of Iowa, which, as before, are derived from the IPUMS dataset by Ruggles et al. (2010). The 1915 data is taken from the Iowa State Census Project by Goldin and Katz (2010).

A drawback of the 1915 Iowa data is that Goldin and Katz do not report the industry in which the worker was active. Consequently, as relative compensation by industry is unavailable in the 1915 data, we are unable to fully capture the effects of the reallocation of labor between these industries. This reallocation effect turns out to have had a significant impact on overall labor-quality growth between 1900 and 1950, as we will show below. In addition, the sole reliance on income data from Iowa introduces a bias in the compensation estimates, as wages for the different categories were not uniform across all states. Iowa may not be the most representative state for this sensitivity check, but unfortunately it is the only source of micro-data on labor income we have prior to 1940.

To tackle these issues, we include the results from 5 separate estimations in table D.3. Column (1) reports the full model that we have relied on so far, based on the 1940 data for the US as a whole, including controls for industries. We drop the industry dummies in (2) and restrict the sample to Iowa in (3). Column (4) shows the results based on the 1915 Iowa data from Golden and Katz. The coefficients from (3) can be directly compared to the estimates from (4). The other columns can be used to gauge the bias introduced by the exclusion of industry specific compensation figures and the sole reliance on data from Iowa. The final column (5) shows the regression based on 1950 census data for the US as a whole. This regression includes a full set of industry dummies and interaction terms and can be directly compared against the results in column (1).

Looking first at columns (3) and (4), table D.3 shows that the gap between male and female wages in Iowa was significantly bigger in 1915 than in 1940; the lower and upper 95 percent confidence limits for the female dummy in model (4) are -0.72 and -0.58 respectively. The estimate for the female dummy in (3) clearly falls outside these bounds. The returns to experience (proxied by age) were smaller in 1915 than 1940. The returns to education were roughly equivalent in the 1915 sample compared to the 1940 Iowa sample; the upper bounds for the high school and college coefficients in (4) are 0.33 and 0.56 respectively. Were we to base our compensation estimates on 1915 (instead of 1940), we would expect the effects on our labor quality index to be mixed. Ignoring the interaction terms, the reduced weight given to female labor in the 1915 would dampen the growth in labor quality, as we observe a sizable increase in the share of women in the labor force over the twentieth century. Similarly, the ageing of the workforce between 1900 and 1950 would show a less pronounced positive effect on labor quality growth. However, the increase in the educational attainment of the workforce during the early twentieth century should have a comparable impact when 1915 weights are used. Comparing column (5) to column (1) we would expect the effect of both gender and age on labor quality growth to be slightly higher based on the 1950 compensation weights, while the effect of education is expected to be lower. The latter can be inferred from the fact that the relative spread between the coefficient for the highest and lowest educational classes is lower based on 1950 data than for the original 1940 data.

As we will show below, of the three labor characteristics (age, gender and education) education is the driving force behind the growth in labor quality over the first half of the twentieth century. The change in educational attainment – particularly the rapid rise in the number of workers that attended high school or even college – is also the most important factor missing from Kendrick's (1961) measure of labor quality. The fact that the 1940 compensation weights allocated to the four educational classes appears to be representative for earlier years is thus reassuring. Based on identical sources, Goldin and Katz (1999: 22, 45) even show that the returns to a year of high school and college education was greater for young men and at least equal for all men in 1915 compared to 1940 when one adjusts the 1915 Iowa data to cover the national economy as a whole. This would mean the contribution of education to labor quality growth would come out even higher if we would include 1915 compensation weights into our analysis. Goldin and Katz also show that in 1950, the returns to education had indeed fallen substantially compared to the pre-war era. This, Goldin and Margo (1992: 32) say, "was primarily the result of a particular confluence of short-run events affecting the demand for labor and of institutional changes brought about by the war and the command economy that accompanied it." The postwar figures are thus less likely to approximate the relative compensation weights for the early twentieth century.

As previously noted, the 1915 Iowa data summarized in table D.3 cannot be used to determine whether the 1940 relative wages by industry are relevant for earlier years, since the earlier population census does not reveal which industries the employees were engaged in. For data on pre-1940 labor compensation by industry we turn to the *National Income and Product Accounts* by the BEA (2009), which provides aggregate data from 1929 onwards. Comparing the industry-specific wages in 1929 to those derived from the 1940 census reveals that, over the course of the 1930s, relative wages by industry did not change much. The three worst-paying industries in 1940 were agriculture, personal and public services and the lumber industry. In 1929, agriculture and personal services also recorded the lowest average compensation per worker, while the lumber industry ranked as the seventh worst paying employer. The highest average annual compensation was recorded in the petroleum and coal products industry for both years. Wage data prior to 1929 is not readily available for the entire US economy, but the 1909 *Census of Manufactures* does report wages, salaries and persons employed for the major 2-digit manufacturing industries. Comparing 1909 to 1940 we observe that the textile and lumber mills consistently paid the lowest wages, while the printing and publishing, petroleum and transportation equipment industries always ranked near the top of the list of best-paying industries. This appears to suggest that the industry-specific wages observed in 1940 are a decent proxy for earlier years. The 1940-based compensation data is thus likely to adequately capture the effects of the reallocation of workers between industries on labor quality.

Decomposition

Although the coefficients from the income regression provide a rough overview of the changes of relative compensation of workers between 1915, 1940 and 1950, the effect on our labor quality estimates can only be properly observed by incorporating the new compensation matrices into our full model. We will re-estimate labor quality change between 1900 and 1950 for the private domestic economy based on the compensation weights derived on the basis of estimations (2) through (5) in table D.3 and compare them to our baseline estimate from column (1). To fully assess the impact of the different compensation weights – both for the development of labor input as well as aggregate production – we should decompose the labor quality index into its underlying constituents. Jorgenson et al. (1999, p. 239) suggest a breakdown of the index on the basis of its distinctive characteristics. They propose the construction of partial indices of labor input in which only a subset of the characteristics is incorporated. To construct such a partial index, we sum the number of workers and the corresponding value shares over some of the characteristics and construct a translog index over the remaining characteristics.

Previously, we used a single subscript *l* to represent the categories of labor input cross-classified by all characteristics except for industry. Below we use a separate subscript for each of the individual characteristics: two sexes, represented by the subscript *s*; five age-groups, represented by *a*; four educational classes, represented by *e*; and thirty-five industries, still represented by *j*. An example of the partial labor input index for gender is given below.

$$\ln\left(\frac{HK_{s_t}}{HK_{s_{t-1}}}\right) = \sum_{s=1}^{2} \bar{v}_s^L \ln\left(\frac{\sum_{a=1}^{5}\sum_{e=1}^{4}\sum_{j=1}^{35} L_{saej_t}}{\sum_{a=1}^{5}\sum_{e=1}^{4}\sum_{j=1}^{35} L_{saej_{t-1}}}\right) \qquad \text{(D.7)}$$

Equation (D.7) is based on equation (D.1), the basic labor input equation introduced in this appendix. However, now the compensation shares $\bar{v}_s$ solely distinguish between the two gender categories and is multiplied by the log change in male and female workers respectively. The resulting partial labor input index only reflects changes in the relative share of men and women in the workforce and ignores the effects of the other characteristics. As before, labor-quality growth can still be derived as the difference between the growth rates of the compensation-weighted, partial index of labor input and employment.

Partial indices for all four characteristics can be computed, which are referred to as first-order indices. In addition to these first-order indices, second-order indices of labor input can also be defined. These depend on any two characteristics of labor input, by adding employment and the corresponding value shares over other characteristics and again constructing a translog index (Jorgenson et al. 1999, p. 270). Similarly, we can define third- and fourth-order indices. In our full model, there are six second-order indices, four third-order indices and one fourth-order index. The fourth-order index reflects compositional shifts among all characteristics, as in equation (D.1).

The first row in table D.4 reports the results from the decomposition of labor-quality growth for the American labor force based on the full US sample for 1940, including controls for industries. The first column in this table displays the annual average log growth over the entire period, while the subsequent columns report the partial, first order indices for education (*e*), age (*a*), gender (*s*) and industry (*j*) respectively. The final column reports the sum of the residual; i.e. second-, third- and fourth-order effects. The other rows in table D.4 report the decomposition of labor quality growth based on the four remaining compensation estimates introduced in table D.3.

Table D.4. Contribution to labor quality growth for the private domestic economy, United States, 1900-1950 (percent p. annum).

		total	educ. (*e*)	age (*a*)	gender (*s*)	industry (*j*)	*resid.*
US 1940	(1)	0.83	0.41	0.15	-0.12	0.48	*-0.09*
US 1940	(2)	0.52	0.38	0.19	-0.14	…	*0.10*
Iowa 1940	(3)	0.47	0.33	0.20	-0.16	…	*0.10*
Iowa 1915	(4)	0.35	0.28	0.15	-0.15	…	*0.08*
US 1950	(5)	0.69	0.34	0.13	-0.12	0.37	*-0.04*

May not sum to total due to rounding. Sources: see text.

The first row in table D.4 shows that the growth of labor quality, at the total economy level, appeared to be driven primarily by the change in educational attainment and shifts in the industrial structure. The contribution of education was positive for all decades and showed a rising trend over time, reflecting the findings by Goldin and Katz (2008). The relocation of labor from low-skill/low-productive sectors (e.g. agriculture) to high-skill sectors (e.g. trade and FIRE), reflected an improvement in the utilization of the workforce, greatly raising the potential output per worker. To a lesser extent, the gradual rise in the experience level of the American workforce, as illustrated by the increase in the average age, also positively contributed to labor-quality growth. In contrast, the rising share of women in the labor force tended to depress the growth of labor quality. Particularly the period between 1940 and 1950 – as a result of the war effort – observed a marked increase in the number of female workers.

The results from estimation (2) – where the variations in income between industries are no longer taken into account – shows a marked drop in the annual average growth of labor quality. The reallocation of workers between industries contributed a little over 0.30 percent per annum to labor quality growth. Note that the contributions of the remaining first order indices changes slightly as well, as the variations in income among individuals is now attributed to these categories instead of to the differences in compensation between industries (see table D.3). If we narrow the 1940 sample in (3) to include compensation figures from Iowa only, we again observe a modest downward adjustment of 0.05 percent. Compared to (2), the difference in annual labor quality growth appears to come from a lower contribution of education as a result of the reduced returns to education we observed for (3) in table D.3.

The penultimate row in table D.4 reports the results based on the 1915 Iowa sample. If we compare the estimates from (4) directly to (3), we see that using the earlier weights would lower labor quality growth by about 0.12 percent per annum. Half of this difference comes from a reduced contribution of education and half from a lower contribution of work experience. Taking the bias for the Iowa sample and the mismeasurement of the reallocation of labor into account – observed in estimations (3) and (2) respectively – we would expect the average labor quality growth for the private domestic economy to be approximately 0.70 percent per annum based on the 1915 compensation weights. The labor quality estimates for the individual industries based on the 1915 income regression appear to be very similar to our baseline findings as well. The correlation between the labor quality estimates based on (1) and (4) for the disaggregate industries measured for each decade individually is a strong 0.97.

The findings on the basis of the 1950 compensation weights in estimation (5) paint a strikingly similar picture. Overall labor quality growth is reduced by 0.14 percent per annum compared to our original estimates in the first row of table D.4. Again, the difference stems primarily from a reduced contribution of education and a lower reallocation effect (*j*). Based on the 1950 compensation data, annual labor quality growth is still approximately 0.70 percent. Once again the correlation between the labor quality estimates for the individual industries based on (1) and (5) is very high: 0.98.

Overall, the modest difference between the labor quality results at the total economy level based on the 1915, 1950 and the original 1940 weights of approximately 0.12-0.14 percent per annum shows that our results are quite robust. This conclusion is reinforced by the striking similarity between the disaggregate results based on the two sets of weights. The benefits of the detailed 1940 estimate, that not only covers the income differences for the full US sample but can also take the reallocation effects of the shift in employment between industries into account, outweighs the need to incorporate changes in the relative incomes over time into the analysis. We prefer the 1940 weights over the 1950 weights as the latter falls outside the period we study in this paper. The postwar figures are also less likely to capture the relative compensation between the labor categories for the early twentieth century, particularly in the case of the educational classes.

Appendix References

Abramovitz, Moses. 1964. *Evidences of Long Swings in Aggregate Construction since the Civil War.* New York: Columbia University Press.

Bakker, Gerben. 2012. "How Motion Pictures Industrialized Entertainment." *Journal of Economic History*, 72(4): 1036-1063.

Bureau of Labor Statistics, "Historical Multifactor Productivity Measures", http://www.bls.gov/mfp/home.htm (October 2014).

Carter, Susan B., Scott S. Gartner, Michael R. Haines, Alan L. Olmstead, Richard Sutch, and Gavin Wright (Eds.). 2006. *Historical Statistics of the United States: Earliest Times to the Present*. Cambridge: Cambridge University Press.

Central Statistical Office. 1956. *National Income Statistics: Sources and Methods.* London: HMSO.

Chandler, Alfred D., Jr. 1990. *Scale and Scope. The Dynamics of Industrial Capitalism.* Cambridge, Mass.: Belknap Press.

Denison, E. 1962. *The Sources of Economic Growth in the United States and the Alternatives before Us*. New York: Committee for Economic Development.

Denison, E., and J. Poullier. *Why Growth Rates Differ: Postwar Experience in Nine Western Countries*. Washington D.C.: Brookings Institution Press, 1967.

Field, Alexander J. 2003. "The Most Technologically Progressive Decade of the Century," *American Economic Review* 93(4): 1399-1413.

____. 2006. "Technological Change and U.S. Productivity Growth in the Interwar Years," *Journal of Economic History* 66(1): 203-236.

Fraumeni, Barbara M. 1997. "The Measurement of Depreciation in the U.S. National Income and Product Accounts," *Survey of Current Business*, 77(7): 7-23.

Gallman, Robert E. and Thomas J. Weiss. 1969. "The Service Industries in the Nineteenth Century." In *Production and Productivity in the Service Industries,* edited by Victor R. Fuchs, 287-381. New York: Columbia University Press.

Goldin, C., and L. Katz. 1999. "The Returns to Skill in the United States across the Twentieth Century." *National Bureau of Economic Research Working Paper* 7126: 1–49.

Goldin, C., and L. Katz. 2008. *The Race between Education and Technology*. Cambridge: Belknap Press of Harvard University Press.

Goldin, C., and L. Katz. 2010. *The 1915 Iowa State Census Project*. ICPSR28501-v1. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2010-12-14. http://doi.org/10.3886/ICPSR28501.v1

Goldin, C. and R. Margo. 1992. "The Great Compression: The Wage Structure in the United States at Mid-Century", *The Quarterly Journal of Economics,* 107(1): 1-34.

Goldsmith, Raymond W. 1956, *A Study of Saving in the United States*, Volume III, Princeton: Princeton University Press

Goldsmith, Raymond W. 1958. *Studies in Capital Formation and Financing III: Financial Intermediaries in the American Economy since 1900.* Princeton: Princeton University Press.

Gordon, R. 2010. "Revisiting U.S. Productivity Growth over the Past Century with a View of the Future." *National Bureau of Economic Research Working Paper* 15834: 1–30.

Gordon, Robert J. 2016. *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War*. Princeton, NJ.: Princeton University Press.

Gould, Jacob M. 1946. *Output and Productivity in the Electric and Gas Utilities, 1899-1942*. New York: National Bureau of Economic Research.

Griliches, Z. 1963. "The Sources of Measured Productivity Growth: United States Agriculture, 1940–60." *Journal of Political Economy* 71: 331–346.

Jorgenson, D., F. Gollop, and B. Fraumeni. 1999. *Productivity and US Economic Growth*, 2nd ed. New York: toExcel.

Jorgenson, D., and Z. Griliches. 1967. "The Explanation of Productivity Change." *Review of Economic Studies* 34: 249–283.

Jorgenson, D., M. Ho, and K. Stiroh. 2008. "A Retrospective Look at the U.S. Productivity Growth Resurgence." *Journal of Economic Perspectives* 22: 3–24.

Jowett, Garth S. 1974. "The First Motion Picture Audiences,' *Journal of Popular Film*, 3 (Winter):39-45.

Kendrick, John W. 1961, *Productivity Trends in the United States*, Princeton: Princeton University Press.

King, Willford I. 1930. *The National Income and its Purchasing Power*. New York: National Bureau of Economic Research.

Kuznets, Simon S. 1941. *National Income and its Composition, 1919-1938.* New York: National Bureau of Economic Research.

Kuznets, Simon S. 1961. *Capital in the American Economy: Its Formation and Financing.* Princeton: Princeton University Press .

Lebergott, Stanley. 1996. *Consumer Expenditures: New Measures and Old Motives.* Princeton: Princeton University Press.

Leontief, Wassily W. 1953. *Studies in the Structure of the American Economy: Theoretical and Empirical Explorations in Input-Output Analysis.* New York: Oxford University Press.

Long, J. Scott and Freese, Jeremy (2006). *Regression Models for Categorical Dependent Variables Using Stata. Second Edition.* College Station, TX: StataCorp LP.

National Bureau of Economic Research, "US Business Cycle Expansions and Contractions," http://www.nber.org/cycles.html (accessed 28 November 2015).

Philippon, Thomas. 2014 "Has the US Finance Industry Become Less Efficient? On the Theory and Measurement of Financial Intermediation." *American Economic Review*, forthcoming.

Ruggles, S., T. Alexander, Genadek K., R. Goeken, and M. Schroeder. 2010. *Integrated Public Use Microdata Series*. 5.0. Minneapolis: University of Minnesota.

U.S. Bureau of the Census. 1913. *Thirteenth Census of the United States*, Vol. 8. Washington, D.C.: U.S. Government Printing Office.

____. 1960. *Historical Statistics of the United States: Colonial Times to 1957.* Washington D.C.: US Department of Commerce, Bureau of the Census.

U.S. Bureau of Economic Analysis. 1966. *The National Income and Product Accounts of the United States, 1929-1965: Statistical Tables*, Washington, D.C.: U.S. Government Printing Office.

____. 1993. *Fixed Reproducible Tangible Wealth in the United States, 1925-89*, Washington, D.C.: U.S. Government Printing Office.

____. 2002. *Fixed Assets*, http://www.bea.gov/National/FAweb/Index2002.htm (accessed April 4, 2014).

____. 2003. *Fixed Assets and Consumer Durable Goods in the United States, 1925–99*, Washington, D.C.: U.S. Government Printing Office.

____. 2009. *National Income and Product Accounts* (accessed January 11, 2010).

____. 2010. *Fixed Assets* (accessed December 8, 2011).

____. 2011. "Value Added by Industry, Gross Output by Industry, Intermediate Inputs by Industry, the Components of Value Added by Industry, and Employment by Industry, 1947-1997," *Historical Industry Accounts Data,* http://bea.gov/industry/io_histannual.htm (accessed April 4, 2014).

U.S. Bureau of Labor Statistics. 1943. *Wholesale Prices, July-December and Year 1942*, Bulletin No. 736, Washington, D.C.: U.S. Government Printing Office.

____. 1949. *Wholesale Prices, 1947*, Bulletin No. 947, Washington, D.C.: U.S. Government Printing Office.

____. 1958. *Wholesale Prices, and Price Indexes 1957*, Bulletin No. 1235, Washington, D.C.: U.S. Government Printing Office.

U.S. Bureau of the Census. 1975. *Historical Statistics of the United States, Colonial Times to 1970*, Washington, D.C.: U.S. Government Printing Office.

Whitney, W. G. 1968. *The Structure of the American Economy in the Late Nineteenth Century.* Cambridge, Mass.: Harvard University, Ph.D. dissertation.