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The Sources of Growth in a Technologically Progressive Economy: the United States, 1899-1941

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JEL Classification: N11, N12, O47, O51.

Keywords: productivity growth; total factor productivity; great inventions; spillovers; United States — history

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Introduction

One of the most famous findings in growth economics is Robert Solow's (1957) discovery 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 John Kendrick (1961) which estimated that from 1869 to 1953 and 1909 to 1948, the growth in total factor productivity (TFP) accounted for 80.0 and 88.5 percent 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 the quality of labor or the capital stock.

The context for these estimates is the episode of technological advance which is often called the 'second industrial revolution'. During this time, the United States overtook Britain as the world's leading economy and in the process achieved unprecedented rates of TFP growth of 1.3 percent per year.[1] During the early decades of the twentieth century, the United States was at 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). Robert Gordon (1999; 2016) described TFP growth in the period between 1891 and 1972 as 'one big wave' based on a few major technology clusters ('great inventions') 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 Alexander 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'.

Against this background, the main contribution of this paper is to provide a consistent growth account, not only taking changes in the number of hours worked and the available stock of capital into account, but also controlling for the heterogeneity across these workers and between different types of capital. This allows us, for the first time, to properly compare the technological progress achieved in the US during the post-war era to the technological change realized between 1899 and 1941. In order to achieve a full understanding of the sources behind this growth, we break aggregate U.S. TFP growth down into the underlying contributions of 38 sectors consistent with the detailed sectoral level reported for the U.S. after World War II. We thus develop new insights into the origins and the process of American productivity growth in the early twentieth century.

Our analytic narrative supersedes that of Kendrick (1961) which has been the main source available to researchers until now. We develop much improved and extended estimates which provide a more complete description of the sectoral pattern of TFP growth across the American economy. Our growth accounting covers in detail about 80 percent of the private domestic economy (PDE) compared with 50 percent in Kendrick's estimates. In addition, 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

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[1] Not only was 1.3 percent 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 percent per year (Abramovitz and David, 2001; Crafts, 2004a; Matthews et al., 1982).

contribution of capital inputs on a capital-services basis where feasible (i.e., 1929-1941), and we obtain a set of value-added weights which underpin the measurement of sectoral contributions to total TFP growth. Our initial analysis assumes that there were no cross-sector TFP spillovers but Paul David (1991) argued that the diffusion of electricity did in fact generate such spillovers. We therefore perform an additional exercise and incorporate these spillovers in our growth accounts. We use the results of these investigations to challenge, or at least to qualify, claims made by Field, Gordon, and Solow.

To this end, we address three issues. First, we re-examine the rate of TFP growth in the PDE prior to 1941 which allows us to review the contribution made by TFP to labor productivity growth. Second, we re-consider whether the 1930s really was the most technologically progressive decade of the twentieth century. Third, we quantify the impact of the technology clusters that are said to comprise the 'great inventions'; in doing so we develop estimates with and without TFP spillovers.

In outline, our approach is as follows. We use conventional neoclassical growth accounting assumptions, starting with the estimates in Kendrick (1961) for 1899-1929 and improving and extending 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 U.S. Bureau of Economic Analysis' (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. We also compute rank correlations to examine inter-temporal persistence of productivity performance at the sectoral level. In order to pursue the issue of TFP spillovers, we develop a regression analysis similar to David (1991) using our new TFP numbers. This permits an estimate of the importance of the 'great inventions' for TFP growth which takes account of TFP spillovers across sectors.

The results of these analyses are quite different from those of earlier work in a number of important aspects. First, we find a much higher rate of growth of labor quality than did Kendrick (1961); for 1899-1941, our estimate is about 0.8 percent per year while his was about 0.3 percent per year. An immediate corollary is that we estimate a lower rate of TFP growth in the PDE at 1.3 percent per year during 1899-1941 compared with Kendrick's estimate of 1.7 percent per year. Accordingly, TFP growth accounted for 60 percent of labor productivity growth rather than the 7/8th proportion found by Solow (1957). Second, we do not agree with Field (2003) that the 1930s was the most technologically progressive decade if the criterion is TFP growth in the PDE; we estimate that TFP growth was 1.86 percent per year during 1929-41 compared with 1.98 percent per year during 1948-60 and 2.21 percent per year during 1960-73. Third, we estimate that the technology clusters associated with Gordon's 'great inventions' accounted for just under 40 percent of TFP growth in the PDE during 1899-1941. Their contribution rose steadily from about 0.3 percentage points per year in 1899-1909 to just over 0.8 percentage points per year in 1929-41. This is impressive but possibly less overwhelming than a reader of Gordon (2016) might imagine. Contrary to Gordon's 'great inventions' thesis, we find that TFP-growth originated in a wide variety of sectors and that big unglamorous sectors like Construction, Farming, and Foods sometimes had a substantial impact on growth. Including TFP spillover effects, we find that the 'great inventions' could have accounted for 55 percent of TFP growth in the 1930s.

Finally, we discuss the context of our findings by considering the reasons for 'American exceptionalism' which is revealed by superior productivity performance compared with other leading economies. We highlight several aspects of the 'national innovation system' including, in particular, the greater efficiency of American producers in utilizing new technology which may have been underpinned by the relative effectiveness of the creative destruction process in the United States prior to World War II.

1. Existing evidence on the sources of American productivity growth

Studies of long-run American productivity growth have been hampered up to now by the lack of readily available data on output growth, capital and skill formation and technological change for the first half of the twentieth century. Particularly the comparison between the pre- and post-war periods suffers from discrepancies in the definitions and methods used to estimate the growth in total factor inputs and must somehow deal with substantial differences in the coverage and detail of industries underlying the growth in the Private Domestic Economy (PDE). Only with detailed, industry-level data will we be able to properly analyze the longitudinal effect of long-run waves of innovation and TFP-growth, such as the one hypothesized by Gordon (2016). Similarly, only with consistent measures of the change in output, employment, hours worked, labor quality, stocks and composition of capital, all at the industry level, are we able to assess the contribution technological change made to the productive capacity of the American economy prior to the Second World War.

In this section, we will first review previous attempts to harmonize the measure of TFP-growth for the (long) twentieth century, focusing especially on the estimation of labor quality which either played a major or only a marginal role in the rapid growth of the American economy's productive capacity, depending on which study one consults. Second, we will discuss existing claims of sectoral contributions to TFP growth, which have also been distorted by a lack of detail in the breakdown of productivity growth and inconsistent measures of technological change over the last century. Third, we will discuss the literature on the effect of technological spillovers during the second industrial revolution, which has hitherto suffered from incomplete or biased industry-level productivity data.

Since Solow (1957) several scholars have made important contributions to his growth accounting framework, helping to identify the sources of growth in the United States in the first half of the twentieth century. A common theme in these later studies is to incorporate an estimate of the contribution made by improvements in labor quality, which was not considered by Solow, to labor productivity growth and thus to downsize somewhat the importance of TFP growth. However, the methods that have been used so far vary and none of them has proven to be entirely satisfactory.

The major research project of Kendrick (1961) adjusted labor input to capture the implications of changes in the composition of employment based on wage differentials between different occupations. This allowed a component of improvements in labor quality to be added to growth in person-hours. For the PDE in 1909-49, the period investigated by Solow (1957), this gave a rate of growth of labor quality of 0.31 percent per year and reduced the TFP contribution to labor productivity from 88 percent to 78 percent. Unfortunately, this procedure leaves out of account the impact of improved labor quality *within* occupations which is potentially a serious omission as these decades saw large increases in educational attainment of the workforce (Goldin and Katz, 2008).

The next milestone was the work of Edward Denison (1962), subsequently updated and extended in a series of volumes culminating in Denison (1985). Denison gave great weight to the issue of labor quality and made quite elaborate estimates of its rate of improvement. His work is not, however, consistent with the approach used by the BLS today and is undermined by relying on assumptions which are not generally regarded as acceptable. The strength of Denison's work was a serious attempt to capture the impact of education on labor quality using estimates of educational attainment and associated wage differentials, but the weaknesses included an arbitrary assumption to discount 40 percent of these differentials as due to intrinsic ability, unwarranted adjustments for the impact of changing hours of work on productivity and a failure to deal adequately with shifts of employment between industries.

Denison's original estimates showed a large contribution from labor quality which was estimated to have increased by 1.06 percent per year between 1913 and 1950 which if used to correct Kendrick's TFP estimates would imply a revision to 54 percent of labor productivity (Gordon, 2000). If, however, Denison's estimates are adjusted to make them more nearly comparable with the BLS methodology by removing the ability correction and the hours effect on productivity, the rate of growth of labor quality over 1913 to 1950 would give a corrected TFP contribution of 75 percent of labor productivity growth during those years (Gordon, 2000). A very similar approach to using Denison's work was adopted by Moses Abramovitz and Paul David (2001) who found that TFP corrected for labor quality accounted for 67 percent and 77 percent of labor productivity growth in the PDE during 1905-27 and 1929-48, respectively. Nevertheless, these would all be incomplete calculations because they do not include a proper accounting for inter-industry occupational change.

Gordon (2000) also proposed adjustments to Kendrick's estimates of capital inputs to make them more comparable with modern methods and to deal with various biases in official statistics, notably concerning assumed lifetimes of assets during the 1940s and 1950s and government capital formation during World War II. Gordon proposed a crude correction to capital stock estimates based on asset-price weighting to approximate what might be obtained by rental-price weighting, in effect significantly increasing the weighting given to equipment relative to structures and moving closer to estimating capital inputs on a capital-services basis. Taking all Gordon's (2000) adjustments, both to capital and labor inputs, into account produces an estimate of TFP growth at 1.00 percent per year during 1913 to 1950 which amounts to 56 percent of labor productivity growth. However, as we will discuss below, this treatment of capital inputs is based on questionable assumptions which are not evidence based.[2]

Gordon (2016) puts forward a much-revised view of the role of TFP growth in the American economy during the long twentieth century. The revisions to his earlier work stem primarily from his adoption of modern NIPA estimates of real output based on chain-linking of the price deflator. He has also changed

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[2] See Section 4, below.

his estimate of labor quality now dropping a modified Denison approach in favor of using an index of educational attainment based on the work of Claudia Goldin and Lawrence Katz (2008). The key message is that the era of high TFP growth, which was yet to run its course when Solow (1957) wrote, was transient. For the halcyon period from 1920 to 1970, these new estimates are that TFP growth averaged 1.89 percent per year or 67 percent of labor productivity growth. In contrast, for 1890 to 1920 TFP growth at just 0.46 percent per year and for 1970 to 2014 at 0.64 percent per year accounted for only 31 percent and 40 percent of labor productivity growth, respectively. Question marks remain concerning the capital input estimates which are updated but based on similar assumptions to Gordon's earlier study. The new real output measures may not be an improvement for the 1930s and 1940s when price movements were volatile (Crafts, 2016; section 4 below).

Lastly, Field (2003) announced the finding that the 1930s was the most technologically progressive decade of the twentieth century. His finding was based on using the Kendrick database for the period 1929 to 1941 whereas Kendrick himself (1961) used the years 1929 to 1937 in his comparisons of sub-periods. Field argued, reasonably enough, that 1941 was less affected by problems of capacity under-utilization in the recovery from the depression. Field did not attempt to correct Kendrick's flawed estimates of labor quality, however, resulting in an upward bias to his TFP growth estimates. His finding would have come as a surprise to earlier writers. Denison (1985), who estimated a much higher rate of labor quality growth, found that TFP growth in 1929-41 was less than half that of 1948-73. Field does not even address the subsequent refinements that have been made to labor productivity growth. Abramovitz and David (2001) and Gordon (2000) did not report TFP growth for the 1929-41 period but took the 1930s and 1940s as one interval; they found that TFP growth at that time was somewhat lower than in the 1950s and early 1960s. In later work, Field (2011; 2013) increased his estimate of TFP growth in the 1930s even further, by making a 'cyclical adjustment' to address what he saw as a problem of still incomplete recovery in 1941.

What are the key takeaways for this paper from this rather bewildering array of results? First, it is generally agreed that TFP growth contributed less to labor productivity growth in the first half of the twentieth century than Solow (1957) thought. Depending on the chosen period and details of method a range of 2/3 to 3/4 rather than 7/8 may seem a reasonable summary of recent estimates. Second, although taking proper account of labor quality growth is recognized as being of central importance, no study has yet provided a comprehensive estimate that embraces both educational improvements within occupations and occupational shifts. Accordingly, it seems likely that labor quality matters more than current studies allow. Third, it would be desirable, if possible, to put estimates of capital input on a capital-services basis but this has yet to be attempted for the pre-World War II period. This adjustment is expected to reduce estimated TFP growth even further.

Following the lead of Kendrick's (1961) landmark study, these studies have not tried to break down the growth of the PDE into the contribution of individual industries' productivity growth. Consequently, the various adjustments to the measurement of TFP, as described above, were not implemented at the industry-level. This highlights another key shortcoming of the literature – it does not provide a detailed account of sectoral contributions to TFP growth prior to World War II even though this is of central importance to understanding the sources of growth at that time. We also do not have a comprehensive set of value added weights by industry – a surprising omission in Kendrick (1961) which has never been rectified.

Gordon (2000) (2016) has stressed the fundamental importance of the great inventions of the late nineteenth and early twentieth centuries to the surge in TFP growth from the 1920s through the 1960s. 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 has not attempted to quantify the growth contribution of these four technologies over time.

Although the great inventions obviously made a significant contribution to productivity advance, nevertheless it is reasonable to suppose that the United States had characteristics which were conducive to TFP growth generally and were potentially conducive to many sources of TFP growth across much or all of the economy implying that, while important, the great inventions may not have been dominant. Two major American advantages, especially relative to European countries, were the scope and quality of its human capital and an absence of obstacles to creative destruction. Goldin and Katz (2008) noted the importance of the rapid expansion of secondary and college education as having a major indirect effect on TFP growth while David Mowery and Nathan Rosenberg (2000) stressed the increasing role of university-business knowledge transfers in a wide array of sectors. Marcel Timmer et al. (2016) showed that American firms used new technology much more efficiently than their German counterparts who were sheltered by cartels and a less-competitive environment and Pieter Woltjer (2013) found similar results when comparing American with British firms.

The method most commonly used to attribute sectoral TFP growth contributions across sectors uses own-sector value added weights. In the presence of (unremunerated) TFP spillovers, this may not be appropriate.[3] The modern literature relating to ICT has tended to look for spillovers within sectors (Basu and Fernald, 2007; Stiroh, 2002) in which case there is no problem for conventional sectoral accounting. If there are inter-sectoral spillovers, then the originating sector will receive too little and the receiving sector too much credit. Identifying spillovers would lead to a redistribution of TFP growth contributions across sectors rather than an increase in total TFP growth. This issue arises in particular in the context of so-called general purpose technologies (GPT), notably in the first half of the twentieth century in the case of electricity. Warren Devine (1983) itemized several reasons why TFP spillovers might flow from changes in the design of factories facilitated by the shift to machinery with electric unit drive including enhanced flexibility of configuration, improved materials handling, greater feasibility of single-story plants, and lighter factory buildings all of which were capital-saving.

So, in summary, we need a detailed industry breakdown of TFP-growth to make a proper estimate of aggregate TFP-growth that is net of all labor quality growth, comparable with post-war estimates, to understand the role and magnitude of TFP spillovers, to quantify the impact of the great inventions, and to settle the debate about the 1930s. Yet, until now, more than half a century after Kendrick's ground-breaking study, we are still completely in the dark about the exact contribution of individual industries to pre-war US productivity growth. In what follows we will provide light where previously there was darkness.

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[3] It is important to distinguish TFP spillovers from capital deepening contributions to labor productivity growth in sectors which make use of equipment in which the new technology is embodied. The former are epitomized by learning externalities while the latter entail financial outlays which are expected to earn a rate of return. In general, the existence of TFP spillovers is quite controversial.

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 still 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 David, Field and Gordon. 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 (PDE) and for five sectors which in turn are divided into 33 industries. These sectors covered 54 percent of the PDE in 1953. TFP growth for the remaining 46 percent – which includes construction, distribution, 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 economy; for 1899 to 1953, TFP in the covered sector was estimated at 2.1 percent per year, for the PDE at 1.7 percent and the residual sector was calculated as 1.3 percent (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 (1)

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

where α is the share of capital compensation in value added. For the PDE and for the five main sectors, labor inputs are based on person-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 nominal value added or of the productivity growth contribution of each industry (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. First, we provide estimates of TFP growth for a more complete set of industries, thereby reducing the size of the residual sector. We add estimates for construction, distribution, finance, insurance and real estate (FIRE), spectator entertainment, and the post office. In addition, we merged Kendrick's pre-1929 separate estimates for 'Food' and 'Beverages' into one aggregate, 'Foods' comparable to the relevant NIPA sector for 1929-1941. However, we were unable to find sources that would allow estimates for the healthcare, hotels and restaurants, and waterworks sectors. Our extensions mean that coverage goes up from 54 percent to 78 percent of the PDE on average for the period between 1899 and 1941. Second, we provide a full set of value added weights and productivity growth contributions at the industry level. Third, we construct estimates for a 1929-41 sub-period rather than the years 1929-37 to address the issues raised by Field (2011). Last, 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. We estimate labor quality at the industry level.

For the inclusion of the five hard-to-measure sectors – namely, construction, wholesale and retail distribution, FIRE, spectator entertainment, and postal services – we estimated capital, labor, factor income shares and output for five benchmark years in the early twentieth century using a variety of sources that included censuses, the *National Income and Product Accounts* (NIPA), as well as a variety of secondary sources. For the new, as well as the original 33 industries estimated by Kendrick, we calculated TFP growth rates and derived the average share in the PDE's value added for all periods.

These value added shares were multiplied by each industry's TFP-growth to obtain estimates of each sector's intensive growth contribution to TFP growth in the total private economy (see Appendices A and B for full details). Kendrick (1961) did not provide estimates of the contributions of individual industries to aggregate TFP-growth. By doing so, we obtain important new insights into the growth process that underpinned the prewar economy.

Next, we developed industry level estimates that extend Kendrick's estimates for 1929-37 through 1941. Real output is estimated on the basis industry-level estimates of nominal value added from NIPA, deflated 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 based on capital services. We calculated the industry-level stock of capital for the PDE between 1929 and 1941 using a Perpetual Inventory Method (PIM) and the investment and depreciation series taken from the U.S. Bureau of Economic Analysis' (BEA) *Fixed Assets* tables.[4] 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.[5] We present full details in Appendix C.

Two features of the methods that we employ deserve some comment. These relate to the way in which industrial contributions to aggregate TFP growth are calculated and to the way in which we measure labor quality.

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 total value added in the PDE. We then sum these individual contributions of all n industries to obtain TFP growth for the aggregate PDE so that

$$\frac{\Delta A_{PDE}}{A_{PDE}} = \sum_{j=1}^{n} \omega_j \frac{\Delta A_j}{A_j} \qquad (2)$$

This approach can be interpreted as measuring an industry's capacity to contribute to economy wide productivity. An industry's intensive growth contribution (IGC) therefore depends not only on its rate of TFP growth but also on its size. It should be noted, however, that the components of this aggregate are not an accurate measure of disembodied technical change (OECD, 2001).[6]

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[4] 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.

[5] 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.

[6] 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.

Our approach to measuring labor quality improves on that of Kendrick by taking account of the implications of the rapid increase in years of schooling on the quality of workers in each occupation over time. In addition, it also allows for changes in gender composition and experience of the labor force. Our method permits measurement of labor quality at the industry level. Not surprisingly, our method finds a higher rate of growth of labor quality than Kendrick; labor quality in the PDE during 1899-1941 is estimated to have grown at 0.8 percent per year compared with Kendrick's estimate of 0.3 percent.

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

$$\frac{\Delta HK}{HK} = \sum_{l=1}^{q} \bar{v}_l \frac{\Delta L_l}{L_l} \tag{3}$$

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 labor characteristic *l,* divided by the total wage sum

$$v_l = \frac{p_l \Delta L_l}{\sum_{l=1}^{q} p_l \Delta L_l} \tag{4}$$

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.

$$\frac{\Delta LQ}{LQ} = \sum_{l=1}^{q} \bar{v}_l \frac{\Delta L_l}{L_l} - \frac{\Delta L}{L} \tag{5}$$

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 based on 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 based on 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 (5). Full details of our estimation method are reported in Appendix D.

Equation (2) considers only the direct effect of an industry's contribution to TFP growth. It might, however, be supposed that there may be indirect effects in the form of TFP spillovers. This has indeed been strongly argued by David (1991) with regard to the impact of electricity in American manufacturing in the 1920s. Gordon's notion of 'great inventions' as technology clusters also seems to encompass TFP spillovers. It might therefore be appropriate to take account of spillovers when estimating the impact of the 'great inventions'. This would amount to a redistribution of the IGC across sectors rather than raising aggregate TFP growth in the PDE. There is, however, no generally agreed method for measuring

TFP spillovers. We have adopted an approach similar to that employed by David (1991) but we realize that the results need to be treated with caution.

To capture the TFP spillovers from electricity, we use an OLS regression to estimate the effect of the growth of electrical motors per hour of labor on the acceleration in TFP growth relative to the preceding period for all manufacturing industries in our sample for the periods 1919-29 and 1929-41. To investigate the full extent of TFP spillovers from the great inventions, we estimate the effect of the growth in capital services from capital assets directly linked to the great inventions on the acceleration in TFP growth; i.e. services from electrical equipment, electrical instruments and transportation equipment. We run the capital services regression for our full sample (i.e. all industries in the PDE) and for manufacturing only. Systematic data on capital services is only available from 1929 onwards, so here we can only estimate spillovers during the period 1929-41. The acceleration of TFP growth is defined as the difference between TFP growth in the current and the previous period, taking 1919-1929 with the preceding 1899-1919 and taking 1929-1941 with the preceding 1919-1929. Following David (1991), the growth in electricity capital during the 1920s has been proxied by the growth of the number of horse powers of secondary motors in use from the Censuses of Manufacturing, as reported in DuBoff (1979). The great inventions' capital services are based on the investment figures listed in the BEA's Detailed Fixed Assets tables and the methods described in appendix C.

3. Results

This section reports our industry-level estimates of value added weights, growth of labor quality and TFP, together with our estimates of intensive growth contributions, i.e., the sectoral decomposition of TFP growth, which is derived from them. We also point out some noteworthy features of these data.

For the private domestic economy, Table 1 shows the revised breakdown of the growth in hourly labor productivity. In Kendrick (1961), of the 2.16 percent annual growth in labor productivity between 1899 and 1941, 13 percent of the total (0.28 percentage points per annum) was attributed to the growth of capital inputs, 10 percent (0.22 percentage points per annum) to the growth in labor quality (i.e. labor composition), and as much as 77 percent (1.66 percentage points per annum) to the growth in TFP. The revisions proposed by this paper, which are discussed in detail in the rest of this section, lead to a very different breakdown of the sources to labor productivity growth: 14 percent of it is attributed to the growth of capital inputs, as much as 26 percent to the growth of labor quality, and 'only' 60 percent to the growth of TFP. This leads us to conclude that Solow's claim that 7/8th of productivity growth in this era was caused by TFP-growth is a significant exaggeration of the contribution of the residual.

Value added weights are reported in Table 2. The relatively large sectors of Wholesale & retail trade and Finance, insurance and real estate (FIRE) – which are included in this study, but were not covered by Kendrick – contributed nearly as much to the PDE as the entire manufacturing sector. Over the entire period, manufacturing accounts for only about a quarter of total value added. Confining a discussion of productivity performance to that sector alone is potentially quite misleading. Strong productivity growth for the whole economy would normally require other sectors to make significant contributions. 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. Goldin and Katz (2008) show that while only 11 percent of those aged 14 to 17 were enrolled in high school in 1900, by 1938 this had risen to 68 percent. The discussion in Appendix D illustrates that the rapid growth in labor quality between 1899 and 1941 indeed originated primarily from increases in educational attainment: for the PDE, education accounted for nearly 50 percent of average annual growth in labor quality during this period. It should also be noted that labor quality grows much faster for the PDE than the estimates at the industry level suggest. This difference is explained by the impact of the sectoral reallocation of labor, which mainly concerned workers moving out of agriculture. Apart from the contribution of education and sectoral shifts, the increased average age of workers raised labor quality over the long run while an increase in the proportion of females from 18 percent at the start of the period to 24 percent at the end largely offset the age effect.

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 1929-1941) is 1.14 percent per year while the lowest (Leather products in 1899-1909) is -0.71 percent per year. [7] The range in successive sub-periods is 1.64, 1.20, 0.98, and 1.08 percentage points per annum, 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. Contrary to some priors, the correlations between labor quality growth and refined TFP growth (reported in Table 4) are quite low across our 38 sectors at 0.02 for the 1900s, 0.08 for the 1910s, 0.03 for the 1920s, 0.14 for the 1930s, and, finally, 0.10 for the whole period, 1899-1941. The fastest labor quality growth over the entire period 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), mainly resulting from our upward adjustment to labor quality growth: between 1899 and 1941 we estimate TFP growth in the PDE at 1.3 percent per year compared with 1.7 percent according to Kendrick. Obviously, this still represents a strong performance relative either to the nineteenth century or rivals like the United Kingdom. The fastest TFP growth during these years was in 1929-1941 for the PDE but not for manufacturing where TFP growth was much faster in the 1920s. 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 3 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 nine 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 25 observations (about 16 percent) with negative TFP growth; 13 of these were for 1909-1919 which may have been affected by World War I. The 6 sectors whose TFP growth fell by at least 2.0 percentage points between 1899-1909 and 1909-1919 showed an average improvement in TFP growth of 4.8 percentage points between 1909-1919 and 1919-1929.

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[7] 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 5 displays estimates of sectoral intensive growth contributions (IGC). The sum of negative IGC of measured sectors was small – below 10 percent of total TFP growth in each decade, except for 1909-1919. The IGC depends both on TFP growth and a sector's size. The sector with the fastest TFP growth rate never had the largest IGC in any period. Still, rank correlations between TFP growth and IGC are reasonably high most of the time, namely, 0.6, 0.9, 0.4, and 0.9 in successive periods, and 0.5 for the whole period. To facilitate comparisons, Table 6 provides rankings 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 Farming, none of which would be thought of as an exciting new, technologically progressive industry.[8] Wholesale and retail trade, with a value added weight of 14.1 percent, benefited from improvements in transport and communications and increased store sizes (Field, 2011) but would not usually be considered at the heart of the second industrial revolution. Over the whole period 1899-1941, it provided the largest IGC but ranked only 24th in TFP growth. Likewise, Farming was a large, unglamorous sector (with a value added weight of 10.5 percent) which had low TFP-growth but ranked third in IGC over the whole period, and second in the 1930s, 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 1919-1929 when it accounted for about three quarters of all TFP growth; this was exceptional and its average contribution over 1899-1941 was 'only' about forty percent.[9] This was, however, still well above its value added weight of about a quarter of GDP.

4. The Most Technologically Progressive Decade?

Field (2003) made the claim that the 1930s, defined as 1929-1941, 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 in terms of sectoral contributions. In this section, we re-examine the first of these claims using the new estimates that we reported in section 3, leaving our discussion of sectoral contributions to the next section.

In Table 7, we compare TFP growth rates for the private domestic economy (PDE) over the long twentieth century, where the post-1948 estimates are taken from the Bureau of Labor Statistics (BLS, 2014). On the basis of our new estimates, the 1930s no longer report the fastest TFP residual. TFP growth was undoubtedly strong and arguably quite remarkable for an economy that experienced the Great Depression within this period, but was still below the TFP growth experienced during the Golden

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[8] 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.

[9] While the general point in the text is correct, the proportions quoted are best thought of as good approximations, given that aggregation of a large number of sectors to a level lower than the PNE in the short run leads to redistribution effects because of measurement imperfections. For 1899-1941, for example, the proportion would be 39 or 40 percent depending on the calculation method, and for 1919-1929, the range of the proportion would be 69-75 percent.

Age (1948 to 1973).[10] Nevertheless, TFP growth at almost 1.9 percent per year makes the fears of secular stagnation expressed by Alvin Hansen (1939) seem misplaced.

There are a number of reasons why our findings deviate from those of Field (2003). First, as remarked in section 3 above, we follow Kendrick in basing our comparisons on the PDE rather than the PNE. Second, we argue that the pre-1948 figures by Kendrick (on which Field (2003) based its claims) are not really comparable with the post-1948 estimates. The methodology behind our estimation of the factor inputs – particularly the adjustment for labor quality and, for the post-1929 period, the estimation of capital services – make our pre-war estimates compatible with the more recent growth accounts by the BLS for the post-war era.

To see how the updated methodology affects the productivity estimates, Table 1 breaks down the growth in the PDE for the period 1929-41, comparing the original estimates by Kendrick (1961) – which were used in Field (2003) to support its case – with our own. In this conventional growth accounting framework, TFP growth is defined as the residual of labor productivity growth and the sum of the weighted contributions of the growth in capital per hour worked and the composition of labor (i.e. labor quality).[11] By controlling for the heterogeneity across workers and types of capital, our estimates show a considerably larger contribution of capital and labor quality to labor productivity growth. The difference between Kendrick's capital input contribution and our own is fully accounted for by the adjustment in the composition of capital (i.e. capital services). Our new labor quality estimates exceed those of Kendrick by accounting for improvements in educational attainment within occupations, as noted in section 2. Given the increase in factor inputs, our TFP residual is considerably reduced compared with Kendrick's original figure (1.86 vs. 2.27 percent per year), as was reported in Table 1.

The findings for the 1930s underscore a fundamental problem underlying the comparison of TFP estimates between different studies. The methods used in newer studies generally result in more encompassing measures of factor inputs. Aiming to reduce the 'measure of our ignorance', newer growth accounting studies tend to depress TFP growth. As Table 8 shows, this effect is not only evident for the 1930s, comparing growth rates for all peak-to-peak years from 1929 up to 1969 shows that the earlier study by Kendrick (1973), which uses methods identical to his 1961 study, consistently yields higher ratios of TFP to labor productivity relative to the later estimates by the BLS. Whereas TFP was responsible for approximately 80 percent of labor productivity growth over the entire period 1929-1969 according to Kendrick, our own study linked to the figures by the BLS estimate this share to be closer to 65 percent. Essential for any intertemporal or interspatial comparison of TFP is that identical methods and definitions are used for the measure of outputs and inputs. Field's (2003) reliance on the early study by Kendrick fails to meet this test. As discussed in section 2, we took special care to mirror the methods used by the BLS, making our new estimates directly comparable to the post-war TFP estimates.

A later study, Field (2011: 43, 100, 169-91), made a cyclical adjustment to Field's (2003) original calculation which raises the estimate of (underlying) TFP growth for the PNE from 2.31 to 2.78 percent per year. His rationale was that, although 1941 was the first year since 1929 that BLS unemployment averaged less than 10 percent which made it far preferable to 1937 as a (peacetime) peak year, even so 1941 is not ideal, as unemployment was higher (9.9 percent) than in 1929 (3.2 percent) or 1948 (3.8 percent). 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 capital

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[10] If the whole period 1948 to 1973 is considered, as in Field (2011), the TFP growth rate for the PDE is 2.12 percent per year, which is also superior to 1929-41.

[11] The aggregate capital share of 23 percent, used to weight the factor inputs, is based on Kendrick (1961: 285).

hoarding. On the basis of a regression of changes in log TFP on changes in the unemployment rate, he argued that, if the economy had been at full employment in 1941, TFP would have been 5.6 percent higher and so the average growth rate of TFP over the 12 years 1929-41 would have been 0.47 percent higher.[12]

We do not think that the above cyclical adjustment is justified. Moreover, we do not believe that any cyclical adjustment is warranted. There are several reasons for our skepticism including the use of more accurate unemployment estimates, evidence that the economy was already at or below the Non-Accelerating Inflation Rate of Unemployment (NAIRU) in 1941, and an analysis which shows that a capacity utilization adjustment to TFP is inappropriate after 1937. We will discuss these points in turn.

It is generally accepted that the unemployment figures used in the Field papers have been superseded by estimates made by David Weir (1992) which remove relief workers employed by the government from the unemployment total as proposed by Michael Darby (1976). On this basis, 5.99 percent of the labor force was unemployed in 1941 compared with 2.89 percent in 1929 and 3.73 percent in 1948. A Field-type correction to TFP in 1941 would be only 2.1 percent and 'cyclically-adjusted' TFP growth of the PNE would be 2.48 percent per year during 1929-41.

It is, however, highly likely that in 1941 the NAIRU was higher than in 1948 and could well have been around 6 percent or more of the labor force. In particular, a key feature of the pre-war American economy was a 'hard core' of long-term unemployment reflecting the scarring effect of the depression and the unemployment of these peripheral workers did not restrain wage growth (Jensen, 1989). In the 1940 Census, 33 percent of the unemployed (excluding relief workers) were long-term (Hatton and Thomas, 2010). Evidence that the peacetime output gap had closed by 1941 can be found in the behavior of wages and prices which exhibit rapidly increasing inflation. Nominal hourly earnings of production workers in manufacturing in 1941 were up 17.7 percent on 1937 and the 10.6 percent annual increase in 1941 was the fourth-largest annual increase since data began in 1910.[13] Similarly, nominal total compensation per employee for all industries in 1941 was up 14.8 percent on 1937 and rose by 10.6 percent in the year.[14] CPI inflation was 5.0 percent in 1941 compared with 0.0 percent in 1929 while the GDP deflator rose by 6.8 percent against 0.2 percent in 1929.[15]

Robert Inklaar et al. (2011) provided a test of the cyclical nature of productivity in the interwar U.S. economy. They found 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 discrepancy between TFP and technology had vanished. This suggests that capital hoarding was not prevalent in 1941.

Field's (2011) argument amounts to suggesting that true capital inputs are overestimated by conventional growth accounting methods. In contrast, Gordon (2016: 659-663) argues that capital inputs are seriously underestimated by standard growth accounting and hence TFP growth is

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[12] Field's (2011: 171) regression is $\Delta \ln TFP = 0.0283 - 0.0092 \Delta UR$. The change in unemployment rate to move to full employment is (9.9 – 3.8) = 6.1 based on the difference between unemployment in 1948 and in 1941.

[13] Carter et al. (2006), series Ba 4361.

[14] Carter et al. (2006), series Ba 4419.

[15] Officer and Williamson (2017); Johnston and Williamson (2017).

exaggerated. In particular, he questions whether the depreciation rates, which are fixed over time, are representative for the Depression era. As investment collapsed, Gordon believes that the expected life-time of all assets increased substantially during the 1930s. This lower rate of depreciation would lead to a greater increase in the capital stock than in the BEA estimates. As a crude proxy for these varying rates of depreciation, Gordon suggests multiplying official depreciation rates by the ratio of investment to the official capital stock for each year relative to the average for 1925-1972. If this procedure is applied to our capital input estimates, TFP growth for the PDE during 1929-41 is reduced by 0.18 percent per year (for more details see Appendix C). It should be noted, however, that no evidence is available to validate Gordon's assumptions about delayed retirement of capital.

In a recent re-working of his estimates, Field (2013) drops the Kendrick output series in favor of more recent NIPA data, based on annual chain-linking of prices to deflate nominal output, as the basis for a new calculation. The new output series grows faster than the old NIPA series based on 1929 prices because the GDP deflator has changed; this implies a higher rate of TFP growth. Field now finds that average TFP growth in the PNE during 1929-41 was 2.54 percent per year or 2.97 percent after making a cyclical adjustment.[16]

Although there are often good reasons to adopt annual chain-linking of the price index, it is known to be potentially misleading during periods of cyclical volatility because the problem of 'chain drift' can become quite serious. Optimal linking intervals should be based on choosing periods with relatively similar prices. Christian Ehemann (2007) used the Dijkstra algorithm to solve this problem and found that the optimal interval to leave weights unchanged for the GDP deflator is 1930-1942. In other words, the old series is preferable to the new.

We do not believe it is appropriate to modify our TFP growth estimates along the lines proposed by Field or Gordon. However, for those who take a different view we provide a 'ready reckoner' (Table 9) of the approximate impact of making different assumptions in terms of the deviation from our baseline estimate. Comparing Tables 7 and 9, we see that the only way to restore 1929-41 to being the period with the highest TFP growth is to make a cyclical correction of the size proposed by Field.

In sum, we believe that our estimate of TFP growth reported in Table 7 is the best available. We do not think it is desirable to make a cyclical adjustment or to deviate from conventional depreciation rates for the capital stock or to adopt chain-linked real output measures. We conclude that TFP growth in the 1930s was indeed lower than in the periods 1948 to 1960 and 1960 to 1973.

5. Did the Great Inventions Dominate TFP Growth?

Over the first half of the twentieth century, most industries made a substantial contribution to overall TFP growth. Table 5 shows that the IGC was distributed widely across industries, that no single industry was responsible for the preponderance of TFP growth in any given period. This was true for the industries within the manufacturing sector as well as industries in the rest of the PDE, suggesting that not one but several factors sustained the broad base for technological change across the American economy.

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[16] Field (2013) re-estimates the regression with the new data, obtaining $\Delta \ln TFP = 0.0306 - 0.0084 \Delta UR$, and then proceeds as before using the new coefficient on ΔUR. Our objections to this approach remain as stated above.

In his well-known account of American economic growth, Gordon (2016) describes a 'special century' of TFP growth which reached its apogee between 1920 and 1970 when the ramifications of the second industrial revolution held sway. He argued that this was driven by 'great inventions' in four technology clusters: electricity, the internal combustion engine together with derivative inventions such as interstate highways and supermarkets, rearranging molecules, and the entertainment, communication and information sector. Surprisingly, Gordon did not attempt to quantify the growth contribution of these four clusters over time. Thus the question remains whether or not the great-invention sectors of the second industrial revolution dominated overall TFP growth in our period.

Answering this question raises some problems. First, do we take account only of direct contributions to TFP growth or should an estimate of (unremunerated) TFP spillovers also be included?[17] If spillover effects are to be taken into account, then the issue arises as to what methodology to use. We follow earlier writers in looking for correlations at the sectoral level between the growth of capital equipment that embodies the great inventions and TFP growth. Second, is Gordon's taxonomy appropriate? Here the key issue is how to treat the Wholesale and retail trade sector which makes a large contribution to aggregate TFP growth, notably in the 'technologically progressive' 1930s. This sector would not normally figure as a part of the second industrial revolution but clearly benefited from technologies invented in the second industrial revolution. Even so, it is not obvious that this sector's TFP growth derived entirely from spillover effects of the great inventions. We provide information that allows a calculation of the impact of the great inventions on TFP growth treating wholesale and retail trade in three different ways: taking its TFP growth to be directly part of the great-invention contribution, treating it as a great-invention TFP spillover effect, or classifying it under other sectors which are not part of the second industrial revolution.

Turning first to an analysis which does not include possible TFP spillover effects, Table 10 confirms that the great inventions contributed a considerable share to TFP growth. For the first decade in the twentieth century, using Gordon's taxonomy and including Wholesale & retail trade, these sectors contributed 29 percent of TFP growth in the PDE, which subsequently rose to 45 percent in the 1930s.[18] In absolute terms, the increase in the contribution to annual TFP growth was even more pronounced, rising from 0.27 percentage points in 1899-1909 to 0.84 percentage points in 1929-41 (Table 5). The average over 1899-1941 as a whole was 0.49 percentage points - similar to the contribution of the entire manufacturing sector. It should be noted, however, that Wholesale and retail trade looms large in these numbers. Reclassifying this sector as outside the realm of great inventions in terms of a direct contribution to TFP growth would reduce the (remaining) great-invention share to 18 percent of TFP growth in the 1930s (compared with a 12 percent share of PDE value added) and 21 percent of TFP growth over the whole 1899-1941 period (compared with a 9 percent share of PDE value added).

Although the great-invention sectors were very important – accounting for about 38 percent of total TFP growth in 1899-1941 – they did not comprise a dominant component of TFP growth. The sources of TFP growth were more diverse than a reader of Gordon might suppose. This point is underlined by a

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[17] In principle, TFP spillover effects are distinct from the capital-deepening contribution to labor productivity growth from investment in new forms of capital goods which embody the great invention technology. They essentially represent externalities, for example, in the form of learning effects which enhance TFP.

[18] We use the current sub-periods because the PDE sectoral disaggregation is only available for these intervals, and we need the whole PDE to take into account services. However, as a sensitivity analysis we were able to check, for manufacturing only, the effect of an alternative periodization, namely 1899-1914 and 1914-1929. Using these alternative sub-periods does not change our findings for manufacturing substantially, and does not make the overall picture very different. The results are available from the authors.

comparison with the modern ICT era. Over the period 1974 to 2012, according to Byrne et al. (2013), TFP growth in ICT-producing sectors contributed about 54 percent of TFP growth in the PNE (0.43 percent per year out of 0.79). Although the percentage point contribution of ICT to TFP growth was a little lower than that of the great inventions taken together (0.43 vs. 0.49 percentage points per annum), the weakness of TFP growth in the rest of the American economy gave ICT a relatively high share of overall intensive growth (54 percent, vs. 38 percent for the great inventions) and thus a stronger claim to have been a 'dominant technology'.

We now extend our estimate of the contribution of the great inventions to TFP growth by considering TFP spillovers. These are estimated using an approach similar to that of David (1991) who looked at spillovers derived from electricity in the 1920s. The case for electricity as a source of TFP spillovers was made by Devine (1983), who noted several reasons why such spillovers might flow from changes in the design of factories. He showed that, facilitated by the shift to machinery with unit drive, the introduction of electricity enhanced flexibility of production, improved materials handling, made single-storey plants feasible, and allowed for lighter factory buildings, all of which were capital-saving. Horsepower in secondary motors in manufacturing grew rapidly in the interwar years, averaging 6.2 percent per year between 1919 and 1929 and 2.9 percent per year between 1929 and 1939 (DuBoff, 1979).

To estimate the size of these electrical spillovers we run cross-section regressions similar to David (1991), which link the accelerations in TFP growth to the growth of secondary electric motors per unit of labor. We use our own estimates of TFP growth and a larger sample of manufacturing industries compared to David.[19] The results are reported in Table 11. In regression (1), we find evidence in favor of TFP spillovers for the 1920s, but we cannot reject the null hypothesis for the 1930s in regression (2). This is perhaps not surprising since the literature has singled out the 1920s as the period when the impact of electricity was most substantial. Our results do show that, during the 1920s, spillovers accounted for a lower proportion of the TFP growth acceleration than previously suggested.

We run a similar exercise for the 1930s, where we now estimate the size of the TFP spillovers based on flows from the increase in the services of great inventions capital, instead of just electricity.[20] Regressions (3) and (4) in Table 11 show that for the manufacturing sector we find a significant and positive relation between the growth in great inventions' capital services and the acceleration of TFP growth. Extending the sample to include all industries in the PDE nullifies this result. We therefore use the results from regression (3) to estimate spillovers only within the manufacturing sector.

Table 12 presents an accounting of contributions to labor productivity growth in the manufacturing sector and the PDE during the interwar period. This takes account of TFP spillovers using regressions (1) and (3) above to estimate the impact of the growth of electric motors and great-inventions capital services. If these spillovers are added to the share of the TFP contribution of the great inventions in the PDE, this rises by about 10 percentage points in each period - to 50 percent of the aggregate in the 1920s (0.81/1.63) and to 56 percent in the 1930s (1.05/1.86). If TFP growth in the wholesale and retail trade sector is categorized entirely as spillovers, then TFP growth from great-invention spillovers comprises a significant part of TFP growth in the PDE at about 18 percent in the 1920s and 38 percent in the 1930s. Finally, it should be noted that, even including spillover effects, electricity does not dominate TFP growth in the 1920s, the period when it is supposed to have exercised a pervasive effect. Based on

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[19] 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.

[20] It is not possible to do this analysis prior to 1929, the year for which the NIPA are first available.

Tables 5 and 12, we estimate that the direct effects (0.029 + 0.042) plus spillovers in manufacturing (0.16) add up to a TFP growth contribution for electricals of 0.23 percentage points per year, about 14 percent of the 1.63 annual growth of TFP in the PDE.

Our estimates of TFP spillovers should be regarded as a pioneering attempt to fill an important gap in the evidence base. Nevertheless, it seems to us that it is quite unlikely that further research on this topic will be able to overturn our conclusion that, contrary to Gordon's assertions, the great inventions did not dominate TFP growth in the decades before 1941.

6. American Exceptionalism

If the great-inventions were not the sole drivers behind the strong productivity growth in the US during the pre-war era, what then could explain the rapid rate of technological progress? Crucially, what underlying dynamic could account for the fact that nearly all sectors were swept along in this wave of innovation, particularly during the 1930s when growth was strikingly broad-based? In this section, we argue that it was the combination of a highly educated, flexible labor force, an effective innovation system and a penchant for creative destruction.

To put the growth of the US economy during the first half of the twentieth century into context, it is helpful to compare it with its main industrial rivals. Robin Matthews et al. (1982) show that crude total-economy TFP growth in the UK averaged about 0.7 percent per year between 1924-37, less than half of the 1.8 percent growth in refined TFP we report for the US between 1919 and 1941 and a third of the crude TFP growth reported by Kendrick (1961) for the same period. TFP growth was faster in all US sectors compared to the UK, with the notable exceptions of agriculture and construction. In terms of labor productivity, the US was also forging comfortably ahead. In 1909, output per hour worked in German manufacturing stood at 60 percent of the American level, which had reduced to just 45 percent by 1936 (Timmer et al., 2016: 877). British manufacturing fared no better: in 1899, hourly productivity was 50 percent of the US level, which decreased to 37 percent by 1938 (de Jong and Woltjer, 2011: 487). Similarly, Stephen Broadberry (2006) found that the American services sector was considerably more productive than its European counterparts. Clearly US firms exploited the opportunities of the second industrial revolution better than their overseas rivals.

There was considerable exchange of technological know-how between the US and Western Europe, particularly following the First World War. German and British entrepreneurs traveled to the US to study American organization first hand, aiming to incorporate American machinery and management techniques in their production lines (Braun 1984; Nolan, 1994, Bowden and Higgins, 2004; Eichengreen, 2004; Richter and Streb, 2011; Ristuccia and Tooze, 2013). At the same time, the US frequently imported technology from across the Atlantic. In chemicals, for example, it obtained various patents at the end of the First World War because of wartime expropriations (Moser and Voena, 2012). The acquisition of patents continued throughout the 1920s. Standard Oil of New Jersey licensed the entire oil patent portfolio of IG Farben, the German chemicals cartel (Bakker, 2013: 1801-2; Enos, 1962).[21] During the 1930s, many top German scientists fled to the United States, generating important knowledge spillovers (Moser et al., 2014). In a substantial number of sectors, particularly the more

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[21] The amount paid for IG Farben's patent portfolio was 35 million dollars. This acquisition thus accounted for about 30 percent of total industrial R&D outlays for the entire US in 1930, emphasizing the importance of knowledge absorption versus original R&D.

‘modern’ manufacturing industries such as chemicals, machine-tools and transportation equipment, German, British and American manufactures were using similar techniques and had adopted a comparable mix of capital and labor.

Clearly, a strict dichotomy in technological paths or differences in capital intensity alone cannot explain the rising gap in both labor- and total factor productivity. Instead, recent evidence suggests that American producers were considerably more efficient than their European counterparts. A decomposition of manufacturing labor-productivity levels in 1936 reveals that slightly over half of the gap between Germany and the US is accounted for by inefficiencies in the German production process (Timmer et al., 2016: 893). Similarly, even though rapid capital deepening in British manufacturing between 1907 and 1930 increased its productivity *potential* by one percent per year relative to the US, its *realized* annual labor-productivity growth lay 1.2 percent below the standard set by the US (Woltjer, 2013: 111). A sharp decline in the efficiency of British producers explains nearly two-thirds of the 2.2 percent shortfall in potential output per hour worked. American industries were almost universally situated at or near the edge of the global technology frontier, rapidly pushing the production possibility frontier upwards throughout the early twentieth century.

In part, the inefficiencies in European industries reflected the fact that British and German firms needed time to assimilate the new American technologies, learn how to apply them effectively and adopt them to local circumstances (Arrow, 1962; Basu and Weil, 1998). Still, American producers adopted the techniques they imported from Europe much more expeditiously. The relative US efficiency lead in sectors like industrial chemicals or petroleum refining – both major importers of intangible assets – was greater than for the manufacturing sector on average (Timmer et al., 2016: 893). Broad-based American efficiency and growth was propelled by an effective combination of incremental process improvements, a well-established innovation system and a wave of rationalization during the 1930s.

During the interwar period, industrial research laboratories, and applied science and engineering in universities were becoming more important but research and development (R&D) was still concentrated in relatively few sectors, notably, chemicals, electrical machinery, rubber, and petroleum (Mowery and Rosenberg, 1989). Other sectors benefited from access to the pool of highly flexible labor, which, by the 1920s, had become exceptionally skilled by international standards (Acemoglu, 1998; Goldin and Katz, 2008). Creative destruction, the virtuous combination of technological progress and cost reductions associated with exit and rationalization, played an important part during the Great Depression. TFP advance on the railroads was promoted by track closures in the face of financial pressure (Field 2011, chapter 12), while the share of trucks in intercity transportation almost tripled, rising from 3.3 percent in 1929 to 9.7 percent in 1939, and that of pipelines grew from 4.4 to 10.2 percent (Winston et al., 1990).[22] Likewise, in the production of automobiles this rationalization process was boosted by strong competition from innovating new entrants. Ford’s central production system was outperformed by the decentralized system of General Motors (GM), reducing Ford’s market share in the interwar period from 56 to 19 percent and increasing GM’s from 12 to 48 percent between 1921 and 1940 (Chandler, 1962). The severe downturn of the early 1930s only accelerated the permanent exit of many low productivity automobile plants (Bresnahan and Raff, 1991). In general, American manufacturers were far less reluctant to discard their old machinery and adopt new production techniques than their European counterparts (Salter, 1966: 72-3; Magee, 2004: 82).

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[22] Modal shares of intercity freight in ton-miles.

Especially since the failure of trusts and cartels and the introduction of the Sherman (1890) and Clayton (1914) Acts (Lamoreaux, 1985), the threat of creative destruction itself also induced American firms to innovate. Based on micro evidence from the 1920s, Tom Nicholas (2003) showed that particularly firms with high levels of market power had strong incentives to innovate in order to pre-empt potential new entry and capture rents. Increases in stock market rewards for innovation pushed firms to continuously refine production processes and invent new products. The increasing complexity of technology developed during the second industrial revolution, particularly in sectors such as chemicals and electricity, also led to the spread of in-house R&D at the expense of independent inventors (Nicholas, 2010: 58). The rise of large firms in the US through the wave of mergers during the turn of the century facilitated this process, as large US firms had both access to the cash and the expertise needed to setup research departments (Bakker, 2013). Still, independent inventors continued to create inventions that were complementary to knowledge generated in-house. The favorable environment that American cities provided to these independent inventors – through close proximity to patent agents and lawyers as well as other inventors and industry itself – boosted technological change (Nicholas, 2010).

Total expenditure in R&D by American industry far outstripped the expenditure by British firms. At nominal exchange rates, expenditure on industrial R&D was roughly 10.0 times larger in the US than the UK in the year 1930 and still 7.5 times larger by 1938.[23] David Edgerton and Sally Horrocks (1994: 223) find similar ratios based on employment levels. Since the ratio of US/UK exchange adjusted nominal GDP ranged only between 3.4 and 4.3 during the 1930s, R&D can go some way in explaining both the transatlantic efficiency gap and the strong growth potential of the American economy. The sizable expenditures on R&D enabled American producers not just to develop new products but also facilitated the introduction of imported techniques in existing production lines and helped producers to modify new products to fit American consumer demands.

Finally, it is important to note that competition in product markets was relatively robust in the United States, a large free trade area, compared with its European rivals. A notable contrast is with the United Kingdom, which in the 1930s imposed tariffs and encouraged cartels such that competition was undermined in many sectors and productivity performance was significantly impaired (Crafts, 2012). Although Franklin Roosevelt's 'New Deal', enacted in 1933, which limited competition and vastly increased labor's bargaining power, threatened to undermine the process of creative destruction, the detrimental effects of the New Deal policies were limited. By 1935 the Supreme Court had ruled that the act's suspensions of antitrust laws were unconstitutional and by the end of the 1930s Roosevelt switched tack and pursued a pro-competition policy instead (Cole and Ohanian, 2004: 785-8).

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[23] Using Mowery and Rosenberg (1989: 69) and estimates based on DSIR reports, Federation of British Industries (FBI) surveys and FBI archives from Edgerton and Horrocks (1994: 217, 226). GDP-deflators from Johnston and Williamson (2017) and exchange rates from Board of Governors of the Federal Reserve System (1943: 681); see also Bakker (2013: 1797-8).

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.

Our growth accounting estimates find that TFP growth in the PDE averaged 1.3 percent per year during the years from 1899 to 1941. This compares with Kendrick's (1961) estimate of 1.7 percent 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 percent per year which is considerably higher than the 0.3 percent 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. An important implication of our estimates is that they undermine Solow's famous (1957) claim that the residual was responsible for about 7/8th of labor productivity growth; we believe that TFP growth accounted for 'only' about 60 percent.

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 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 percent per annum in these years, the highest pre-war growth rate. This makes Hansen's (1939) fears of secular stagnation seem implausible.

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. It appears that TFP growth accrued across the economy from multiple disparate sources. This means that although the sectors which Gordon (2016) identified as comprising the 'great inventions' made a substantial direct contribution averaging just under 40 percent of TFP growth they did not represent a dominant component of TFP growth. This conclusion survives when we take account of TFP spillovers across sectors.

Finally, it is important to recognize that the United States outperformed other leading economies in the interwar period. It exploited the opportunities for productivity advance that came from the second industrial revolution better. This underlines the strength of the national innovation system that was in place by the early twentieth century. The United States was, of course, pre-eminent in performing R&D but also intervened less than leading European economies to inhibit the forces of creative destruction.

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Table 1. *Sources of Growth in the Private Domestic Economy (PDE): BCW and Kendrick Estimates for 1899-1941 Compared percent per annum).*

		1899-1929		1929-41		1899-1941	
		BCW	Kendrick	BCW	Kendrick	BCW	KenDrick
1	Labor productivity ((2)+(5)+(6))	2.04	2.04	2.48	2.48	2.16	2.16
	Contributions from:						
2	Capital input ((3)+(4))	0.38	0.38	0.15	0.04	0.31	0.28
3	Capital stocks	0.38	0.38	0.04	0.04	0.28	0.28
4	Capital composition			0.11		0.03	
5	Labor composition	0.59	0.25	0.46	0.16	0.55	0.22
6	Total factor productivity	1.07	1.42	1.86	2.27	1.29	1.66

Notes: All variables are expressed in per hour terms. Contributions of capital and labor to productivity are based on a capital share of 32 percent for the period 1899-1929 and 23 percent for 1929-41, identical to the figures used by Kendrick (1961: 285). Growth rates calculated with continuous compounding. Contributions may not sum to total due to rounding.

Sources: own calculations and Kendrick (1961: 333-5).

Table 2. *Industry Value Added as percentage of the PDE, United States, 1899-1941.*

Industry	Value added (percentage of the PDE)				
	1899-1919	1909-1919	1919-1929	1929-1941	1899-1941
Farming	13.1	11.4	9.8	8.2	10.5
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	0.7	0.7
Oil and Gas	0.4	0.5	0.7	0.9	0.6
Non-metals	0.4	0.3	0.3	0.2	0.3
Foods*	4.1	3.7	3.3	3.5	3.6
Tobacco	0.9	0.9	0.9	1.2	1.0
Textiles	1.9	1.9	1.9	1.9	1.9
Apparel	1.7	1.5	1.4	1.3	1.4
Leather Products	0.9	0.8	0.6	0.6	0.7
Lumber Products	2.3	1.8	1.3	0.8	1.5
Paper	0.5	0.5	0.6	0.7	0.6
Printing Publishing	1.4	1.6	1.8	1.7	1.6
Chemicals	1.0	1.1	1.2	1.4	1.2
Petroleum, Coal Products	0.6	0.9	1.3	1.3	1.0
Rubber Products	0.2	0.3	0.4	0.4	0.3
Stone, clay, glass	0.7	0.8	0.9	0.9	0.8
Primary Metals	2.7	2.6	2.5	2.4	2.5
Fabricated Metals	1.0	1.3	1.6	1.6	1.4
Machinery Non-Electric	2.3	2.2	2.1	2.0	2.2
Electric Machinery	0.4	0.7	0.9	1.1	0.8
Transport Equipment	1.0	1.4	1.9	2.1	1.6
Furniture	0.5	0.6	0.7	0.7	0.6
Miscellaneous	0.9	0.8	0.7	0.7	0.8
Electric Utilities	0.5	1.2	1.8	2.2	1.4
Manufactured Gas	0.1	0.2	0.2	0.2	0.2
Natural Gas	0.1	0.2	0.2	0.3	0.2
Construction*	5.5	4.9	4.4	3.4	4.5
Wholesale & retail trade*	13.9	13.9	14.0	14.6	14.1
Railroads	6.4	6.1	5.8	4.6	5.7
Local Transit	1.1	1.1	1.0	0.9	1.0
Residual Transport	1.1	1.3	1.4	1.8	1.4
Telephone	0.3	0.5	0.7	0.9	0.6
Telegraph	0.1	0.1	0.2	0.1	0.1
Post Office*	0.5	0.5	0.6	0.6	0.5
FIRE*	4.7	8.2	11.7	11.6	9.2
Spectator Entertainment*	0.4	0.5	0.5	0.6	0.5
Manufacturing	24.9	25.4	25.9	26.2	25.6
Great inventions	19.8	22.1	24.4	26.3	23.3
Aggregate measured sectors	75.1	77.9	80.7	78.8	78.2
Government sector	3.5	4.2	4.8	8.2	5.3
Residual sector	24.9	22.1	19.3	21.2	21.8

Notes: 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 = Finance, insurance & real estate.

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*	0.06	-0.06	0.26	0.41	0.18
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*	-0.36	-0.25	0.41	0.54	0.11
Spectator Entertainment*	0.21	0.77	0.30	0.24	0.37
Manufacturing	0.21	0.71	0.56	0.43	0.47
Great inventions*	0.25	0.62	0.29	0.24	0.35
Aggregate measured sectors	0.99	1.09	0.81	0.75	0.90
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. The Manufacturing, Great inventions, Aggregate measured sectors and PDE aggregates include the shift effect on labor quality of workers moving between sectors.
Source: own calculation, see text and Appendix D. Average annual growth rates calculated using continuous compounding.

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	1.1	2.5	0.7
Metals	1.0	1.8	3.4	0.6	1.6
Anthracite Coal	-0.5	0.1	-0.4	0.3	-0.1
Bituminous Coal	1.0	1.5	2.0	1.8	1.6
Oil and Gas	1.3	1.0	4.8	2.1	2.3
Non-metals	1.5	0.0	5.6	3.6	2.7
Foods*	0.5	-1.8	4.4	3.7	1.8
Tobacco	1.5	4.7	4.1	5.8	4.1
Textiles	0.7	0.4	2.4	3.3	1.8
Apparel	0.5	2.2	3.6	-0.4	1.4
Leather Products	0.6	0.3	2.7	-0.1	0.8
Lumber Products	-0.3	-1.5	2.1	-1.7	-0.4
Paper	1.7	-0.2	4.0	1.1	1.6
Printing Publishing	3.7	2.7	3.4	0.3	2.4
Chemicals	0.7	-1.1	6.8	2.1	2.1
Petroleum, Coal Products	0.5	-1.5	7.8	-1.1	1.3
Rubber Products	1.9	6.5	7.0	1.5	4.1
Stone, clay, glass	2.2	0.4	5.1	1.7	2.3
Primary Metals	2.6	-0.9	4.9	2.3	2.2
Fabricated Metals	2.3	1.4	4.1	1.3	2.2
Machinery Non-Electric	1.0	0.4	2.2	2.2	1.5
Electric Machinery	0.0	-0.1	3.1	4.7	2.0
Transport Equipment	1.2	6.7	7.6	3.6	4.7
Furniture	-0.5	-0.8	4.0	1.4	1.0
Miscellaneous	0.8	-1.0	3.9	1.6	1.3
Electric Utilities	5.0	7.6	2.3	5.2	5.0
Manufactured Gas	4.1	4.8	2.8	2.0	3.4
Natural Gas	0.1	1.0	-0.1	3.8	1.3
Construction*	4.3	-1.5	0.8	0.3	1.0
Wholesale & retail trade*	1.6	0.0	0.9	3.4	1.6
Railroads	1.8	2.9	1.3	2.6	2.2
Local Transit	1.0	2.2	3.6	0.4	1.7
Residual Transport	-1.3	1.4	6.7	5.6	3.2
Telephone	4.5	1.9	1.1	1.4	2.2
Telegraph	1.6	-1.3	4.4	0.9	1.3
Post Office*	1.4	2.5	0.1	0.8	1.2
FIRE*	0.7	-0.0	0.3	-1.4	-0.2
Spectator Entertainment*	4.0	10.8	3.2	4.4	5.5
Manufacturing	0.7	0.0	4.7	2.3	2.0
Great inventions*	1.4	1.0	2.7	3.2	2.1
Aggregate measured sectors	0.5	0.0	1.9	1.7	1.1
Residual sector	2.4	3.0	0.5	2.3	2.0
PDE	0.9	0.6	1.6	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	-1.8	-0.4	-1.7	-0.4
Maximum	5.0	10.8	7.9	5.8	5.5
Range	6.4	12.6	8.3	7.5	6.0

Notes: * = sector measured in this paper but not by Kendrick. Kendrick's aggregate measured sector comprises Farming, Mining, Manufacturing, Transportation, Communication & Public Utilities). 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). Growth rates calculated using continuous compounding.
Source: Kendrick 1961, 136-7; own calculations, see text, Appendices B and C (industry data), Appendix D (labor quality).

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

Industry	Intensive Growth Contribution (VA-share x TFP growth)				
	1899-1909	1909-1919	1919-1929	1929-1941	1899-1941
Farming	-0.031	-0.079	0.103	0.206	0.079
Metals	0.006	0.011	0.020	0.003	0.010
Anthracite Coal	-0.002	0.000	-0.001	0.001	0.000
Bituminous Coal	0.007	0.010	0.014	0.013	0.011
Oil and Gas	0.005	0.005	0.033	0.018	0.014
Non-metals	0.006	0.000	0.015	0.008	0.008
Foods*	0.022	-0.066	0.145	0.131	0.066
Tobacco	0.014	0.042	0.037	0.067	0.040
Textiles	0.014	0.008	0.046	0.062	0.034
Apparel	0.009	0.033	0.049	-0.006	0.020
Leather Products	0.005	0.002	0.017	0.000	0.006
Lumber Products	-0.008	-0.027	0.027	-0.014	-0.006
Paper	0.008	-0.001	0.024	0.008	0.010
Printing Publishing	0.054	0.043	0.060	0.005	0.039
Chemicals	0.007	-0.012	0.080	0.030	0.025
Petroleum, Coal Products	0.003	-0.014	0.103	-0.014	0.014
Rubber Products	0.004	0.020	0.028	0.007	0.014
Stone, clay, glass	0.016	0.004	0.045	0.016	0.020
Primary Metals	0.069	-0.024	0.122	0.054	0.056
Fabricated Metals	0.023	0.018	0.065	0.021	0.031
Machinery Non-Electric	0.024	0.010	0.048	0.044	0.032
Electric Machinery	0.000	-0.001	0.029	0.050	0.016
Transport Equipment	0.013	0.097	0.141	0.078	0.078
Furniture	-0.003	-0.005	0.027	0.010	0.006
Miscellaneous	0.007	-0.008	0.027	0.010	0.010
Electric Utilities	0.025	0.088	0.042	0.112	0.073
Manufactured Gas	0.005	0.007	0.005	0.004	0.006
Natural Gas	0.000	0.002	0.000	0.013	0.003
Construction*	0.239	-0.074	0.036	0.012	0.044
Wholesale & retail trade*	0.217	0.004	0.127	0.494	0.221
Railroads	0.116	0.177	0.076	0.119	0.123
Local Transit	0.012	0.024	0.037	0.003	0.018
Residual Transport	-0.015	0.018	0.094	0. 099	0.045
Telephone	0.014	0.010	0.008	0.012	0.014
Telegraph	0.002	-0.002	0.007	0.001	0.002
Post Office*	0.006	0.013	0.001	0.005	0.006
FIRE*	0.031	0.000	0.031	-0.158	-0.016
Spectator Entertainment*	0.016	0.050	0.017	0.025	0.027
Great inventions*	0.268	0.229	0.649	0.836	0. 494
Aggregate measured sectors	0. 345	-0.206	1.535	1.375	0.856
Residual sector	0.585	0. 668	0.096	0. 485	0. 438
PDE	0.930	0.642	1.631	1.861	1.294
Mean	0.025	0.010	0.047	0.041	0.031
Coefficient of variation	2.157	4.316	0.852	2.283	1.322

Notes: * = sector measured in this paper but not by Kendrick.
Source: derived from Tables 2 and 4.

Table 6. *Industries Ranked by TFP-growth and Intensive Growth Contribution, 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*	Tobacco	Wholesale and retail trade*	Spectator entertainment*	Wholesale and retail trade*
2	Telephone	Wholesale and retail trade*	Electric Utilities	Transport Equipment	Transport Equipment	Transport Equipment	Residual Transport	Farming	Electric Utilities	Railroads
3	Construction*	Railroads	Transport Equipment	Electric Utilities	Rubber Products	Wholesale and retail trade*	Electric Utilities	Foods*	Transport Equipment	Farming
4	Manufactured Gas	Primary Metals	Rubber Products	Spectator entertainment*	Chemicals	Primary Metals	Electric Machinery	Railroads	Tobacco	Transport Equipment
5	Spectator entertainment*	Printing Publishing	Manufactured Gas	Printing Publishing	Residual Transport	Farming	Spectator entertainment*	Electric Utilities	Rubber Products	Electric Utilities
6	Printing Publishing	FIRE*	Tobacco	Tobacco	Nonmetals	Petroleum, Coal Products	Natural Gas	Residual Transport	Manufactured Gas	Foods*
7	Primary Metals	Electric Utilities	Railroads	Apparel	Stone, clay, glass	Residual Transport	Foods*	Transport Equipment	Residual Transport	Primary Metals
8	Fabricated Metals	Machinery NonElectric	Printing Publishing	Local Transit	Primary Metals	Chemicals	Transport Equipment	Tobacco	Nonmetals	Residual Transport
9	Stone, clay, glass	Fabricated Metals	Post office*	Rubber Products	Oil and Gas	Railroads	Nonmetals	Textiles	Printing Publishing	Construction*
10	Rubber Products	Foods*	Apparel	Fabricated Metals	Foods*	Fabricated Metals	Wholesale and retail trade*	Primary Metals	Stone, clay, glass	Tobacco
11	Railroads	Stone, clay, glass	Local Transit	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	Fabricated Metals	Textiles
13	Telegraph	Telephone	Metals	Metals	Fabricated Metals	Machinery NonElectric	Farming	Chemicals	Primary Metals	Machinery NonElectric
14	Wholesale and retail trade*	Tobacco	Bituminous Coal	Bituminous Coal	Paper	Textiles	Primary Metals	Spectator entertainment*	Telephone	Fabricated Metals
15	Tobacco	Textiles	Fabricated Metals	Telephone	Furniture	Stone, clay, glass	Machinery NonElectric	Fabricated Metals	Railroads	Spectator entertainment*
16	Nonmetals	Transport Equipment	Residual Transport	Machinery NonElectric	Miscellaneous	Electric Utilities	Chemicals	Oil and Gas	Chemicals	Chemicals
17	Post office*	Local Transit	Natural Gas	Textiles	Apparel	Local Transit	Oil and Gas	Stone, clay, glass	Electric Machinery	Apparel
18	Oil and Gas	Apparel	Oil and Gas	Manufactured Gas	Local Transit	Tobacco	Manufactured Gas	Natural Gas	Foods*	Stone, clay, glass
19	Transport Equipment	Paper	Machinery NonElectric	Oil and Gas	Printing Publishing	Construction*	Bituminous Coal	Bituminous Coal	Textiles	Local Transit

20	Bituminous Coal	Miscellaneous	Stone, clay, glass	Wholesale and retail trade*	Metals	Oil and Gas	Stone, clay, glass	Telephone	Local Transit	Electric Machinery
21	Local Transit	Chemicals	Textiles	Stone, clay, glass	Spectator entertainment*	FIRE*	Miscellaneous	Construction*	Paper	Oil and Gas
22	Machinery NonElectric	Bituminous Coal	Leather Products	Leather Products	Electric Machinery	Electric Machinery	Rubber Products	Miscellaneous	Metals	Rubber Products
23	Metals	Post office*	Anthracite Coal	Natural Gas	Manufactured Gas	Rubber Products	Furniture	Furniture	Bituminous Coal	Petroleum, Coal Products
24	Miscellaneous	Metals	Nonmetals	Anthracite Coal	Leather Products	Miscellaneous	Telephone	Paper	Wholesale and retail trade*	Telephone
25	Textiles	Nonmetals	Wholesale and retail trade*	Nonmetals	Textiles	Lumber Products	Fabricated Metals	Nonmetals	Machinery NonElectric	Bituminous Coal
26	Chemicals	Leather Products	FIRE*	FIRE*	Electric Utilities	Furniture	Paper	Rubber Products	Apparel	Miscellaneous
27	FIRE*	Manufactured Gas	Electric Machinery	Electric Machinery	Machinery NonElectric	Paper	Telegraph	Printing Publishing	Telegraph	Metals
28	Leather Products	Oil and Gas	Paper	Paper	Lumber Products	Metals	Post office*	Post office*	Miscellaneous	Paper
29	Apparel	Rubber Products	Farming	Telegraph	Bituminous Coal	Leather Products	Metals	Manufactured Gas	Petroleum, Coal Products	Nonmetals
30	Foods*	Petroleum, Coal Products	Furniture	Furniture	Railroads	Spectator entertainment*	Local Transit	Metals	Natural Gas	Post office*
31	Petroleum, Coal Products	Telegraph	Primary Metals	Miscellaneous	Telephone	Nonmetals	Construction*	Local Transit	Post office*	Furniture
32	Natural Gas	Natural Gas	Miscellaneous	Chemicals	Farming	Bituminous Coal	Anthracite Coal	Telegraph	Furniture	Leather Products
33	Electric Machinery	Electric Machinery	Chemicals	Petroleum, Coal Products	Wholesale and retail trade*	Telephone	Printing Publishing	Anthracite Coal	Construction*	Manufactured Gas
34	Farming	Anthracite Coal	Telegraph	Primary Metals	Construction*	Telegraph	Leather Products	Leather Products	Leather Products	Natural Gas
35	Lumber Products	Furniture	Petroleum, Coal Products	Lumber Products	FIRE*	Manufactured Gas	Apparel	Apparel	Farming	Telegraph
36	Furniture	Lumber Products	Construction*	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	FIRE*	Lumber Products	FIRE*	Lumber Products
38	Residual Transport	Farming	Foods*	Farming	Anthracite Coal	Anthracite Coal	Lumber Products	FIRE*	Lumber Products	FIRE*
Rank order corr.	0.6		0.9		0.4		0.9		0.5	

Source: Tables 4 and 5.

Notes: * = sector measured in this paper but not by Kendrick. ‘Rank order corr.’ refers to the rank order correlation between TFP growth and the intensive growth contribution for each period.

Table 7. *TFP Growth in the Private Domestic Economy, United States, 1899-2007 (percent per annum).*

Period	TFP-growth (percent per annum)
1899-1909	0.93
1909-1919	0.64
1919-1929	1.63
1929-1941	1.86
1948-1960	1.98
1960-1973	2.21
1973-1989	0.48
1989-2000	0.97
2000-2007	1.44

Note: the post-war break points are chosen on the basis of NBER business cycle peaks. Following standard practice in the growth literature, we report growth rates using continuous compounding, and we have reported the post-war rates from the Bureau of Labor Statistics (BLS) also in this format in the table. The BLS computes its published official headline rate from its level data using discrete compounding. If we would use the latter method for the above table, there would only be small changes in the second decimal for selected periods: the rate for 1919-1929 then would become 1.64 percent per annum, that for 1929-1941 1.88 percent per annum, that for 1948-1960 and 1960-1973 would become 2.00 and 2.23 percent per annum, respectively, and that for 1989-200 and 2000-2007 would become 0.98 and 1.45 percent per annum, respectively.
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. *Measure of Our Ignorance: the ratio of TFP to Labor Productivity from Different Vintages, 1929-69 (percent of output per hour).*

	Ratio of TFP to Output per Hour (%)		
Period	BCW/BLS	Kendrick	Difference
1929-1941	75	92	17
1941-1948	55	69	14
1948-1960	60	71	11
1960-1969	68	75	7

Notes: Private Domestic Economy.
Sources: own calculation, Bureau of Labor Statistics, “Historical Multifactor Productivity Measures”, http://www.bls.gov/mfp/home.htm (October 2014), Kendrick (1961: 333-5), and Kendrick (1973: 243-4).

Table 9. *Deviations from Baseline TFP Growth Estimate for the Private Economy, 1929-1941, percentage-point per year.*

Treatment	Authors	Change (%-point p.a.)
Cyclical Adjustment	Field (2013)	0.43
Revised Cyclical Adjustment	BCW (2017)	0.17
Chain-Linked Output	Field (2013)	0.23
Revised Depreciation Rates	Gordon (2016)	- 0.18

Note: BCW (2017) refers to this paper. All rates based on the PNE except for the last rate, using revised depreciation rates, which is for the PDE.
Sources: Field (2013); own calculations (see text and Appendix tables C3 and C4); Gordon (2016).

Table 10. *Intensive Growth Contribution by Industry, as share of TFP growth in the PDE, 1899-1941, percent of total.*

	1899 1909	1909 1919	1919 1929	1929 1941	1899 1941
All other sectors	71	64	60	55	62
Great-inventions sectors	29	36	40	45	38
Of which:					
Rearranging molecules	2	0	15	2	5
Electricity	2	11	4	9	7
Internal combustion engine	22	16	19	32	24
Entertainment, comm. and information	3	8	2	2	3
Memorandum Item:					
Wholesale and retail trade	23	1	8	27	17

Note: 'All other sectors' refer to TFP growth in the PDE, minus the IGC for the great inventions sectors. The great inventions sectors are, respectively, for rearranging molecules: oil and gas mining, chemicals, petroleum and coal products, rubber products; for electricity: electric machinery, electric utilities; for the internal combustion engine: transport equipment, wholesale and retail trade, local transit; for entertainment, communication and information: telephone, spectator entertainment. To calculate the proportions of the four groups within the Great Inventions, it has been assumed that the effect on labor quality of workers shifting sectors was proportionate for each of the four constituent groups. Percentages may not sum to totals due to rounding. For further details, see the Appendix.

Table 11. *Regressions of TFP Spillovers from 'Great Inventions' for a Cross-Section of Industries in the United States, 1919-1941.*

	Regression (1)	Regression (2)	Regression (3)	Regression (4)
Period	1919 - 1929	1929 - 1941	1929 - 1941	1929 - 1941
Independent variable	Electric Horsepower per Hour	Electric Horsepower per Hour	Great Inventions Capital per Hour	Great Inventions Capital per Hour
Sector	Manu-facturing	Manu-facturing	Manu-facturing	PDE
Intercept	2.41***	-2. 60**	-3.27***	-1.36***
	(4.04)	(-2.42)	(-4.94)	(-2.76)
Coefficient	0.19**	-0.01	0.21*	-0.03
	(2.19)	(-0.04)	(1.85)	(-0.33)
R^2	0.22	0.00	0.17	0.00
Adjusted R^2	0.17	-0.06	0.12	-0.03
Observations	19	19	19	37

Notes: t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. 'Great Inventions Capital per Hour' refers to the services rendered by Great inventions capital per hour worked. The dependent variable for regression (1) is the acceleration in TFP growth from the period 1899-1919 to the period 1919-1929 (the latter growth rate minus the former). The dependent variable for regressions (2), (3) and (4) is the acceleration in TFP-growth from the period 1919-1929 to the period 1929-1941. These are derived from Table 4. The independent variables are based on the average rates of growth of the variable per hour worked for 1919-1929 for regression (1), 1929-1939 for regression (2) and 1929-1941 for regressions (3) and (4). Repeating regression (2) with as dependent variable the acceleration in TFP growth from 1919-1929 to 1929-1939 yields very similar and similarly insignificant results ($R^2 = 0.00$; results available from the authors). No capital services data was available for Spectator Entertainment, and therefore the industry was dropped from the PDE sectors.

Table 12. *Contributions to Growth of Labor Productivity, 1919-1941 (percentage-points per annum).*

		1919-1929		1929-1941	
		Manufacturing	PDE	Manufacturing	PDE
1	Labor productivity ((2) + (3) + (4))	5.45	2.36	2.61	2.48
	Contributions from:				
2	Labor composition	0.43	0.46	0.33	0.46
3	Capital deepening	0.29	0.27	-0.04	0.15
4	Total factor productivity ((5) + (6) + (7))	4.73	1.63	2.32	1.86
5	Great inventions TFP	1.46	0.65	0.58	0.84
6	Electricity & great inventions spillovers	0.60	0.16	0.79	0.21
7	Other TFP	2.66	0.81	0.95	0.81
	Contribution great inventions TFP to labor productivity ((5) + (6))	2.06	0.81	1.37	1.05
	Share contribution to LP (((5)+(6))/(1)) (%)	38	34	52	42
	Share contribution to TFP (((5)+(6))/(4)) (%)	44	50	59	56
	Memorandum Item:				
	Wholesale and retail trade TFP		0.13		0.49

Notes: The great inventions capital services represent flows from available stocks of Electrical Equipment, Electrical Instruments and Transportation Equipment in all industries. For the contribution to TFP growth, we take the great Inventions sectors to be identical to those listed in the notes to Table 11. For the period 1919-29 the share of capital in the PDE is assumed to be 29 percent and for the manufacturing sector it is 23 percent; for the period 1929-41 the capital share for both sectors are 23 percent (see Kendrick (1961: 285, 453)). Manufacturing TFP-growth includes redistribution effects (see the main text).The growth rates have been calculated using continuous compounding.

Sources: Labor productivity and capital deepening is from Kendrick (1961), Labor composition from Table 3 of this paper, Great Inventions TFP from Table 4 of this paper, Great Inventions spillovers based on Table 11 of this paper.

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 rates 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.

Government value added has been estimated using John Wallis’ (2006) estimate for 1902 of government expenditure, compensation of government employees and net interest paid by government and government surplus or deficit, as no estimate for 1899 itself was available (John Joseph Wallis, “Total government expenditure, by character and object: 1902–1995” in Carter et al. (2006), series Ea 14, 52, 53 and 59). All these values were then extrapolated back to 1899 using GDP-growth from Johnston and Williamson (2017), to arrive at an estimate of government value added for 1899. Then the value added of the Post Office for 1899 (see Appendices A1 and B3) was subtracted, to arrive at the government value added used in this paper to estimate the size of the private domestic economy. As a further coherence check of this estimate, the average ratio of government gross fixed capital consumption to government total labor compensation for 1929-1941 was taken from the National Income and Product Accounts, and it has been assumed that a similar ratio existed in 1902 and in the estimated 1899, which yielded an estimate of 1899 government value added as 3.0 percent of GDP, which was just marginally lower than the original estimate above of 3.1 percent of GDP, and gives further confidence in that (latter) estimate. In any case, the findings of this paper are not very sensitive to the difference between the two estimates.

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 two 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.

For the government sector, from the National Income and Product Accounts the 'Compensation of employees, general government, federal, state and local' (excluding 'Government enterprises', which are partially in our sector 'Post Office' and partially in our Residual Sector) and the 'Government consumption of fixed capital', excluding the lines for 'Government enterprises' have been taken to calculate government value added.

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.

The value added for the government sector 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 person-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 the 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 person-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 and Real Estate (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 (2015, 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 person-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.

B6. Foods

We needed to make an adjustment for the Food sector in order to combine Kendrick’s (1961) separate series for crude ‘Food’ TFP-growth and for crude ‘Beverages’ TFP-growth into one aggregate series for crude Food TFP-growth for 1899-1929 which is comparable with the NIPA data for 1929-1941.

From Fabricant (1940: 608-610), the weights for Beverages value added as share of total value added for Food for 1899, 1909, 1919 and 1929 have been taken to compute average weights for 1899-1909, 1909-1919 and 1919-1929. These weights have then been used to merge Kendrick’s separate series of crude TFP-growth. From the resulting rate then has been subtracted the labor quality growth in Food as reported in Table 3 to arrive at refined TFP-growth for Food for 1899-1929 that is comparable with the NIPA data for 1929-1941.

It should be noted that the resulting TFP-growth rate for Food masks two very different trends for ‘Food’ compared to ‘Beverages’ that was visible in the Kendrick crude TFP-growth rates, and this may have been the reason why Kendrick found it necessary to list the sectors separately. The disaggregated data show that TFP-growth in Beverages was massively negative (-5.6 percent per annum) in the 1910s, almost nil (-0.2 percent per annum) in the 1920s and massively positive in Kendrick’s 1930s (1929-1937) with 15.2 percent per annum, while crude TFP for Food shrank with only 0.4 percent per annum in the 1910s, grew with 5.3 percent per annum in the 1920s, and grew with only 1.5 percent per annum in the latter period (Kendrick 1961: 136). Our Foods sector, combining Kendrick’s ‘Food’ and ‘Beverages’, was by far the largest manufacturing sector in all sub periods, ranging from 1.2 - 1.6 times the next largest manufacturing sector. The end of Prohibition coincided with a massive 15.2 percent per annum growth of Beverages crude TFP between 1929 and 1937, and this clearly had a large pull on manufacturing TFP-growth as a whole.

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 C1 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 C1, 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 C1. *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*.

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

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.

$$N_{k,t} = \sum_{i=1}^{t} N_{i,k,t} \qquad \text{(C.2)}$$

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 C1).

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

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 $p_{k,t}^I$.[24]

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

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 C2 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

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[24] 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 C2. *Average Annual Rates of Growth of Capital Input, United States, 1929-1941, in percent per annum.*

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

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

Table C3 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. 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.[25]

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 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.

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

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 C3 and C4 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.

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 and no significant differences in 17 industries.[26]

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.[27] 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.

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

[27] 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	-0.5	-0.1
Leather Products	-0.1	-0.1	0.0	-0.1	-0.2	-0.1
Lumber Products	-1.7	-1.7	0.0	-1.7	-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	-0.2
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	2.3	0.0	2.3	2.0	-0.3
Fabricated Metals	1.3	1.3	0.0	1.3	1.2	-0.1
Machinery Non-Electric	2.1	2.2	0.1	2.2	2.0	-0.2
Electric Machinery	4.6	4.7	0.1	4.7	4.6	-0.1
Transport Equipment	3.6	3.6	0.0	3.6	3.4	-0.2
Furniture	1.4	1.4	0.0	1.4	1.4	-0.1
Miscellaneous	1.7	1.6	-0.1	1.6	1.4	-0.2
Electric Utilities	5.2	5.2	0.0	5.2	4.7	-0.4
Manufactured Gas	2.0	2.0	0.0	2.0	1.7	-0.3
Natural Gas	3.8	3.8	0.0	3.8	3.4	-0.4
Construction*	0.4	0.3	0.0	0.3	0.3	-0.1
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	5.6	0.1	5.6	5.6	0.0
Telephone	1.3	1.4	0.1	1.4	1.1	-0.2
Telegraph	0.8	0.9	0.0	0.9	0.7	-0.1
Post Office*	0.6	0.8	0.1	0.8	0.4	-0.3
FIRE*	-1.3	-1.4	0.0	-1.4	-1.8	-0.4
Spectator Entertainment*	4.4	4.4	0.0	4.4	4.4	0.0
Great Inventions*	3.2	3.2	-0.1	3.2	3.0	-0.2
Aggregate measured sectors	1.8	1.7	0.0	1.7	1.5	-0.2
Residual sector	2.7	2.3	-0.4	2.3	2.3	0.0
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	-1.7	0.0	-1.7	-1.9	-0.1
Maximum	5.8	5.8	-0.1	5.8	5.6	-0.2
Range	7.5	7.5	0.0	7.5	7.5	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	Intensive Growth Contribution (VA share x TFP growth)					
	Effect capital services			Effect variable retirement		
	Stock	Serv.	Diff.	SD	VR	Diff.
Farming	0.212	0.206	-0.006	0.206	0.179	-0.027
Metals	0.006	0.003	-0.003	0.003	0.001	-0.003
Anthracite Coal	0.001	0.001	0.000	0.001	0.001	0.000
Bituminous Coal	0.013	0.013	0.000	0.013	0.012	0.000
Oil and Gas	0.018	0.018	0.000	0.018	0.012	-0.006
Non-metals	0.008	0.008	-0.001	0.008	0.007	-0.001
Foods*	0.132	0.131	-0.001	0.131	0.123	-0.008
Tobacco	0.067	0.067	-0.001	0.067	0.061	-0.005
Textiles	0.063	0.062	-0.001	0.062	0.058	-0.004
Apparel	-0.005	-0.006	0.000	-0.006	-0.007	-0.001
Leather Products	0.000	0.000	0.000	0.000	-0.001	-0.001
Lumber Products	-0.014	-0.014	0.000	-0.014	-0.015	-0.001
Paper	0.008	0.008	0.000	0.008	0.007	-0.001
Printing Publishing	0.005	0.005	0.000	0.005	0.003	-0.002
Chemicals	0.031	0.030	-0.001	0.030	0.027	-0.004
Petroleum, Coal Products	-0.015	-0.014	0.001	-0.014	-0.020	-0.007
Rubber Products	0.007	0.007	0.000	0.007	0.006	0.000
Stone, clay, glass	0.017	0.016	-0.001	0.016	0.014	-0.002
Primary Metals	0.054	0.054	0.000	0.054	0.048	-0.006
Fabricated Metals	0.021	0.021	0.000	0.021	0.019	-0.002
Machinery Non-Electric	0.042	0.044	0.002	0.044	0.041	-0.003
Electric Machinery	0.049	0.050	0.001	0.050	0.049	-0.001
Transport Equipment	0.078	0.078	-0.001	0.078	0.073	-0.005
Furniture	0.010	0.010	0.000	0.010	0.009	0.000
Miscellaneous	0.011	0.010	-0.001	0.010	0.009	-0.001
Electric Utilities	0.112	0.112	0.000	0.112	0.102	-0.009
Manufactured Gas	0.004	0.004	0.000	0.004	0.003	-0.001
Natural Gas	0.013	0.013	0.000	0.013	0.012	-0.001
Construction*	0.013	0.012	-0.001	0.012	0.009	-0.003
Wholesale & retail trade*	0.509	0.494	-0.015	0.494	0.483	-0.011
Railroads	0.118	0.119	0.000	0.119	0.112	-0.007
Local Transit	0.004	0.003	-0.001	0.003	0.002	-0.001
Residual Transport	0.097	0.099	0.002	0.099	0.099	-0.001
Telephone	0.012	0.012	0.001	0.012	0.010	-0.002
Telegraph	0.001	0.001	0.000	0.001	0.001	0.000
Post Office*	0.004	0.005	0.001	0.005	0.003	-0.002
FIRE*	-0.156	-0.158	-0.003	-0.158	-0.207	-0.049
Spectator Entertainment*	0.025	0.025	0.000	0.025	0.025	0.000
Great Inventions*	0.851	0.836	-0.015	0.836	0.789	-0.047
Aggregate measured sectors	1.405	1.375	-0.029	1.375	1.198	-0.178
Residual sector	0.569	0.485	-0.083	0.485	0.481	-0.005
PDE	1.974	1.861	-0.113	1.861	1.679	-0.182
Mean	0.041	0.041	-0.001	0.041	0.036	-0.005
Coefficient of variation	2.290	2.283	-0.007	2.283	2.584	0.301

Minimum	-0.156	-0.158	-0.003	-0.158	-0.207	-0.049
Maximum	0.509	0.494	-0.015	0.494	0.483	-0.011
Range	0.665	0.653	-0.013	0.653	0.690	0.038

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 person-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 D1). 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 D1. *Average Annual Rates of Growth of Labor Quality, United States, 1899-1941, percent per annum.*

	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; this paper.

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.[28] Dropping the industry subscript *j* for ease of notation, the growth of labor input for industry *j* can thus be represented as

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

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

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

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

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[28] 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.

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

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.[29] These employment and compensation matrices can then be used to calculate labor quality on the basis of equation (D.5).

Educational attainment

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 D2) 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

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

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).[30]

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[29] 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.

[30] 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.

Table D2. *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 D2, 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 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.[31] 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

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[31] 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.

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 D2).

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 D2. 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 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 D3. Labor Income Estimates for Iowa and the United States, 1915, 1940 and 1950, Dependent Variable: Log of Labor 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

Notes: 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 D3 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 D3. 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 D3 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 D3 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 D3 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.

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

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 D4 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 D4 report the decomposition of labor quality growth based on the four remaining compensation estimates introduced in table D3.

Table D4. *Contribution to Labor Quality Growth for the Private Domestic Economy, United States, 1900-1950, in percent per 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

Note: May not sum to total due to rounding. Educ. = Education. Resid. = Residual.
Sources: see text.

The first row in table D4 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 D3). 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 D3.

The penultimate row in table D4 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 D4. 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

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