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Can general purpose technology theory explain economic growth? Electrical Power as a case study

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CAN GENERAL PURPOSE TECHNOLOGY THEORY EXPLAIN ECONOMIC GROWTH? ELECTRICAL POWER AS A CASE STUDY

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Abstract

Does the concept of General Purpose Technologies help explain periods of faster and slower productivity advance in economies? The paper develops a new comparative data set on the usage of electricity in the manufacturing sectors of the USA, Britain, France, Germany and Japan and proceeds to evaluate the hypothesis of a *productivity bonus* as postulated by many existing GPT models. Using the case of the diffusion of electrical power in the early twentieth century this paper shows that there was no generalized productivity boost from electrical power diffusion as postulated by many existing GPT models. The productivity gains from this GPT varied widely across economies and industries, suggesting that the power of GPTs to predict aggregate or sectoral growth is limited.

KEY WORDS: General Purpose Technologies, Economic Growth, Economic History, Productivity, Long Swings
JEL CLASSIFICATION: N11, N12, N13, N14, N60, O40

INTRODUCTION

This paper challenges the usefulness of General Purpose Technology (GPT) theory as a way of conceptualising the relationship between technological advances and long-term historical economic growth. We do this by concentrating on GPT theory's main and most intuitive claim: that the introduction of a GPT must have long-term positive repercussions on growth through a non-ephemeral shift in productivity.

To make our case we look at electricity diffusion in the early 20th century. Electricity is one of the very rare examples of a technology that is unanimously seen in the literature as an historical example of a GPT. The consensus is that in the early 20th century electricity diffusion improved aggregate productivity mainly by increasing labour productivity in the manufacturing sector. We therefore investigate the link between electricity diffusion and labour productivity in this sector where the effects of the new GPT should be more obvious and prominent. We start by looking at the quantitative record of the relationship between electricity diffusion and productivity in the long term in a comparative perspective by employing time-series quantitative methods to investigate the historical experience of a number of industrial countries beyond the US. We find that the result previously observed for the US of a strong relationship between electricity diffusion and long-term productivity increases cannot be readily extended to other countries. The claim to generality of the GPT theory seems substantially weakened by the fact that there are examples of countries in which electricity diffusion does not engender a positive shift in long term productivity.

Moreover, we complement this finding by investigating the micro-level mechanism that supposedly underpins the relationship between electricity diffusion and productivity. This mechanism is that the diffusion of electricity had considerable effects on aggregate productivity because it brought about substantial productivity increases in a countless variety of industrial processes and sectors (the 'general' part of GPT). To look at the relationship between electricity diffusion and productivity shifts at the micro-level we use the example provided by the UK manufacturing sector in the early 1930s. The UK Census of Production for 1935 is one of the few historical sources outside the US that provide extensive disaggregated data on output, labour input and electricity consumption by industrial sector. On the basis of this data we observe that the correlation between electricity diffusion and labour productivity is at best moderate and on many counts weak.

There are five steps to our analysis. In section 1 we review the literature. In section 2 we present our data providing quantitative evidence on electricity usage in the manufacturing sector on a per worker basis for five of the major industrial countries before WWII. In section 3 we use this macro data to show that, at the aggregate level, the national electricity diffusion paths were not necessarily associated with a *productivity bonus* in the manufacturing sector. This result challenges the heuristic power of the key empirical macroeconomic hypotheses of the GPT literature. In section 4 we use detailed disaggregated information on electricity consumption per worker and output growth contained in the UK Census of Production for 108 manufacturing industries for the years 1930 and 1935 to assess the nature, spread, and effects of the electricity diffusion process at the industry level. Again we fail to find unambiguous evidence of a clear relationship between electricity diffusion and surges in productivity. In section 5 we conclude by observing that the theory in itself is problematic as it gives undue emphasis to one dimension of the effects of technological innovation over productivity (the *width* of the diffusion process) while underplaying two other dimensions that are in principle equally important (the *depth* of the potential productivity benefits and the *rapidity* of the diffusion of the new technology). As such the theory provides an inaccurate description of historical economic growth.

1. GPT THEORY AND ELECTRICITY: A SURVEY

That technological change is an important determinant of modern economic growth is an idea that most economists would agree upon. However, the details of this relationship are less clear. In the last two decades a new way to conceptualise the relationship between technology and growth has emerged: the idea of General Purpose Technologies. GPTs are seen as infrequent but pervasive exogenous technological shocks able to generate low frequency (long-term) positive effects on economic growth by transforming the productivity potential of economies (Jovanovic and Rousseau, 2005; Aghion and Howitt, 2009).

To date much of the work on GPTs has been theoretical in nature, informing us of *possible* outcomes for economic growth but offering limited insights on *actual* historical economic growth. Working with fairly simple prototype models of GPTs a number of macroeconomic growth hypotheses have been accepted in the literature; for example, much of the early literature (Hornstein and Krusell 1996, Greenwood and Yorokoglu 1997), argues that the diffusion of a new GPT is correlated with a productivity slowdown in the early phase of the diffusion process, and *after some time* this is followed by productivity acceleration. As the title of a 1998 article by Helpman and Trajtenberg put it there would be “a time to sow and a time to reap".[1] Indeed it is these growth effects that make GPTs inherently different from other technological changes. As Helpman puts it:

> Growth that is driven by general purpose technologies is different from growth driven by incremental innovation. Unlike incremental innovation, GPTs can trigger an uneven growth trajectory, which starts with a prolonged slowdown followed by a fast acceleration.
>
> (Helpman, 2004, p. 51)

This idea can also be found in David (1991), in Bresnahan and Trajtenberg (1995), in Helpman and Trajtenberg (1998a and 1998b), in Aghion and Hewitt (1998)[2] and has been specified as a stylized fact of economic growth in the survey of GPTs by Jovanovic and Rousseau (2005, p. 1187) who state:

> But overall the evidence clearly supports the view that technological progress is uneven, that it does entail the episodic arrival of GPTs, and that these GPTs bring on turbulence and lower growth early on and higher growth and prosperity later. The bottom line is that with a wider body of data and fifteen more years of it than David (1991) had at his disposal, we confirm his hypothesis that Electrification and IT adoption are manifestations of the same force at work, namely the introduction of a GPT.

And yet GPT models are not univocal in their predictions of the effects of GPTs on productivity. For example the prediction of a *productivity slowdown* in the early stages of the arrival of a new GPT is not universally accepted, and part of the theoretical literature on GPTs casts doubts as to whether a slowdown is a necessary feature of describing the effects of a new GPT (Lipsey et al., 2005). The only feature that seems common to all GPT models (and has the most intuitive appeal) is that the introduction of a new GPT should eventually determine a productivity surge. Therefore, here we use the available data to evaluate the evidence only on the central claim of the GPT theory, that of a *productivity bonus*.

GPT models are, at present, simple thought experiments and have serious limitations when used to describe and explain historical economic growth. Lipsey et al. (2005, p. 384) review the literature as it developed since the early 1990s and argue that all models to date share the common problem that they deal with a complex historical economic system inappropriately, seeing shifts in the rate of economic growth as the outcome of a single GPT. In reality, at any point in time, change in the rate of economic growth will be an outcome of

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[1] This hypothesis follows David 1990.

[2] A similar argument is developed earlier by Phelps-Brown and Handfield-Jones (1952) as an application to the late 19th-century "climacteric" in Britain's economic growth.

the stock of GPTs at different stages of their life cycle, and as such, the link between a particular GPT and historical economic growth is not uniquely determined. So while episodic effects on economic growth are a reasonable research hypothesis, the expectation that they would generate long-term growth regularities or quasi-cyclical patterns in the shape of a productivity slowdown followed by a productivity surge is far more questionable.

In the last few years the GPT approach has come under growing attack. Joel Mokyr suggested that it can hardly be described as a theory and that its academic currency is on the wane (Mokyr, 2006). Alexander Field (2011) convincingly suggests that GPT theory has little heuristic power. Moreover he shows that the criteria commonly used by the literature to identify GPTs and to separate them from the rest of technical progress (what Helpman describes as incremental innovation) are at best subjective. But they are also flawed in the sense of being too restrictive and to exclude technological transformations likely to produce significant growth effects. Indeed the impossibility of effectively using the proposed criteria for GPT selection has led to the compilation of vastly subjective and heterogeneous lists of historical examples of GPTs. The heterogeneity of choice is such that only three GPTs appear in all the eleven compilations surveyed by Field. They are what Field calls the Big Three namely: (1) IT or ICT (or more specifically semiconductors, or computer, or Internet); (2) electricity; and (3) steam. These are indeed the three GPTs mentioned in the original article by David (1990) from which much of the GPT literature originates.

Field observes that steam has already been dealt a serious blow in its status as a GPT by Crafts and Mills (2004). Moreover, we note that it is very difficult to describe steam as a GPT as its application was restricted to an exceedingly small number of uses for the first half century after Newcomen's Dudley Castle Machine of 1712. Even after Watt invented the separate condenser, steam engine take-up remained for many decades slow and limited to a handful of uses (mostly mining). Similarly, the development of high-pressure steam engines in the first two decades of the 19th century did not expand steam use much beyond the realm of mining. It is only with the further advances in high-pressure technology and with the arrival of compounding in the 1840s and 50s, that steam can start to lay claims of generality in its use at least when it comes to textile production, metallurgy, land and, later, sea transport. Yet, even in 1870 two thirds of steam power was concentrated in coal-mining, cotton textiles, and metal manufactures (Crafts and Mills, 2004). In other words it took more than a century and a half for steam to become a GPT. The development of steam was so slow, its diffusion process so gradual, as to prevent any of the sudden accelerations and decelerations in growth and productivity that theory associates with GPTs.

This leaves GPT literature with only two agreed examples: ICT; and its historical antecedent: electricity. We concentrate on the latter. In particular we look at the diffusion of electricity in the manufacturing sector before World War II. The focus on the manufacturing sector is the result of evidence indicating that the acceleration in US labour productivity growth during the 1920s originated almost entirely in the manufacturing sector (David and Wright, 2003; Field, 2011). This surge in labour productivity in the manufacturing sector was common to all manufacturing industries and accounted for a substantial proportion of the increase in TFP observed in the first part of the interwar years. If there is a productive sector where the effects of electricity as a GPT on productivity should be magnified and easily detectable it is likely to be manufacturing.

To evaluate the hypothesis of a link between GPT and productivity growth we have built a new comparative data set of electricity diffusion in the manufacturing sector for the major industrial economies of the 20th Century – covering the US, the UK, France, Germany and Japan (the data is described fully in a Data Appendix to this paper)[3]. The selection of countries allows us to compare the experience of the US, as the technological leader, with the technologically 'relatively backward' economies of the early 20th Century.

David and Wright (2003) focus on the considerable acceleration of productivity growth in the US in the 1920s and associate this with a substantial increase in labour productivity and a concurrent fall in capital intensity in the US manufacturing sector. They see the upsurge in labour productivity as a direct result of the diffusion of electricity-based GPTs in production, and of the supply shock to the labour market caused by increasing restrictions on mass-immigration. Although David and Wright also consider the experience of Britain and Japan, they rely on a descriptive analysis of the diffusion of electricity in the manufacturing sectors for these economies[4].

To date the literature on the effect of electricity diffusion on aggregate output has mostly been based on a descriptive evaluation of historical productivity data. For example, David and Wright (2003) use Kendrick's productivity data to show the existence of a high growth phase in the 1920s. Jovanovic and Rousseau (2005) use ocular inspection of a Hodrick-Prescott trend of growth rates in output per man-hour to justify evidence of a

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[3] This is available from the authors.

[4] This leads David and Wright (2003, pp. 147-55) to argue that the use of electricity in manufacturing in Japan and Britain matched that of the US by the 1930s with similar productivity surges, suggesting that follower countries can accelerate the benefits of using the new technology. We show below that the quantitative evidence suggests that the US maintained its leadership position throughout the interwar period, even though Britain and Japan were diffusing the use of electricity in manufacturing rapidly in the interwar period.

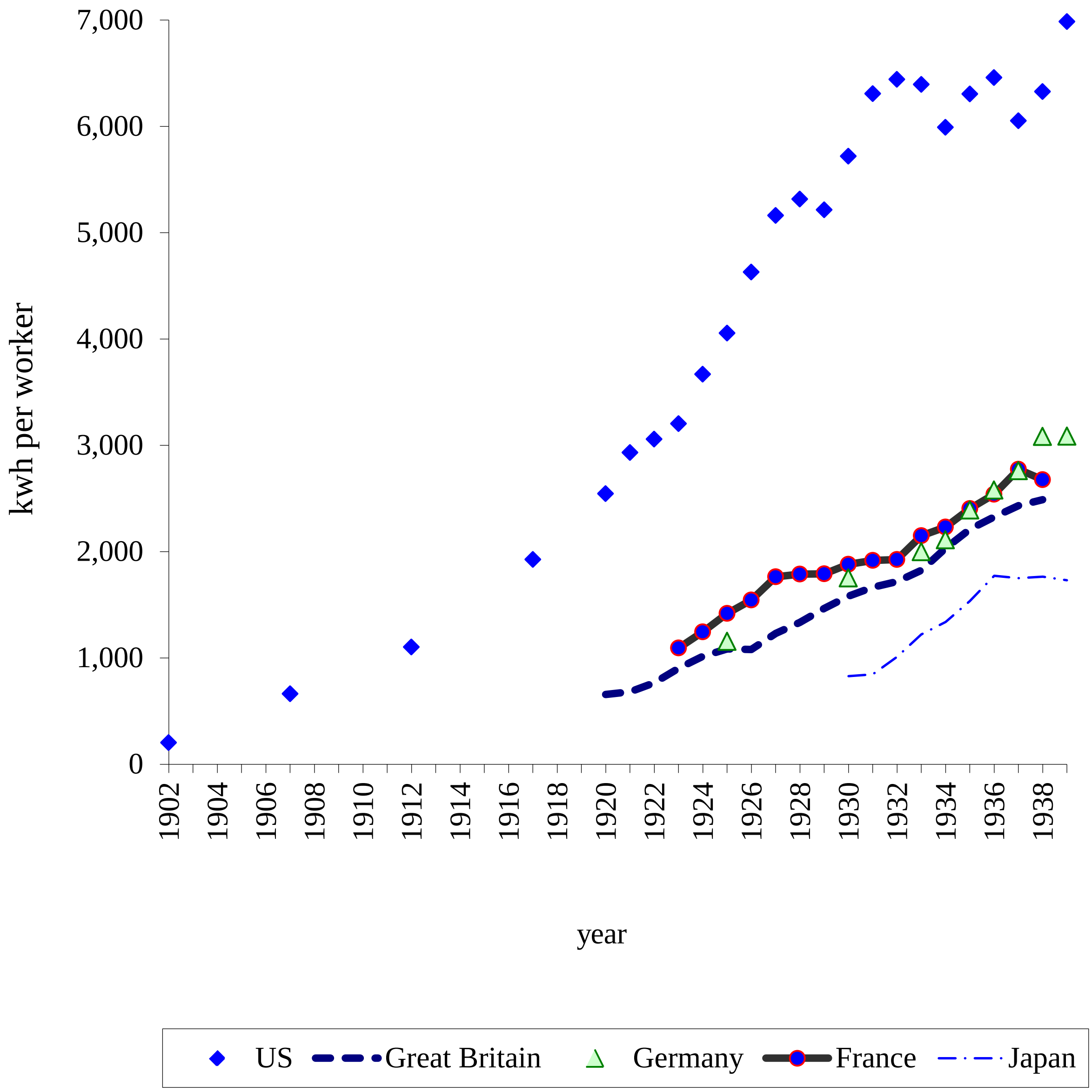
productivity bonus. Our aim is to use time series techniques to describe the trend movements of economic growth as a way of avoiding selection bias.

2. MEASURING THE ADOPTION OF ELECTRICITY IN THE MANUFACTURING SECTOR

The traditional indicator of the extent of electrification of production has been the capacity of primary electric motors. These are motors driven by electricity purchased from utilities and, therefore, not produced within the plant. An indicator of the extent of electrification of production in the manufacturing sector that is directly linked to labour productivity is the capacity (in *HP*) of primary electric motors per employee. Data on primary electric capacity is relatively easy to find, but it should be noted that such an indicator has serious drawbacks as a means of thinking about the effects of the electrification of production methods. Electric motors were not necessarily employed at the same rate across countries because of differences at the national level in the number and length of shifts over which industrial machinery is operated in one day. Moreover, the existence of secondary electric motors (those run on electricity produced within the industrial establishment), introduces a further element of confusion in the comparative exercise. A better and more direct way to assess the comparative contribution of the electrification of manufacturing processes to the growth of productivity is to use measures of electricity consumption per worker in the manufacturing sector. The total electricity consumed by the US manufacturing sector in *GWh* is available in the Department of Commerce (1975, series D130). From this and from the data on employment in the manufacturing sector (Kendrick, 1961) we have obtained the observations on the electricity consumed per employee in the US manufacturing sector that appear in Figure 1.

In order to be able to make international comparisons with the experience of the US we have constructed a similar data set for the total electricity consumed per employee in the UK, French, German and Japanese manufacturing sectors. A comparison of the consumption of electricity per employee in the manufacturing sector in these five countries is presented in Figure 1. This confirms that the adoption of electrical technologies in production was markedly delayed in the European core countries and Japan as compared to the US. The electricity consumed by each employee in the US manufacturing sector remained three times as high as that consumed by his/her European counterpart for much of the period, and fell below this threshold only in the last part of the 1930s Great Depression.

Figure 1. Consumption of electricity per employee in the manufacturing sector



Two key conclusions emerge from this new comparative data set. First, it is clear that the use of electricity in the manufacturing sector was far more extensive in the US than in the other major economies of the inter-war period. The lag between the leader and followers suggests that by the early 1920s the other economies had a comparable usage of electricity in manufacturing to that of the US around 1907. By the mid-1930s the follower countries had a comparable usage to the US in 1920. This result differs from the description of the diffusion of electricity in follower countries during the interwar period by David and Wright (2003) who claim that "...by the end of the 1930s the extent of diffusion of electric power in British manufacturing as a whole essentially matched that in the US."[5]

The quantitative comparative evidence suggests that the US managed to use more electricity per worker earlier than other countries and was able to sustain this lead even when other countries were making significant strides in diffusion in the inter-war period. The reason for the US lead in the use of electricity per worker is related to the rich resource endowment of the US, resulting in the relative cheapness of electricity. This in turn was due to the relative cheapness of thermal generation in the US, owing to the low price of the natural resources (oil and coal) employed. This hypothesis can be evaluated using census data for Britain and the US. In 1935 the British manufacturing sector was reported to have bought 7,100 *GWh* of electric energy at a cost of £ 23,570, 000. This meant that the average cost of a *KWh* for the British manufacturer was £ 0.00332 or 0.80*d* of the time.[6] At the prevailing exchange rate of $ 4.971 per pound (Mitchell 1988, p. 703) in 1935 the price of a *KWh* bought by the average British manufacturer was equal to $ 0.0165. As a term of comparison we observe that in 1929 and 1937 the average price paid by US manufacturers to acquire a *KWh* was $ 0.0127, and $ 0.0102 respectively.[7] This suggests that the price of electricity paid by British manufacturers in 1935 was ca. 50 per cent higher than that paid by their US counterparts. Given the strict correlation between the cost of electricity and the cost of its direct substitutes (coal, oil, etc.), this price differential indicates that sources of power *in general* were considerably cheaper in the US than in the UK. In turn, this should be a strong indication of the *energy intensive* nature of production in the US, provided that one takes the not entirely unreasonable view that other production inputs such as capital and labour were not substantially cheaper in the US than in the UK (Broadberry, 1997, p. 101). Indeed, there is strong evidence to suggest that the cost of labour relative to the cost of electric energy in manufacturing was at least twice as high in the US than in the UK, France, Germany and Japan for the duration of the second quarter of the twentieth century (Broadberry 1997, Table

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[5] David and Wright, 2003, pp. 149-50. As pointed out in Section 4 below, one way to reconcile this view with the evidence is that the use of electricity in the UK and Japan suggests a *widening* of use but the intensity and extent of use (measured as electricity per worker) was relatively low compared to the USA.

[6] Our calculation is made on the basis of the individual industry cost returns of the 1935 UK census of production. The original figures refer to electricity purchased and used, including electricity generated in other works under the same ownership.

[7] Our calculations are based on data from the 1939 US census of manufactures. Note that the data on the US *KWh* cost in manufacturing given by Broadberry 1997 in Table 7.5 p. 101 is mistakenly expressed in pence, while it should be expressed in US cents (see Melman 1956, p. 206). Also note that the Melman's calculations based on the electricity price paid by large manufacturers are very close to our calculations based on the more comprehensive census returns in the US case, and are substantially lower than for the UK (0.69*d* as opposed to our 0.80*d*).

7.5, p. 101 and Melman 1956, p. 206 and 213). We can only agree with Broadberry's remarks on the likely continuation of the effect of energy endowments on comparative labour productivity in the rest of the century (Broadberry 1997, p. 102).[8]

The second key feature of the new data set is that the major European economies shared a common experience in the adoption of electricity in the manufacturing sector, despite their differing stages of development and per capita income (Japan shared a similar trend from a lower level of electricity per worker). This common path of electricity adoption by the European countries provides an opportunity to evaluate whether any productivity effects also follow common movements.

3. A PRODUCTIVITY-BONUS FROM ELECTRICITY USAGE? TIME SERIES EVIDENCE

David and Wright (2003) see the upsurge in labour productivity growth in the USA during the 1920s as a direct lagged result of the diffusion of electricity-based General Purpose Technology in manufacturing production. This explanation for US economic growth in the 1920s is seen as a *first approximation* as they also stress the importance of other variables. To illustrate the extent of trend acceleration they use Kendrick's manufacturing sector productivity data to show the existence of a low growth phase during 1889-1913, compared to the 1920s. For most of the 1920s the rate of growth of labour productivity was clearly high, averaging 5 per cent per annum during 1920-29. Table 1 calculates the geometric growth rates for a number of long period comparisons. US labour productivity growth before 1913 displays as a series of long swings (Abramovitz 1961; 1968), representing periods of accelerated and retarded economic growth. The acceleration of growth rates observed during 1900-1913 relative to 1889-1900 is mainly cyclical in nature, comparable in magnitude to the acceleration of the 1880s.

[8] Abramovitz and David (2000, pp. 50-53) stress the fundamental importance of natural resource abundance in shaping the form, rate, and underlying technologies of US growth up to the first quarter of the twentieth century. They also maintain that natural resource abundance continued to play an important role in US growth in the rest of the century. In a similar fashion Wright (1990, p. 651) notes that '… the single most robust characteristic of American manufacturing exports was intensity in nonreproducible natural resources. In fact, their relative resource intensity was increasing over the half-century prior to the Great Depression.' Resource abundance characterises US industry as a whole in the last two centuries, and it is a necessary condition for many of the distinctively American industrial developments in this period (*ibid*. p. 653, and p. 661).

Table 1: Labour Productivity Growth in US manufacturing (per cent growth per annum)

	GROWTH RATE
1869-1879	0.72
1879-1889[9]	2.20
1889-1900	0.85
1900-1913	1.89

Clearly the 5 per cent growth rate observed in the 1920s is historically unprecedented even if compared only to high growth episodes in the past. This interpretation of US economic growth is supported by other research. Harrison and Weder (2009) stress the very high total factor productivity growth of the 1920s as evidence of a supply-side technology based explanation of high US economic growth. Although Field (2011) raises some doubts about the idea of GPT he agrees with the productivity bonus effects of electricity use in manufacturing during the 1920s.

To assess the magnitude of the productivity bonus we focus on describing the trend movements in labour productivity growth using a number of time-series techniques. Economic historians have described the cyclical path of the US economy before World War II as displaying a number of cycles of differing durations. The average period of the long swing fluctuations was around the 20-year frequency[10]. To analyse the extent of trend acceleration we use two models of time series decomposition that are able to deal with this cyclical structure (both methods are outlined in detail in the technical Appendix). First, we use the unobserved components time series model of Harvey (1989) to describe the trend in labour productivity once we model a short business cycle and a long-swing in the data. Although such a time-series structural model has the limitation of imposing a *specific* structure upon the data, it has the advantage of nesting two extreme specifications for the trend, the deterministic or trend-stationary model and the stochastic trend or `difference stationary' model. We also use the wavelet methodology to decompose labour productivity data into "approximations" and "details": approximations capture the high-scale, low-frequency (trend) components of the data; and the details are the low-scale (cyclical) components. The

[9] The pre-1889 data are based on the benchmark years of 1869, 1879 and 1889.
[10] Jones and Olken (2005) have described this feature of modern economic growth as "Start-Stop Growth", entailing large swings of growth within twenty-year intervals. Comin and Gertler (2006) have emphasised the importance of "medium-term business cycles". Although both these studies focus on the US experience after World War II, the pre WWII period displayed similar growth features.

major advantage of the wavelet method is that the non-parametric nature of the decomposition is able to capture the irregular nature of the period and amplitude of economic cycles and captures cyclical processes of different durations. The trend in the US labour productivity that results from these time-series models is depicted in Figure 2. Both decomposition methods yield similar trend lines; the proportional differences between the two trend lines mainly range around two per cent.

Another filter that is widely used in business cycle discussions is the Hodrick–Prescott filter. We use the trend estimate obtained with this filter as a robustness check on the trend descriptions that arise from our other two models (Unobserved Components, and Wavelet Methodology). Clearly, as is well known, the H-P filter retains much of the low frequency cyclical movements in the data within the trend component which explains the more cyclical-looking trend line. For the wavelet method and the Kalman filter structural model these low frequency movements have been explicitly decomposed in the trend-cycle decomposition. Hence, although the different filters display differences regarding the cyclical movements of the economy they all agree that the trend component of US labour productivity displays non-linear process with some trend-acceleration observed in the interwar period relative to the past. The movements of labour productivity in the manufacturing sector suggests that a productivity bonus is observed in the interwar period but the trend improvement is relatively mild compared to the large swings of growth observed in the 1920s and 1930s. Hence, there is evidence of a productivity bonus in two forms: first, there is some trend acceleration in the trend component of productivity growth[11]; second, the much higher cyclical volatility of the interwar data generated a high amplitude long swing in productivity during the 1920s and 1930s.

[11] As argued by Field (2011) it is important to consider the trend estimate for the USA up to the period 1941-2 if we are to get a sense of the longer term trend movements of the USA. Hence Figure 2 for the USA is displayed over a slightly longer period than the figures for the other countries which end in the 1930s.

Figure 2 : Trend Estimates in USA manufacturing Sector Productivity (1889-1941)

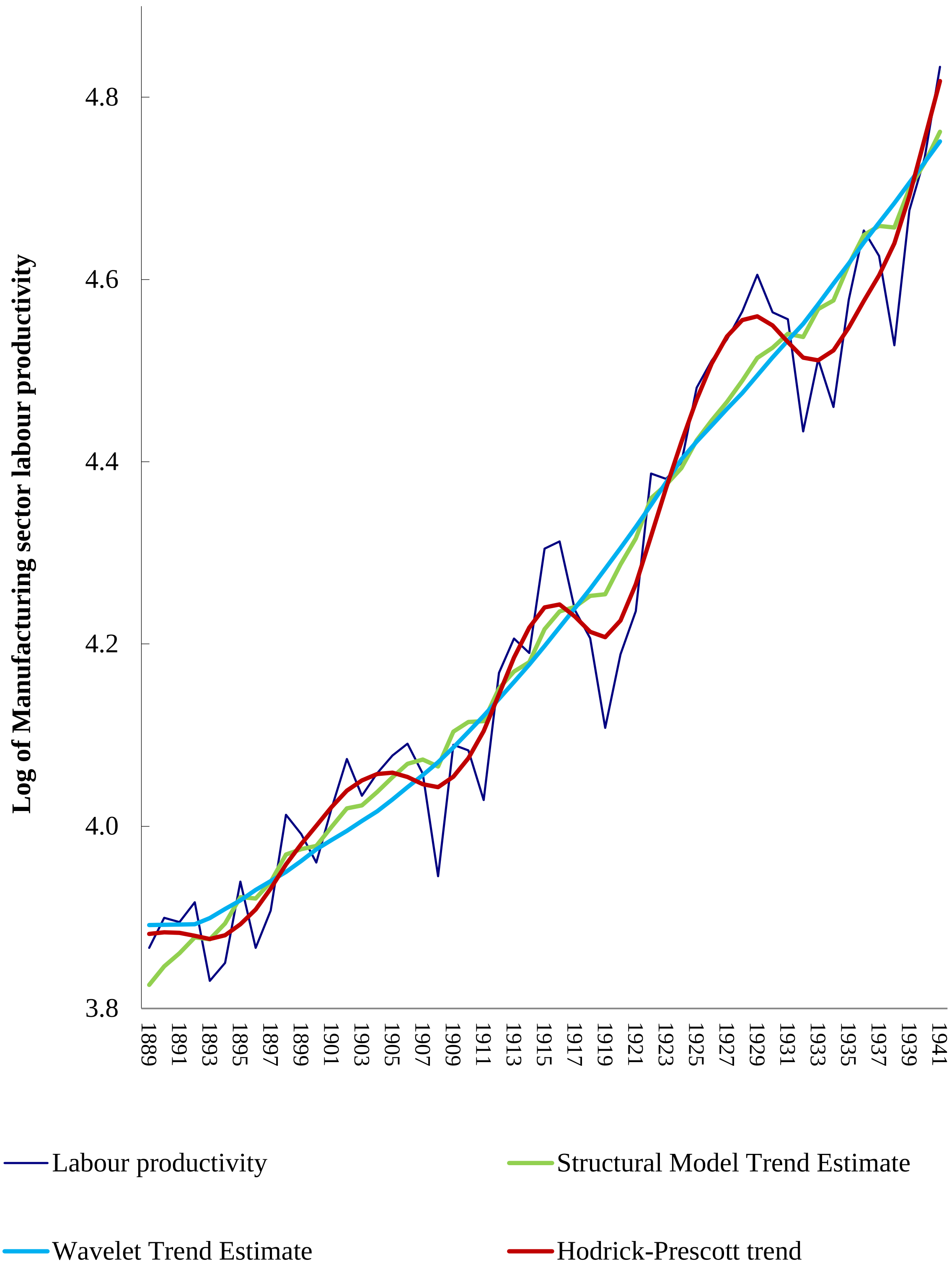


Figure 3 : Trend Estimates in UK manufacturing Sector Productivity (1869-1938)

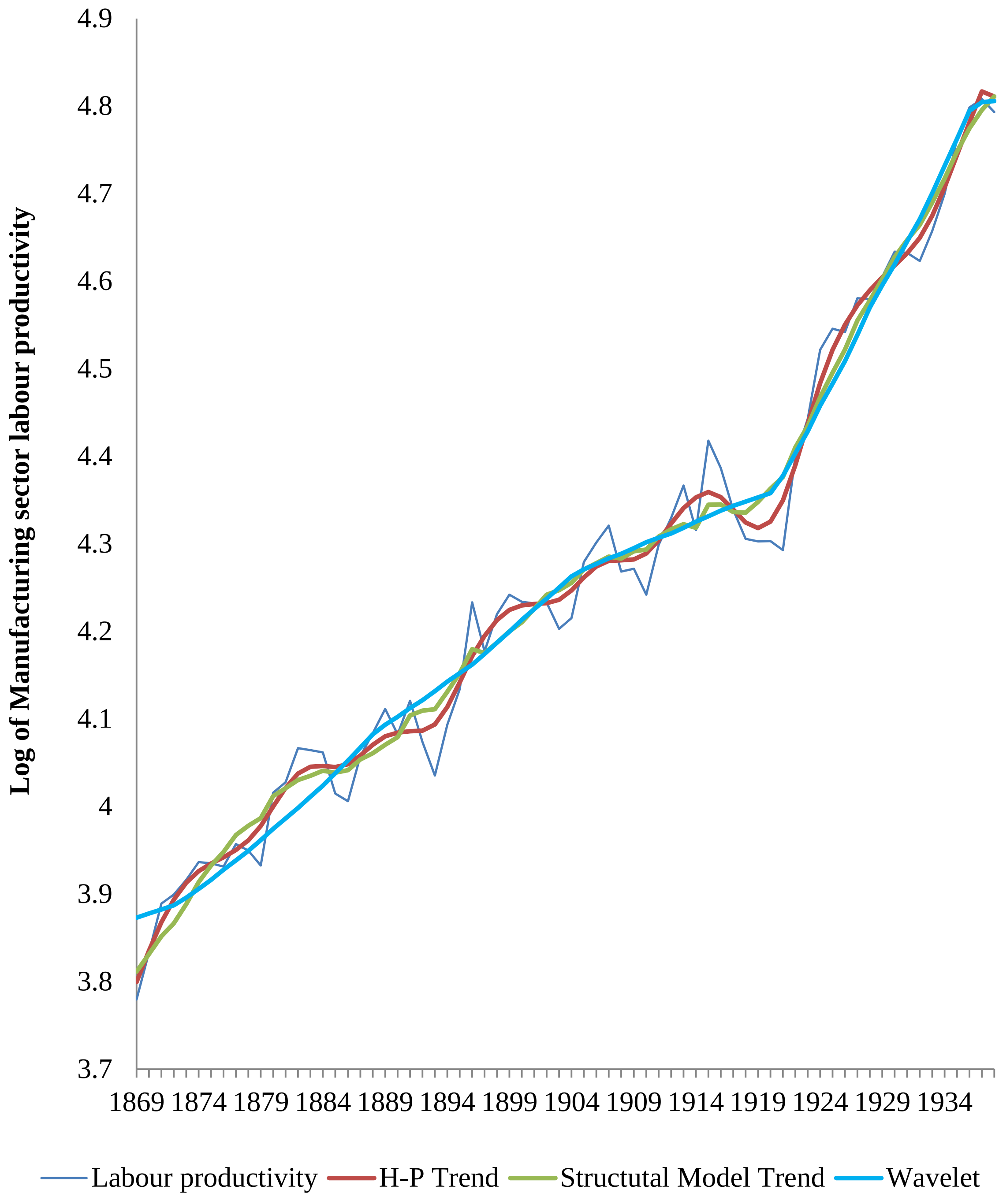


Figure 3 plots British manufacturing sector labour productivity together with the trend estimates from the structural time series model, the wavelet model and H-P filter. All three estimates of the trend performance of productivity in the manufacturing sector are agreed on the broad picture; the trend displays segmentation in the interwar period with a period of trend acceleration in productivity growth.[12] The major gain in manufacturing sector productivity growth begins in the 1920s and maintains momentum into the 1930s. Since the UK manufacturing sector productivity bonus is observed over the inter-war period as a whole this raises doubts about the ability of GPT theory to rationalise these trends as the UK began the 1920s well below the US in its level of electricity per worker. In light of the evidence for the diffusion of electricity usage in British manufacturing, it seems reasonable to conclude that the British manufacturing sector was also able to enjoy significant productivity gains from the adoption of electricity in manufacturing during the interwar period but that these effects on productivity came to fruition much more rapidly than implied by GPT theory.

This description of the trend performance of British industry differs from some existing analyses of inter-war growth trends. Greasley and Oxley (1996) describe a significant segmentation of the trend path of industrial output that was negative following the adverse shocks observed in 1920-1. The results presented above for manufacturing sector productivity suggest the opposite view is consistent with the evidence[13], with productivity growth making significant strides in the interwar period. Crafts (2011) has also postulated a pessimistic view on productivity growth, particularly for the 1930s. We find that the trend improvement in the manufacturing/industrial sector is a feature of the inter-war period as a whole. Crafts' thesis is that the supply-side policy framework of the 1930s was not conducive to rapid productivity growth. If this hypothesis is correct, then other variables must have had very large effects to compensate for this given the trend-acceleration path of industry-sector productivity.

An index for Japanese manufacturing sector labour productivity has been constructed on the basis of the employment data contained in Umemura *et al.* (1988), and of the output of the Japanese manufacturing industry over the period 1896-1940 taken from the Japanese historical national accounts (LTES) [14]. Figure 4 displays Japan's manufacturing sector labour

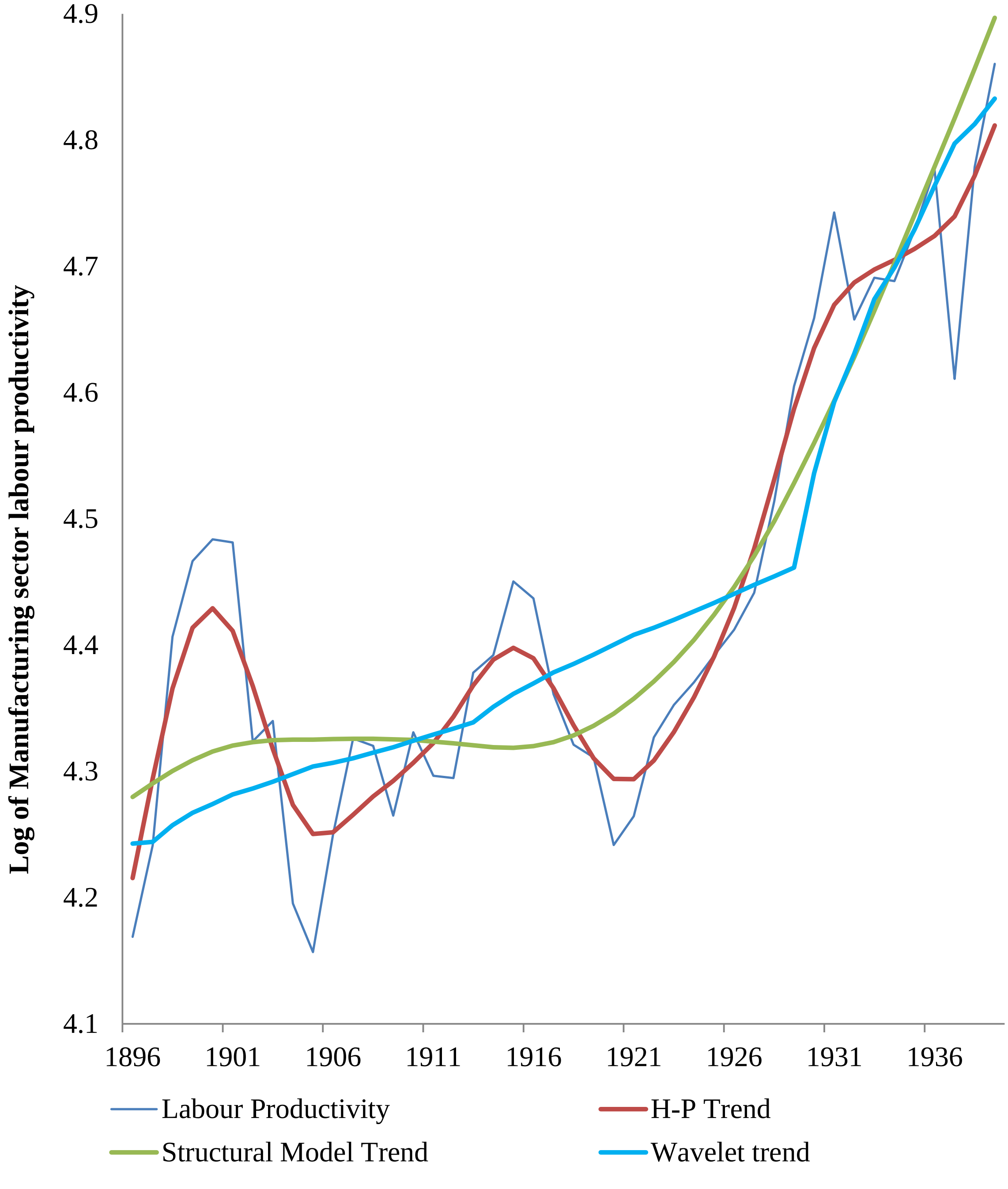
[12] This feature of the growth process is observed with simple descriptive statistics- over the period 1920-38 the mean growth rate of labour productivity doubled relative to the pre-1913 period.

[13] The path of manufacturing sector output and industrial production in general move one for one, suggesting that the differences between our results and the description of Greasley and Oxley is not due to compositional effects.

[14] The data overlap in 1919 and 1920 allowing us to scale the pre-1919 series to be comparable to the interwar series. The employment data were estimated on the basis of annual surveys of establishment with more than nine employees before 1919, of establishments with more than four employees for the period 1919 – 1937, and for all establishments from 1938 onwards. The extrapolation for the smaller establishments before 1938 and the

productivity: the growth rate averaged 1.72% per annum over the period 1896-1940 but labour productivity fluctuated significantly about trend. The three trend estimates for Japan are also presented in Figure 4. The existence of large swings in productivity growth in Japan makes the identification of trend breaks more difficult. Nevertheless, all estimates capture some acceleration in the interwar period, although the specific timing differs.

Figure 4 : Trend Estimates in Japan's manufacturing Sector Productivity: 1896-1938



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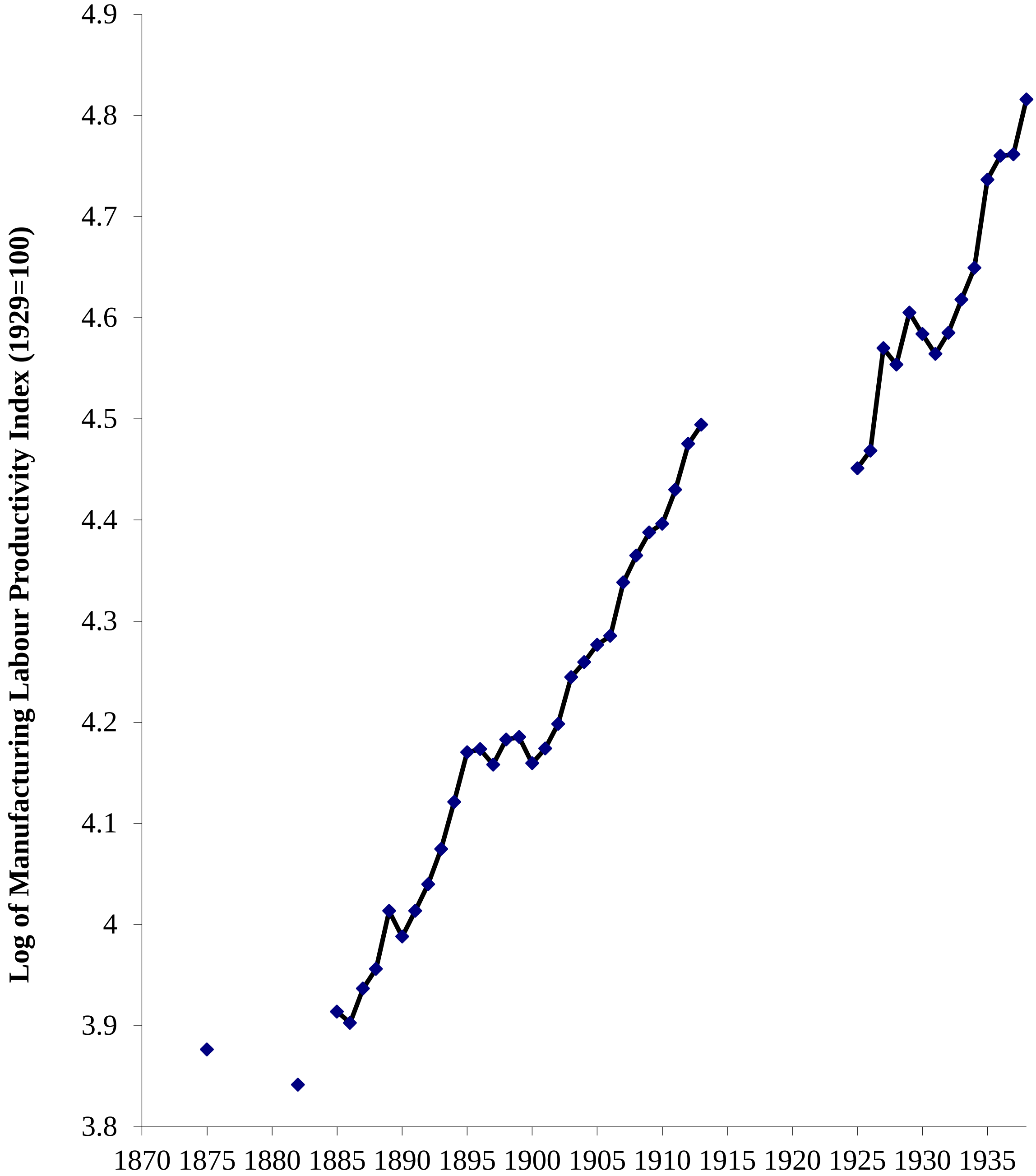
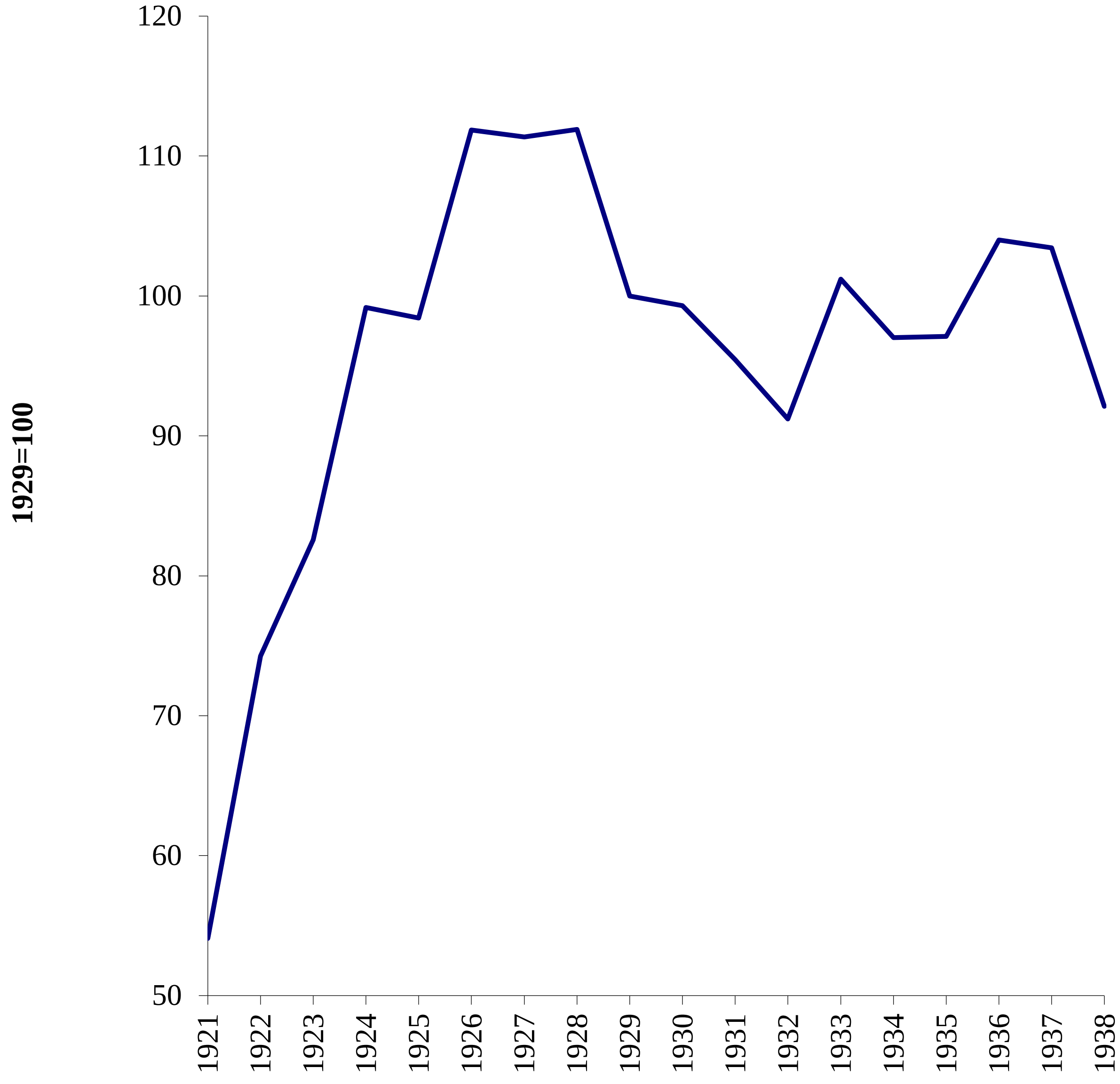
coverage of the State-owned establishments were originally obtained using industrial census information and more comprehensive local surveys when available.

Figure 5 : German Manufacturing Sector Labour Productivity 1875-1938



In the case of Germany the limited availability of annual data means that we cannot employ formal methods to derive an estimate of labour productivity trends. Instead we rely on descriptive statistics to build a picture from the available data. Figure 5 plots labour productivity in the German manufacturing sector on a logarithmic scale using annual data over the period 1885-1938 (there are gaps in the data series over the trans-war period 1914-24). Some benchmarked data for the period 1875-1885 also exist and is included for analysis. During the pre-1913 period labour productivity growth averaged 2.1% per annum over the period 1886-1913. Although the manufacturing sector's labour productivity growth rate over the inter-war period was higher - the growth rate of 1925-38 averaged 2.81% per annum, given the greater variance of interwar growth rates this difference in growth was not large enough to stand out as statistically significant. Hence, the productivity bonus observed in the USA, UK and Japan is absent in the case of Germany.

Figure 6: French Manufacturing sector Labour Productivity Index 1921-1938



In the case of France the availability of data to discuss pre-1914 trends is limited. Labour input data is available only for a few benchmarks observations between 1872 and 1911, which limits us to drawing inferences on the underlying trend.[15] The trend rate of growth of labour productivity growth in industry was below 1 per cent per annum during the period 1872-1911. For the interwar period we were able to build an index of manufacturing sector labour productivity for the period 1921-38.[16] This is presented in Figure 6. It is clear that during the 1920s labour productivity growth in French manufacturing displays high growth rates (representing a doubling of the pre-1911 trend growth rate). However, with the onset of depression in the 1930s, France enters a phase of stagnant productivity growth which extends throughout the lost decade of the 1930s. Summarising, whilst a productivity bonus is observed in the case of the USA, for the four remaining countries here considered things seem more complex. Although the UK, Japan, Germany and France share a common path of electricity diffusion in the manufacturing sector, their productivity growth paths differ. For Britain and Japan we observe trend acceleration spread out over the interwar period; for France productivity growth accelerates in the 1920s and stagnates in the 1930s; for Germany there is no trend acceleration. In light of these case studies the relationship between electricity as a GPT and productivity growth does not fit the stylized facts often found in the GPT literature, even as a first approximation to the growth process. This mixed comparative evidence should also act as a warning against seeing electricity as a GPT driving US economic growth over the interwar period.[17]

4. ELECTRICITY DIFFUSION AND PRODUCTIVITY: DISAGGREGATED EVIDENCE FOR THE UK IN THE 1930S.

Electrification is often seen as a GPT because its effects are seen to be pervasive in a multitude of industries. A GPT is seen as a yeast-like process that works itself across all industries. The disaggregated evidence for the USA reported in David and Wright (2003) suggests that this feature is important in understanding the productivity bonus of the 1920s. The data contained in the 5th Census of Production of the UK for the year 1935 allows us to observe electricity diffusion and productivity growth for another important case study. The

[15] Benchmark observations exist for 1872, 1876,1881,1886, 1891, 1901, 1906 and 1911. We thank Jean-Pierre Dormois for providing us with the available French labour productivity data.

[16] Using the labour input calculations for the manufacturing sector and assuming that the trends in industrial production display significant co-movements with those for the manufacturing sector.

[17] Field (2011) notes that whilst electricity may have been important to the productivity acceleration in US manufacturing during the 1920s a broader set of innovations determined productivity growth over the interwar period as a whole.

Census describes 108 main sectors in manufacturing.[18] In particular, Tables I.A, and IX detail employment, total consumption of electricity and net output at current prices, by the factories with more than 10 workers falling in each industrial category. Net output at current prices, has been traditionally transformed into net output at constant 1935 prices using price information from the censual data. Data availability for electricity consumption relates to two observation points, one in 1930 and the other in 1935. The data confirms that electricity is quickly diffusing in this period. There are only 11 sectors out of 108 in which the increase in electricity consumption is lower than the growth in labour input.[19] Similarly in more than two thirds of industries (79 out of 108) the increase in electricity consumption is above that in net output. The march of electrification in UK production seems nearly ubiquitous in the early 1930s. This confirms that electricity was diffusing extensively in British manufacturing during the 1930s and allows us to evaluate whether there is a marked positive correlation between growth in electricity consumption per worker and labour productivity as postulated by David and Wright for the American case (2003).

David and Wright's case that electricity diffusion would affect growth by markedly increasing labour productivity appears more tenuous for the British case. Columns 5 and 6 in Table A.1 in the appendix provide the rate of growth of labour productivity and of the consumption of electric energy per worker in the 108 sectors between 1930 and 1935. The correlation between these two is positive but weak ($r = 0.22$)[20]. These results suggest that the mechanism posited by David and Wright (2003), according to which the diffusion of electricity allowed for marked increases in labour productivity, was not at work in the British industry in the early 1930s.

If in this case electricity diffusion seems to be weakly correlated with increases in labour productivity it could be possible that it affected capital productivity and Total Factor Productivity. Unfortunately the 1935 UK Census of Production does not include independent observation on capital stocks. It is thus impossible to embark on a standard exercise in

[18] The 1935 Census of Production covers also industries from the mining, and building industries and production under State and local authority ownership. Given that the focus of our investigation is the manufacturing industry we have dropped these additional sectors. Moreover, the Census gives separate readings for net output and employment for two sectors: "Iron and Steel (Blast furnaces)"; and "Iron and Steel (Smelting and Rolling)". Yet, it amalgamates them into a single sector called "Iron and Steel (Blast furnaces and Smelting and Rolling)" when it comes to electricity consumption. Therefore we conflated also the data on output and employment for these sector into figures for "Iron and Steel (Blast furnaces and Smelting and Rolling)".

[19] They are: (1) Packing; (2) Umbrella and Walking Stick; (3) Shipbuilding; (4) Railway Carriage and Wagon Building; (5) Carriage, Cart and Wagon; (6) Fish Curing; (7) Petroleum; (8) Manufactured Fuel; and (9) Musical Instruments; (10) Sports Requisites; and (11) Coopering.

[20] The correlation between labour productivity increase (column 5) and the growth in electricity consumption (column 4) is weaker ($r = 0.15$).

growth accounting. Nevertheless we can use that framework to investigate whether electricity consumption affected a combination of capital input and TFP. Let us write a basic growth accounting equivalence in the following form:

$$(1) \qquad \frac{\Delta Y}{\mathrm{Y}} = \alpha \frac{\Delta K}{\mathrm{K}} + \beta \frac{\Delta L}{\mathrm{L}} + \gamma \frac{\Delta E}{\mathrm{E}} + TFP$$

Where: $\frac{\Delta Y}{\mathrm{Y}}$ is output growth; $\frac{\Delta K}{\mathrm{K}}$ is capital input growth; $\frac{\Delta L}{\mathrm{L}}$ is labour input growth; $\frac{\Delta E}{\mathrm{E}}$ is increase in electricity consumption; TFP is the total factor productivity and α, β, and γ are non-negative constants with α + β + γ = 1. $\frac{\Delta K}{\mathrm{K}}$ can be interpreted as investments not related to electricity. In line with conventional assumptions (see for example Harrison and Weder 2009, p. 366, or Field, 2011, p. 6) we set β = 0.7. This parameter is also consistent with the estimates of factor shares from Matthews *et al.* (1982) for the interwar UK economy. There are obvious caveats that apply to any standard Cobb Douglas type growth accounting exercise. Nevertheless this framework can be helpful in allowing us to summarize the implications of the data. In our case we do not observe $\frac{\Delta K}{\mathrm{K}}$ therefore we set:

$$(2) \qquad \alpha \frac{\Delta K}{\mathrm{K}} + TFP = \psi$$

A little manipulation yields for each of the 108 manufacturing sectors:

$$(3) \qquad \psi_i = \frac{\Delta Y_{\mathrm{i}}}{\mathrm{Y_i}} - 0.7 \frac{\Delta L_{\mathrm{i}}}{\mathrm{L_i}} - \gamma \frac{\Delta E_{\mathrm{i}}}{\mathrm{E_i}} \qquad \text{where } (i = 1, \ldots, 108).$$

This relationship allows us to investigate whether there is a strong positive correlation between large increases in the consumption of electricity and large residuals ψ_i . In order to calculate ψ_i we need to set a value for γ. The objective is that of providing an upper-bound estimation for the residual (which is a sum of the capital input and of TFP). In order to do so we need to dampen the adverse effect that a fast growth in electricity consumption in sector *i* would have on the residual in that sector by setting a low value for γ. We opt for a value of 0.1. Hence (3) becomes:

$$(4) \qquad \psi_i = \frac{\Delta Y_{\mathrm{i}}}{\mathrm{Y_i}} - 0.7 \frac{\Delta L_{\mathrm{i}}}{\mathrm{L_i}} - 0.1 \frac{\Delta E_{\mathrm{i}}}{\mathrm{E_i}}$$

This allows us to calculate a residual ψ_i for each sector (Column 7 in Table A.1 in appendix). Again we find a mild positive correlation (r = 0.57) between growth in the consumption of electricity on one side and the combined effect of TFP and weighted investments on the other.

Clearly neither of these calculations provides a good approximation, let alone an actual measure, of the correlation between electricity diffusion and TFP. The problem arises from the high likelihood of a strong correlation between investment activity and electricity consumption. We know that in this period new production capital was very likely to embody new electricity-related technology. It is thus very likely that a considerable part of the observed correlation between electricity consumption and the residual ψ_i is simply the result of the fact that increased consumption of electricity would require increased investments. To get a better sense of the relationship between electricity diffusion and TFP we must try to disentangle TFP from capital growth. A way to think around this problem is to assume that there would be no increase in electricity consumption without new investments in electricity-embodying capital, and there would be no investments in new productive capital that is devoid of an electricity component. Under this common, but somewhat arbitrary assumption the growth in electricity consumption comes also to represent growth in investments ($\alpha_i = 0$; $\beta_i = 0.7$; $\gamma_i = 0.3$) then we obtain the residual in column 9 of Table A.1 in appendix[21]. This approximation yields a weaker correlation ($r = 0.39$) which is probably a closer indicator of the actual correlation between electricity consumption and TFP.

The conclusion of this exercise is that, at this level of disaggregation (108 industrial sectors), in the UK, during the early 1930s, the effect of electricity diffusion on labour productivity growth is weak. Although the effect of electricity diffusion on a combined measure of Total Factor Productivity and growth of capital input is stronger than for labour productivity this is likely to be due in considerable measure to the strong correlation between investment activity and growth in electricity use. Without independent data on investment dynamics it is difficult to estimate the true TFP component of disaggregated growth. A rough approximation yields only a moderate correlation between electricity diffusion and sectoral TFP.

5. CONCLUDING REMARKS

Our examination of the relationship between electricity usage in manufacturing and productivity bonus in the manufacturing sector suggests that whilst a productivity bonus is

[21] Note that this is the implicit assumption commonly adopted in using HP increase as a proxy for investment in the 1930s, as in this period most of the increase in HP capacity is to do with new electrical installations.

observed in the case of the USA, for the four remaining countries here considered things seem more complex. Although the UK, Japan, Germany and France share a common path of electricity diffusion in the manufacturing sector, we observe heterogeneity in growth effects among them. For Britain, and to a lesser extent Japan, we observe trend acceleration spread out over the interwar period. As noted above, the similarity of trend acceleration in Britain and the USA in the 1920s is difficult to reconcile with a GPT perspective given the relative backwardness of the UK in the electricity diffusion process. Similarly, a GPT approach does not explain why, given a similar process of electricity diffusion the productivity path of the UK should differ so much from that of France where productivity growth accelerated only in 1920s but stagnated in the 1930s, and from that of Germany where there was no trend acceleration at all. In light of these case studies the relationship between electricity diffusion and productivity growth in manufacturing needs to be far more nuanced than is suggested by the stylized facts often found in the GPT literature. Clearly if GPT theory is meant as a first approximation to the growth process, there are potent second approximation effects capable of muddling and possibly obscuring any link between electricity usage and economic growth. Put it differently, the heterogeneity of growth movements in the major industrial countries of the 20th Century suggests that the role of technology diffusion can only be one of a number of important variables determining growth outcomes. The GPT literature has sought to find a link between technological innovation and growth by looking for evidence of trend acceleration in the time-scale of decades. However, it is clear that even within this timescale the determinants of productivity growth are not just technological. In our case the heterogeneity of the productivity paths of industrial countries may be explicable within a technological and a policy perspective. For example, France was able to gain a productivity bonus in the 1920s but was unable to do so in the 1930s under its membership of the Gold Bloc. Similarly although Germany was clearly diffusing electricity usage as fast as other countries the potential growth bonus was moderated by a sequence of adverse effects both in the 1920s and the 1930s.

Moreover, our investigation of the disaggregated effects of electricity diffusion among British industries in the early 1930s sounds further notes of caution over the heuristic power of GPT theory. We find that, although electricity was diffusing rapidly across British industries, the effect of electricity diffusion on labour productivity growth is weak.

Finally, our study of electricity as a GPT can be used in conjunction with other case studies to build a broader picture of GPTs and economic growth. Crafts and Mills (2004) examined the case of steam as a GPT in the 19th Century and found no evidence to support the macroeconomic hypotheses of the GPT framework when trying to explain British 19th-century economic growth. The failure of GPT theory to account for 20th Century growth suggests that caution is needed before we use GPT theory to explain historical economic growth. The bottom line is that the simplicity of GPT theory makes it an appealing theory of episodic growth but its simplicity is also its major weakness as a tool to investigate historical economic growth. Our analysis thus confirms the growing doubts about the usefulness of the concept of GPT. As Field observes, the GPT theory fails to unequivocally individuate more than three historical examples: steam, electricity, and ICT. Of these at least one (steam) is unlikely to have had much of a detectable effect on growth. The productivity bonuses associated with it seem to have taken such an inordinate amount of time to materialise (a century and a half after Newcomen's original invention) as to be quantitatively indistinguishable from the growth effects of a multitude of other technological changes of the 19th century. Our evidence on electricity supports the conclusions of Crafts and Mills (2004) that "the newfound enthusiasm for General Purpose Technology models of long run growth processes should not be taken too far".

The historical case studies of steam and electricity raise the broader question of whether GPT theory can be a theory of macroeconomic growth – the inability of GPT theory to account for the historical record of growth raises strong doubts. What are we left with? With a theory that suggests that GPTs are pervasive technological changes (of which there are few agreed examples), that might or might not produce productivity accelerations. Being pervasive they are more likely than other technological changes to produce effects at the macro level but there are also many examples of less pervasive technological changes that are equally transformational. Presumably less pervasive technologies could have big effects on aggregate productivity if their effects on the productivity of the few sectors affected are of a truly substantial magnitude (*depth* of the effect), and/or if their introduction is comparatively fast and easy (the *speed* of the diffusion process). So we are back to the old truism that big technological changes are going to produce noticeable effects on growth and productivity trends. In summary, we might need to demote GPT theory to a specific case of a more general and mundane relationship between technology and long-term growth according to which a big (not necessarily a pervasive) technological change will have big effects. If it was a small technological change it would be likely to have small effects. This is hardly news and hardly a theory and more in the realm of what the French would describe as a *lapalissade*.[22] Alternatively, GPT theory might be understood as suggesting that a GPT is, in fact, technological change that has all the characteristics of width (generality of diffusion), depth (substantial effects in terms of productivity) and speed (ease of diffusion). Being big, it would have big and detectable effects on long-term aggregate productivity. Unfortunately, should we accept this interpretation of GPT, we would find that there are no historical examples of such a transformative technology. The theory thus would be one that describes something that has never happened in the past. It is left to the reader to decide how useful an economic theory can be if it describes something that, albeit never experienced in the past, might, or might not, happen in the future.

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[22] The term *lapalissade* comes from ironical verses stating the utterly obvious referring to the French General Jacques de la Palice or la Palisse (1470 – 1525).

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APPENDIX

WAVELET TREND-CYCLE DECOMPOSITION[23]

Until recently the windowed Fourier transform (WFT) was the standard method used to detect cyclical components of time series in the frequency domain. The basic idea of the WFT is to break a time series into segments with a selected window function. The Fourier transform is applied to each segment separately.[24] The WFT produces a sequence of 'local' spectrums of the time series $x(t)$ along the time dimension. To assume stationarity and enhance the time information, one must use a short segment (window), which results in a poor frequency resolution. If one uses a long segment (window), frequency resolution improves to the detriment of time resolution, since it is difficult to know what frequencies occur at which time intervals. Clearly a major drawback of the WFT is that it uses a fixed window width to analyze economic time-series that display cycles of low and high frequencies and time-varying features.[25]

The wavelet transform is a new non-parametric method of decomposing nonstationary time series, which solves some of the problems of the windowed Fourier method. The wavelet transform uses a two-parameter family of function: time location (translation) parameter τ and scale parameter λ,

$$WT_x(\tau,\lambda) = \frac{1}{\sqrt{\lambda}} \sum_{t=1}^{N} x(t)\psi^*\left(\frac{t-\tau}{\lambda}\right) \qquad (1)$$

where $\psi^*(.)$ is the complex conjugation of the wavelet function $\psi[(t\text{-}\tau)/\lambda]$, the basis function in the wavelet transform. Wavelet algorithms process data at different scales or resolutions. The wavelet is dilated or compressed to extract frequency information from a time-series $x(t)$. The extent of dilation or compression is determined by the scale parameter λ, which is inversely related to the frequency of the wavelet.[26] Thus, in the wavelet transform, each frequency component is analyzed with a resolution appropriate for its scale.[27]

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[23] We would like to thank Weike Wu with helping us with this Appendix on wavelets.

[24] The windowing is accomplished via a weight function that places less emphasis on data near the interval's endpoints.

[25] Clearly this problem is highly relevant to long-run data analysis, when such changes are more likely to occur.

[26] This is similar to sinusoids. For example, the effect of the scale factor *a* in sine is:

f(t) = sin(t)	;	a = 1
f(t) = sin(2t)	;	a = 1/2
f(t) = sin(4t)	;	a = 1/4

Thus, for a sinusoid $\sin(\omega t)$, the scale factor a is inversely related to the frequency ω.

[27] Because the wavelet is scaled by λ, wavelet analysis is often called a time-scale analysis rather than a time-frequency analysis.

To extract time information, the wavelet transform is computed for each value of the scale parameter λ at different time location τ, similar to the WFT, from beginning to end of the signal $x(t)$. In contrast to the WFT, however, the window width of wavelet transform varies with frequency: the wavelet transform uses short windows at high frequencies and long windows at low frequencies. Thus, the difficult problem of determining an optimum window width is avoided.

Whilst the Fourier transform has a single set of basis functions, sines and cosines, the wavelet transforms have an infinite set of possible basis functions. The wavelet $\psi(t)$ is defined to satisfy the following properties: 1) it integrates to 0, which ensures that $\psi(t)$ is wave like, allowing us to extract frequency components around the trend. 2) It decays sufficiently fast and lasts through a finite period of time or space, in contrast to sine and cosine in Fourier transform, allowing us to obtain localisation in time.

Given a wavelet $\psi(t)$, the corresponding scaling function $\phi(t)$ can be defined to satisfy the following properties : 1) it integrates to 1, i.e. the scaling function is an averaging function; 2) it is normalised to have unit norm; 3) it is orthogonal to all corresponding wavelets; 4) it is orthogonal to its discrete translations; 5) at some scale, it can be obtained as a linear combination of itself at the next scale; 6) the wavelet can be obtained as a linear combination of dilates and translates of the scaling function. Thus, a pair of corresponding scaling function ϕ and wavelet function ψ can be used to represent the smooth trend (low-frequency) part and the detailed (high frequency) part of a signal respectively.

In calculating wavelet coefficients one approach is to use the so-called dyadic scales and time locations (translations): $\lambda = 2^j$ and $\tau = 2^j k$, where j and k are integers. Working with this discrete wavelet transform (DWT) gives efficient estimates, without loss of accuracy. The scaling function and wavelet function are given as:

$$\phi_{j,k}(t) = \frac{1}{\sqrt{2^j}}\phi\left(\frac{t-2^j k}{2^j}\right) \tag{2}$$

$$\psi_{j,k}(t) = \frac{1}{\sqrt{2^j}}\psi\left(\frac{t-2^j k}{2^j}\right) \tag{3}$$

As j (and scale parameter 2^j) increases, the function $\phi_{j,k}$ and $\psi_{j,k}$ get shorter, whereas the translation step (i.e. $2^J k$) gets larger. Thus, time-frequency/scale resolution is not constant but varies with frequency.

There are several types of wavelet functions available. The choice of the wavelet function to be used depends on the application, which requires a trade-off between properties such as smoothness, temporal location, frequency location, symmetry and orthogonality. The Haar, Daubechies, Coiflets and Symlet are four examples of wavelets:

1) The Haar wavelet is the first wavelet, proposed in the 1930s. It is a square wavelet. If a process exhibits discontinuous jumps, the Haar wavelet may be best suited for describing this behaviour. For studies of business cycles, however, the Haar wavelet is not appropriate, given the discontinuous nature of its waveform, which has poor allocation in frequency.
2) Daubechies is the most used family of wavelets. This is nearly symmetric and when the scaling function has the same number of coefficients as the wavelet function, it is orthogonal; otherwise, it is biorthogonal.[28] Daubechies' original paper shows that this wavelet is good for representing polynomial behaviour.
3) Coiflet is more symmetrical than the Daubechies wavelet. Whereas Daubechies wavelet has vanishing moments for the wavelet functions but not for the corresponding scaling functions, Coiflet has vanishing moments for both.
4) Except for the Haar system, no system of wavelet function and corresponding scaling function can be at the same time compactly supported[29] and symmetric. Nevertheless, for practical purposes (in image processing for example), one can try to be as close as possible. Symmlet is a result of this kind of effort.

Within each family of wavelets (such as the Daubechies family), wavelets are often classified by the number of vanishing moments, a stringent mathematical definition related to the number of nonzero coefficients, e.g. Daubechies 4, Daubechies 6, etc. With more nonzero wavelet coefficients, the functions become smoother, resulting in better frequency location but poorer time location.

Wavelets use a multiresolution decomposition (MRD) method. This means that a given time series $x(t)$, with finite variance, can be decomposed into different approximations at different scales. At the first level, $x(t)$ can be decomposed into two components: S_1 is the (smoothed) approximation of $x(t)$ taking into account the low frequencies of the signal and its resolution is half of $x(t)$, whereas the detail D_1 corresponds to the high frequency details of

[28] Classical wavelets require the filters to be orthogonal across both translation and scale, which gives a clean, robust system. In this case, however, the wavelet and scaling functions must have the same length and the length must be even. These restrictions prevent linear phase analysis, which is crucial in image processing. Biorthogonal wavelet is the result of relaxing the restriction of orthogonality.

[29] If a wavelet/scaling function vanishes outside of a finite interval, it has compact support, which is useful for local analysis.

$x(t)$ that are not in S_1. The decomposition process can be implemented recursively at different scales, i.e. successive approximations being decomposed in turn, so that $x(t)$ is broken down into many lower resolution components (e.g. $x(t)$ split into S_1 and D_1; S_1 split into S_2 and D_2; S_2 split into S_3 and D_3; …). MRD produces a family of hierarchically organized decompositions. In theory, the decomposition process can be iterated until the individual details consist of a single sample or pixel. In practice, the level chosen is based on a desired low-pass cut-off frequency. The detail component D_j is the discrepancy between two successive approximations S_{j-1} and S_j. As j increases, the resolution of D_j becomes poorer, which reflect the lower-frequency parts of the series.

$$x(t) \approx S_J(t) + D_J(t) + D_{J-1}(t) + \ldots + D_1(t) \qquad (4)$$

where J is the number of multi-resolution components or scales, and k ranges from 1 to the number of coefficients in the corresponding component. Of those, S_J denotes cycles with periodicity greater that 2^{J+1} periods (the "trend") and the D_j (j = 1, 2, …, J) captures cycles between 2^j and 2^{j+1}.

Mallat (1985, 1989) verified relationships between quadrature mirror filters, hierarchical algorithms[30] and orthonormal wavelet bases. Following Mallat's scheme, the approximation and details components in MRD are derived as,

$$S_J(t) = \sum_k s_{J,k}\ \phi_{J,k}(\mathrm{t}) \qquad (5)$$

$$D_j(t) = \sum_k d_{j,k}\ \psi_{J,k}(t) \qquad j = 1, 2, \ldots, J \qquad (6)$$

where

- J is the number of multi-resolution components or scales, and k ranges from 1 to the number of coefficients in the corresponding component;
- the functions $\phi_{J,k}$ and $\psi_{j,k}$ (j = 1, 2, …, J) are the approximating scaling functions and wavelet functions respectively
- the $s_{J,k}$ are called the smooth coefficients and the $d_{j,k}$ are called the detail coefficients, which represent the smooth trend of the data at the coarsest scale and the deviations at scale j (j = 1, 2, …, J) respectively. With discrete wavelets, they can be approximated as:

$$s_{J,k} = \frac{1}{\sqrt{2^J}} \sum_{t=1}^{N} \phi\left(\frac{t - 2^J k}{2^J}\right) \qquad (7)$$

[30] This is also referred to as a *pyramidal* algorithm.

$$d_{j,k} = \frac{1}{\sqrt{2^j}} \sum_{t=1}^{N} \psi\left(\frac{t - 2^j k}{2^j}\right) \qquad j = 1, 2, \ldots, J \qquad (8)$$

The number of coefficients at a given scale j is related to the width of the wavelet function. When the length of the data n is divisible by 2^J, there are $n/2^j$ coefficients $d_{j,k}$ at scale j (j = 1, 2, …, J). Similarly, at the coarsest scale, there are $n/2^J$ $s_{J,k}$ coefficients[31]. A strong output is given where the shape of $x(t)$ is closely matched by the shape of the chosen wavelet.

Thus, the multiresolution decomposition of expression (4) can be re-written as

$x(t) \approx \sum_k s_{J,}$

KALMAN FILTER STRUCTURAL MODEL OF TIME SERIES DECOMPOSITION

The Kalman filter structural model of time series decomposition we use is based on the work of Harvey (1985, 1989):

$$y_t = \mu_t + \psi_t + \varepsilon_t \qquad (1)$$

where

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \xi_{t-1} \qquad (2)$$

$$\beta_t = \beta_{t-1} + \nu_t \qquad (3)$$

$$\psi_t = (1 - \rho \cos \lambda L)\omega_t + (\rho \sin \lambda L)\omega_t^* / (1 - 2\rho \cos \lambda L + \rho^2 L^2)$$

where μ_t stands for the trend component of y_t; ξ_t allows the trend to shift up and down; ν_t accounts for shocks to the slope, β_t; ψ_t captures the cyclical regularities in y_t; L represents the lag operator; ω_t represents the shocks to the cyclical component; ε_t accounts for short-term erratic movements and possible measurement errors in y_t. ε_t, ξ_t, ν_t and ω_t are assumed to be mutually independent white noise processes, with ω_t^* arising by construction under the constraint that $\sigma(\omega) = \sigma(\omega^*)$; λ is the frequency of the cycle and ρ is the damping factor. The existence of short (high frequency) and long (low frequency) cycles makes it necessary to model a number of cycles simultaneously.

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[31] In total, there are $n(\sum_j 1/2^j + 1/2^J) = n$ coefficients, i.e. $\sum_j n/2^j$ detail coefficients and $1/2^J$ smooth coefficients.

Maximum likelihood estimates of the unknown parameters $\sigma_{(\xi)}$, $\sigma_{(v)}$, $\sigma_{(\varepsilon)}$, $\sigma_{(\omega)}$ and ρ can be obtained by the Kalman filter algorithm. The latter implements a set of recursive equations from given initial values of the parameters, which are successively updated in the light of every new observation (Harvey, 1989).

The model allows ξ and v to vary over time, this allows for the possibility that the trend may be deterministic over sub-periods, while possessing a significant stochastic component over the entire period. The model ultimately lets the data determine the shape of the trend and thus makes it possible to extract the cyclical component under a wide variety of possible trend specifications. The main advantage of this framework is that we can focus both on the nature of trend variations and the patterns of low frequency fluctuations *jointly* and independent of sample selection biases.

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Table A.1: UK industrial sectors from 1930 to 1935.

Trade (1)	ΔY/Y (2)	ΔL/L (3)	ΔE/E (4)	$\frac{\Delta(\frac{Y}{L})}{Y/L}$ (5)	$\frac{\Delta(\frac{E}{L})}{E/L}$ (6)	$\Psi_{1,i}$ (7)	$\Psi_{2,i}$ (8)	$\Psi_{3,i}$ (9)
Cotton Spinning and Doubling	0.25	0.04	0.08	0.31	0.13	0.21	0.22	0.20
Cotton Weaving	0.12	0.12	0.36	0.27	0.54	0.01	0.03	0.07
Woollen and Worsted	0.47	-0.05	0.52	0.40	0.44	0.45	0.44	0.35
Silk and Artificial Silk	1.24	-0.17	1.18	0.91	0.86	1.24	1.21	1.01
Linen and Hemp	0.15	0.03	0.29	0.16	0.34	0.10	0.11	0.04
Jute	0.60	0.16	0.87	0.90	1.22	0.40	0.43	0.22
Hosiery	0.53	-0.09	0.71	0.40	0.57	0.52	0.50	0.38
Textile Finishing	0.13	0.05	0.20	0.19	0.26	0.08	0.09	0.04
Lace	0.18	-0.05	0.36	0.13	0.30	0.18	0.17	0.11
Rope Twine, and Net	0.24	0.10	0.68	0.38	0.87	0.10	0.12	0.04
Canvas Goods, and Sack	0.24	-0.15	0.32	0.08	0.15	0.31	0.29	0.25
Asbestos Goods and Engine and Boiler Packing	0.37	-0.21	0.79	0.13	0.48	0.43	0.39	0.27
Flock and Rag	0.33	0.04	0.32	0.38	0.37	0.27	0.28	0.21
Elastic Webbing	0.39	-0.13	0.81	0.23	0.60	0.40	0.38	0.24
Coir Fibre, Horse-hair & Feather	0.19	-0.06	0.35	0.13	0.27	0.20	0.19	0.13
Roofing Felts	0.33	-0.31	1.00	0.02	0.53	0.45	0.38	0.25
Packing	0.03	0.08	-0.14	0.11	-0.07	-0.01	0.00	0.01
Fellmongery	0.34	-0.03	0.31	0.29	0.27	0.33	0.32	0.26
Leather (Tanning and Dressing)	0.26	-0.06	0.24	0.19	0.17	0.28	0.27	0.23
Leather goods	0.19	-0.18	0.17	0.01	0.00	0.29	0.26	0.26
Tailoring, Dressmaking, Millinery etc.	0.17	-0.12	0.64	0.04	0.46	0.19	0.17	0.07
Boot and shoe	0.27	-0.01	0.21	0.27	0.20	0.26	0.25	0.21
Hat and Cap	0.37	0.02	0.44	0.40	0.47	0.32	0.32	0.23
Glove	0.46	-0.41	1.22	0.04	0.58	0.63	0.55	0.38
Fur	0.80	-0.30	0.53	0.39	0.18	0.95	0.89	0.84
Umbrella and walking Stick	-0.09	0.24	-0.45	0.19	-0.28	-0.21	-0.16	0.12
Iron and Steel (Blast furnaces and Smelting and Rolling)	0.45	0.03	0.49	0.44	0.53	0.38	0.38	0.28
Iron and Steel Foundries	0.33	-0.20	0.61	0.11	0.34	0.41	0.37	0.29
Tinplate	-0.05	0.13	0.15	0.09	0.32	-0.16	-0.13	0.19
Hardware, Hollow-ware, Metallic Furniture and Sheet Metal	0.34	-0.18	1.39	0.14	1.03	0.33	0.29	0.05
Chain, Nail, Screw and Miscellaneous Forgings	0.16	-0.20	0.53	-0.04	0.27	0.24	0.20	0.14
Wrought Iron and Steel Tube	0.42	-0.10	0.37	0.29	0.25	0.45	0.43	0.38
Wire	0.56	-0.07	0.46	0.46	0.37	0.56	0.54	0.46
Tool and Implement	0.52	-0.14	0.30	0.33	0.14	0.59	0.56	0.53
Cutlery	0.97	-0.05	0.33	0.86	0.27	0.97	0.96	0.90
Needle, Pin and Metal Smallwares	0.23	-0.32	0.76	-0.07	0.34	0.37	0.31	0.22
Small Arms	0.21	-0.02	0.08	0.18	0.06	0.22	0.21	0.20
Mechanical Engineering	0.10	0.05	0.22	0.16	0.28	0.05	0.06	0.01
Electrical Engineering	0.57	-0.29	0.59	0.21	0.23	0.71	0.65	0.59
Shipbuilding	-0.40	0.39	-0.27	0.01	0.19	-0.65	-0.57	0.59
Motor and Cycle	0.62	-0.16	0.86	0.40	0.61	0.64	0.61	0.47
Aircraft	0.45	-0.64	1.64	-0.12	0.61	0.74	0.61	0.41

Railway Carriage and Wagon Building	0.06	0.12	0.10	0.20	0.24	-0.03	-0.01	0.05
Carriage, Cart and Wagon	-0.15	0.09	0.04	-0.07	0.14	-0.21	-0.20	0.22
Copper and Brass (Smelting, Rolling, etc.)	0.72	-0.12	0.90	0.53	0.69	0.72	0.69	0.54
Aluminium, Lead, Tin, etc. (Smelting, Rolling, etc.)	0.52	-0.22	0.06	0.25	-0.14	0.67	0.63	0.66
Gold and Silver Refining	-0.26	-0.24	0.55	-0.40	0.25	-0.14	-0.19	0.25
Finished Brass	0.25	-0.07	0.58	0.16	0.47	0.24	0.23	0.13
Plate and Jewellery	-0.02	-0.01	0.40	-0.03	0.39	-0.06	-0.06	0.14
Watch and Clock	1.94	-0.51	0.89	0.86	0.25	2.20	2.10	2.02
Grain Milling	0.65	-0.14	0.70	0.45	0.49	0.67	0.65	0.53
Bread, Cakes, etc.	0.46	-0.27	0.43	0.04	0.13	0.61	0.55	0.52
Biscuit	0.44	-0.22	0.75	0.18	0.44	0.51	0.47	0.36
Cocoa and Sugar Confectionery	0.39	-0.02	0.28	-0.19	0.25	0.38	0.37	0.32
Preserved Foods	0.26	-0.15	0.35	0.10	0.17	0.34	0.30	0.27
Bacon Curing and Sausage	0.72	-0.37	0.95	0.26	0.42	0.89	0.81	0.70
Butter, Cheese, Condensed Milk and Margarine	0.76	-0.24	0.38	0.43	0.12	0.89	0.84	0.81
Sugar and Glucose	-0.16	0.02	0.21	-0.14	0.24	-0.20	-0.20	0.24
Fish Curing	-0.17	0.26	0.18	0.12	0.59	-0.36	-0.31	0.40
Cattle, Dog and Poultry Foods	1.09	-0.44	2.25	0.45	1.25	1.18	1.09	0.73
Ice	-0.01	0.09	0.20	0.10	0.32	-0.09	-0.07	0.13
Brewing and Malting	-0.03	0.09	0.20	0.06	0.32	-0.12	-0.10	0.15
Spirit Distilling	0.82	0.11	0.26	1.04	0.41	0.71	0.73	0.66
Spirit Rectifying, Compounding and Methylating	0.52	-0.32	2.33	0.15	1.52	0.51	0.45	0.04
Aerated Waters, Cider, Vinegar and British Wine	0.51	-0.13	0.75	0.34	0.55	0.52	0.50	0.37
Wholesale Bottling	0.21	-0.10	0.83	0.11	0.66	0.20	0.18	0.03
Tobacco	-0.06	0.08	0.11	0.01	0.20	-0.13	-0.11	0.15
Chemicals, Dyestuffs and Drugs	0.62	-0.10	0.94	0.47	0.76	0.60	0.58	0.41
Fertiliser, Disinfectant, Glue, etc.	-0.02	-0.13	0.52	-0.13	0.35	0.01	-0.01	0.09
Soap, Candle and Perfumery	0.53	-0.08	0.35	0.41	0.25	0.55	0.53	0.47
Paint, Colour and Varnish	0.26	-0.17	0.60	0.08	0.37	0.32	0.28	0.20
Seed Crushing	1.21	-0.05	0.50	1.10	0.43	1.19	1.18	1.09
Oil and Tallow	0.50	-0.20	0.83	0.25	0.52	0.56	0.52	0.39
Petroleum	-0.45	0.26	0.07	-0.55	0.45	-0.64	-0.58	0.65
Explosives and Fireworks	0.20	-0.13	0.29	0.06	0.13	0.27	0.24	0.21
Starch and polishes	0.17	-0.10	0.40	0.07	0.28	0.20	0.18	0.12
Match	0.08	0.06	0.44	0.15	0.54	-0.01	0.00	0.10
Ink, Gum, and Typewriter Requisites	0.23	-0.24	0.54	-0.01	0.24	0.34	0.29	0.23
Rubber	0.39	-0.07	0.37	0.31	0.29	0.40	0.39	0.33
Scientific Instruments, Appliances and Apparatus	0.23	-0.19	0.73	0.04	0.45	0.29	0.26	0.15
Plastic Materials, Buttons and Fancy Articles	1.27	-0.66	2.12	0.37	0.88	1.52	1.39	1.10
Coke and By-Products	0.19	0.08	0.09	0.30	0.19	0.13	0.14	0.11
Manufactured Fuel	-0.10	0.37	0.02	0.67	0.62	-0.36	-0.29	0.37
Linoleum and Oil-cloth	0.76	0.03	0.52	0.81	0.57	0.69	0.69	0.58
Musical Instruments	-0.57	0.51	-0.54	-0.12	-0.07	-0.88	-0.77	0.77
Brush	0.30	-0.08	0.62	0.20	0.50	0.30	0.28	0.17
Games and Toys	0.50	-0.64	0.70	-0.08	0.03	0.88	0.76	0.75
Sports Requisites	-0.01	0.03	-0.03	0.02	0.00	-0.03	-0.02	0.02
Manufactured Abrasives	0.80	-0.26	0.84	0.43	0.46	0.90	0.84	0.73

Incandescent Mantles	-0.23	0.26	1.00	0.04	1.70	-0.51	-0.46	0.71
Cinematograph Film Printing	0.47	-0.33	0.80	0.11	0.35	0.62	0.56	0.46
Brick and Fireclay	0.42	-0.22	0.69	0.16	0.38	0.50	0.46	0.37
China and Earthenware	0.14	-0.01	0.63	0.13	0.61	0.09	0.08	0.04
Glass	0.41	-0.17	0.19	0.21	0.02	0.51	0.47	0.47
Cement	0.21	0.07	0.41	0.30	0.52	0.12	0.14	0.04
Building Materials	0.12	-0.06	0.29	0.06	0.21	0.14	0.12	0.08
Timber (Sawmilling, etc.)	0.34	-0.18	0.48	0.13	0.25	0.42	0.38	0.32
Furniture and Upholstery	0.23	-0.19	1.16	0.03	0.82	0.25	0.21	0.02
Coopering	-0.10	0.17	-0.07	0.08	0.12	-0.21	-0.18	0.20
Cane and Wicker Furniture and Basketware	0.19	-0.17	1.25	0.02	0.93	0.18	0.15	0.07
Wooden Crates, Cases, Boxes, and Trunks	0.09	0.05	0.40	0.15	0.48	0.02	0.03	0.06
Paper	0.60	-0.12	0.66	0.43	0.49	0.62	0.59	0.48
Wallpaper	0.35	-0.06	0.22	0.28	0.15	0.37	0.36	0.33
Printing, Bookbinding, Stereotyping, Engraving, etc.	0.04	0.00	0.54	0.05	0.55	-0.01	-0.01	0.12
Manufactured stationery	0.43	-0.18	1.03	0.21	0.71	0.45	0.41	0.24
Printing and Publication of Newspapers and Periodicals	0.09	-0.11	0.27	-0.02	0.14	0.14	0.12	0.09
Cardboard Box	0.46	-0.24	0.71	0.17	0.38	0.56	0.51	0.41
Pens, Pencils, and Artists' Materials	0.07	0.00	0.23	0.07	0.23	0.05	0.05	0.00

Sources:
Output: Recalculated on the basis of censual data on Net Output from the 1935 Census of Production (for the methodology see: Bowley, Schwartz, and Rhodes 1938, pp. 1-2 and pp. 24 - 31);
Labour input: from "Average number of persons employed (excluding out-workers)" in Table I.A of the 1935 Census of Production;
Electricity Consumption: "Electricity consumed – Total" in Table IX of the 1935 Census of Production

DATA APPENDIX: SOURCES AND METHODS

1. Great Britain

1.1 Estimates of Electricity consumption in the manufacturing sector

From the industrial production census data for 1930, 1935, and 1948 we derive the consumption of purchased electricity by the manufacturing sector in ***GWh***. This can be compared with the data for the sales of electricity to industry (Ministry of Power, *Statistical Digest 1967*, Table 85, p 140). This shows that over time the consumption of electricity by the manufacturing sector accounted for an increasing share of the total sales of electricity to industry. We assumed that the rate of increase of the ratio of consumption to sales was constant between 1918 and 1935, and between 1935 and 1948. Using this assumption and using the dynamic implicit in the sales data, we recalculated a series of the consumption of purchased electricity by the manufacturing sector for the years 1920 – 1948 which is consistent with the census observations. This is reported in table A1, column ***k***. We then calculated the ratio between the census data for the consumption of purchased electricity by the manufacturing sector and the census data for the total consumption of electricity by the manufacturing sector. We then assumed that the rate of increase of this ratio was constant between census observations. We also assumed that the data from the 1912 census of production on the capacity of electric motors in the manufacturing sector driven by purchased electricity as a proportion of the capacity of all the electric motors in the manufacturing sector reflected the ratio between the purchases of electricity and the total consumption of electricity in the manufacturing sector in the same year. Under this assumption we were able to extend backward to 1912 the series for the ratio between consumption of purchased electricity and the total consumption of electricity. The resulting series is in table A1, column ***j***. Using this series and the estimated series for the consumption of purchased electricity by the manufacturing sector, we were able to construct a series for the consumption of electricity in the manufacturing sector for Great Britain (Table A1, last column).

1.2 Employment in the manufacturing sector

We combined census data on employment with Broadberry's index for employment in the manufacturing sector (Broadberry 1997, Table A3.1(a), pp. 43 – 44) to obtain our series on employment in the manufacturing sector. We interpolated the missing data for the period of the First World War using the same method of backward chaining used by Broadberry 1997 for his output figures. In practice this meant observing that the figure for 1920 in Broadberry's index of Employment in manufacturing (1929 = 100) equals 110.5 and is obtained using Feinstein (1972) figure for employment in the British manufacturing sector *excluding Southern Ireland*. In column ***(b)*** of table A2 we rebased the figures for the years 1913 - 1919 for Civilian Employment in Britain *including Southern Ireland* contained in Feinstein 1972, Table 57. We compared the 1913 index number for 1913=105.8 in column ***(d)*** and the original figure in the Broadberry index which was 102.2 [note that column ***(d)*** is obtained by chaining backward Broadberry's index for 1920 using the war-year figures from column ***(c)***]. We thus scaled down each war-year figure linearly so as to force the figure for 1913 to be 102.2. The resulting index is presented in Table A2.

Table A1: Consumption of electricity in Great Britain's manufacturing sector.

	Sales of electricity to industry (GWh).	Manufacturing sector - Consumption of electricity (GWh).			Consumption of purchased electricity by the manufacturing sector / sales of electricity to industry		Purchased/total			Consumption of purchased electricity by the manufacturing sector (GWh - our estimate).	Consumption of electricity - manufacturing sector (GWh - our estimate).
	Great Britain	Purchased	Generated	Total		Estimated	censual data	1912 census capacity figures	Estimated	Great Britain	Great Britain
	a	*b*	*c*	*d*	*e=b/a*	*f*	*g=b/d*	*h*	*j*	*k = a×f*	*l = k×j*
1912						0.733		0.474	0.474		
1913						0.737			0.478		
1914						0.741			0.483		
1915						0.745			0.487		
1916						0.748			0.492		
1917						0.752			0.497		
1918						0.756			0.501		
1919						0.760			0.506		
1920	2,545					0.763			0.510	1,942.6	3,806.2
1921	2,081					0.767			0.515	1,596.2	3,099.7
1922	2,456					0.771			0.520	1,893.1	3,643.6
1923	2,989					0.775			0.524	2,315.1	4,416.9
1924	3,435					0.778			0.529	2,673.5	5,056.3
1925	3,709					0.782			0.533	2,900.6	5,438.7
1926	3,592					0.786			0.538	2,822.6	5,247.3
1927	4,375					0.790			0.542	3,454.2	6,367.3
1928	4,762					0.793			0.547	3,777.6	6,905.0
1929	5,318					0.797			0.552	4,238.6	7,683.3
1930	5,355	4,288.2	3,420.0	7,709.0	0.801	0.801	0.556		0.556	4,288.2	7,709.0
1931	5,282					0.805			0.558	4,249.5	7,618.1
1932	5,518					0.808			0.559	4,460.1	7,973.2
1933	6,073					0.812			0.561	4,931.4	8,791.3
1934	7,060					0.816			0.563	5,759.4	10,238.7
1935	7,853	6,435.7	4,973.7	11,409.4	0.820	0.820	0.564		0.564	6,435.7	11,409.4
1936	8,914					0.826			0.582	7,362.4	12,653.5
1937	10,019					0.832			0.600	8,339.4	13,907.7
1938	10,320					0.839			0.617	8,656.2	14,020.3
1939	11,672					0.845			0.635	9,865.2	15,531.2
1940	13,874					0.852			0.653	11,815.4	18,095.0
1941	16,244					0.858			0.671	13,938.1	20,779.9
1942	19,142					0.864			0.689	16,547.6	24,033.3
1943	20,516					0.871			0.706	17,867.1	25,296.5
1944	19,976					0.877			0.724	17,525.0	24,203.0
1945	17,679					0.884			0.742	15,623.4	21,059.6
1946	17,632					0.890			0.760	15,695.0	20,661.1
1947	17,606					0.897			0.777	15,784.9	20,304.2
1948	19,121	17,266.0	4,446.7	21,712.7	0.903	0.903	0.795		0.795	17,266.0	21,712.7

Sources: ***a*** Ministry of Power, *Statistical Digest 1967*, Table 85, p 140; ***b, c, and d*** Board of Trade, Business Statistics Office, *Census of Production: Final Report*, (censuses of 1930, 1935, 1948 and 1951); ***h*** Board of Trade, Business Statistics Office, *Census of Production: Final Report*, (1924 census).

Table A2. UK Employment in the manufacturing sector (WW1 incl.)

Year	(a) Employment in manufacturing 1929 = 100 (Source: Broadberry 1997)	(b) Total Civilian Employment (including Southern Ireland) Feinstein 1972	(c) Employment in the manufacturing industry (excluding Southern Ireland)	(d)	(e) Employment in manufacturing 1929 = 100
1869	66.9			66.9	66.9
1870	68.8			68.8	68.8
1871	70.8			70.8	70.8
1872	71.7			71.7	71.7
1873	72.1			72.1	72.1
1874	72.2			72.2	72.2
1875	72.3			72.3	72.3
1876	71.8			71.8	71.8
1877	71.5			71.5	71.5
1878	70.5			70.5	70.5
1879	67.6			67.6	67.6
1880	72.3			72.3	72.3
1881	74.1			74.1	74.1
1882	75.9			75.9	75.9
1883	76.6			76.6	76.6
1884	73.0			73.0	73.0
1885	72.9			72.9	72.9
1886	73.0			73.0	73.0
1887	75.9			75.9	75.9
1888	79.0			79.0	79.0
1889	82.4			82.4	82.4
1890	85.5			85.5	85.5
1891	83.1			83.1	83.1
1892	81.5			81.5	81.5
1893	84.5			84.5	84.5
1894	82.4			82.4	82.4
1895	84.1			84.1	84.1
1896	86.6			86.6	86.6
1897	87.9			87.9	87.9
1898	89.1			89.1	89.1
1899	90.6			90.6	90.6
1900	90.3			90.3	90.3
1901	90.2			90.2	90.2
1902	90.4			90.4	90.4
1903	90.9			90.9	90.9
1904	90.4			90.4	90.4
1905	92.1			92.1	92.1
1906	94.3			94.3	94.3
1907	95.0			95.0	95.0
1908	91.6			91.6	91.6
1909	92.4			92.4	92.4
1910	96.2			96.2	96.2
1911	98.6			98.6	98.6
1912	99.6			99.6	99.6
1913	102.2	19,919.0	***6,899,382.6***	***105.8***	***102.2***
1914		19,440.0	***6,733,470.4***	***103.2***	***100.2***
1915		18,400.0	***6,373,243.6***	***97.7***	***95.2***
1916		17,700.0	***6,130,783.3***	***94.0***	***91.9***
1917		17,100.0	***5,922,960.1***	***90.8***	***89.3***
1918		17,060.0	***5,909,105.2***	***90.6***	***89.6***
1919		19,030.0	***6,591,458.0***	***101.0***	***100.5***
1920	110.5	20,810.0	7,208,000.0	110.5	110.5
1921	86.9			86.9	86.9
1922	90.9			90.9	90.9
1923	93.3			93.3	93.3
1924	94.9			94.9	94.9
1925	95.5			95.5	95.5
1926	92.8			92.8	92.8
1927	98.7			98.7	98.7
1928	98.6			98.6	98.6
1929	100.0			100.0	100.0
1930	93.0			93.0	93.0
1931	86.8			86.8	86.8
1932	88.1			88.1	88.1
1933	91.4			91.4	91.4
1934	95.6			95.6	95.6
1935	97.9			97.9	97.9
1936	103.3			103.3	103.3
1937	108.5			108.5	108.5
1938	106.9			106.9	106.9

1.3 Consumption of Electricity per Worker in the Manufacturing Sector

Having estimated the consumption of electricity by the manufacturing sector, and combining it with census data on employment in the manufacturing sector excluding outworkers and with Broadberry's index for employment in the manufacturing sector (Broadberry 1997, Table A3.1(a), pp. 43 – 44) adjusted for the years of WW1 as described above, we were able to construct a series for electricity consumption in the British manufacturing sector per employee (purchased and self-generated - in ***KWh***). This is presented in Table A.3

Table A.3. Per caput electricity consumption in the UK manufacturing sector

Year	**Electricity consumption in the manufacturing sector per employee (purchased and self-generated - in kWh).**
1920	657.0
1921	680.4
1922	764.6
1923	903.0
1924	1016.3
1925	1086.3
1926	1078.6
1927	1230.5
1928	1335.8
1929	1465.6
1930	1581.2
1931	1666.0
1932	1717.9
1933	1825.8
1934	2032.9
1935	2212.2
1936	2325.1
1937	2433.1
1938	2489.5

2. FRANCE.

2.1 Electricity consumption in the manufacturing sector

Electricity consumption in French manufacturing is measured by: **(i)** the electricity consumed as "force motrice" (largely through the grid); (**ii)** electricity consumption of the electrochemical and electrometallurgical industries; and **(iii)** the electricity consumption of the metallurgical industries and other industries.

Table A4: Consumption of electricity in the French manufacturing sector.

Year	(i) Electricity consumption (through the grid) - force motrice (1000kWh)	(ii) Electricity consumption - electrochemical and electrometallurgical industries (1000kWh)	(iii) Electricity consumption - metallurgical industries and other industries (1000kWh)	Electricity consumption - manufacturing industries (1000kWh) (sum of previous three columns)
1923	_575,238_[*]	1,500,000	_3,517,408*_	_5,592,646_
1924	_699,303*_	1,600,000	_4,276,033*_	_6,575,337_
1925	_790,632*_	1,850,000	_4,834,480*_	_7,475,112_
1926	880,284	2,102,052	5,382,676	8,365,012
1927	857,031	2,164,000	5,342,536	8,363,567
1928	886,079	2,636,769	6,244,850	9,767,698
1929	967,384	2,874,462	6,837,072	10,678,918
1930	1,018,139	2,934,295	7,351,029	11,303,463
1931	1,008,805	2,232,000	6,980,695	10,221,500
1932	945,305	1,854,381	6,508,753	9,308,439
1933	968,498	2,162,051	7,070,321	10,200,870
1934	969,407	2,188,256	7,104,892	10,262,555
1935	961,653	2,240,104	7,362,901	10,564,658
1936	916,000	2,502,000	7,832,000	11,250,000
1937	811,661	3,463,739	8,728,739	13,004,139
1938	801,234	3,547,538	8,611,426	12,960,198
1939	816,036	4,222,765	9,208,036	14,246,837
1940	737,801	4,343,330	7,912,582	12,993,713
1941	794,392[(a)]	3,825,000[(a)]	7,648,000[(a)]	_12,267,392_
1942	847,119[(a)]	2,923,763[(a)(b)]	7,447,869[(a)(b)]	_11,218,751_
1943	_875,155**_	3,127,000[(a)]	7,537,000[(a)]	_11,539,155_
1944	_903,191**_	1,851,000[(a)]	5,641,000[(a)]	_8,395,191_
1945	931,227	2,457,000	7,317,472	10,705,699
1946	_1,142,430**_	3,573,000	10,327,000	_15,042,430_
1947	1,353,632	4,407,943	12,107,751	17,869,326
1948	_1,426,430**_	4,430,000	14,480,000	_20,336,430_
1949	_1,499,227**_	3,940,000	15,921,000	_21,360,227_
1950	_1,572,025**_	4,487,000	17,312,000	_23,371,025_
1951	_1,644,822**_	5,624,000	19,664,000	_26,932,822_
1952	1,717,620	6,823,525	20,530,000	29,071,145

Notes: *estimated see below; **linearly interpolated; (a) does not include Moselle, Haut Rhin, and Bas Rhin; (b) does not include Corse

These original data series were published in the following official publications for the three columns above:

Column (i)

France - Ministère de l'industrie et du commerce, Service technique de l'énergie électrique et des grands barrages, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1952*, Paris: Imprimerie Nationale 1954, p. 33, and table 8 p.52;

France - Ministère de l'industrie et du commerce, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1947*, Paris: Imprimerie Nationale 1949, table 3, p. 17 and table 8, p. 25;

France - Ministère de la production industrielle, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1945,* Paris: Imprimerie Nationale 1947, table 6, p. 13;

France - Ministère de la production industrielle, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1942*, Paris: Imprimerie Nationale 1945, table 6, p. 13;

France - Secrétariat d'Etat a la production industrielle, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1939*, Paris: Imprimerie Nationale 1941, table 13, p. 14;

France - Ministère de la Production industrielle et du travail (Service central de l'électricité), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1938*, Paris: Imprimerie Nationale 1940, table 13, p. 17;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1935*, Paris: Imprimerie Nationale 1937, table 13, p. 17;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1934*, Paris: Imprimerie Nationale 1936, table 13, p. 67 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1927*, Paris: Imprimerie Nationale 1929, table 7, p. 12 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er juillet 1928*, Paris: Imprimerie Nationale (1930?), table 7, p. 83 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1929*, Paris: Imprimerie Nationale 1931, table 7, p. 12 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er janvier 1929*, Paris: Imprimerie Nationale 1930, table 7, p. 83 and table 7, p. 89 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er janvier 1931*, Paris: Imprimerie Nationale 1932, table 7, p. 100 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1932*, Paris: Imprimerie Nationale 1934, table 7, p. 116 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1933, Paris: Imprimerie Nationale 1935, table 7, p. 24.

The figures for the years 1923, 1924, and 1925 were estimated assuming that 'force motrice' was 8.82% of total electricity consumption in those years. The figure of 8.82% is that observed for 1926. The source for total consumption of electricity in France in 1923, 1924, and 1925 is the same.

Column (ii)

France - Ministère de l'industrie et du commerce, Service technique de l'énergie électrique et des grands barrages, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1952*, Paris: Imprimerie Nationale 1954, p. 32 ;

France - Ministère de l'industrie et du commerce, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1947*, Paris: Imprimerie Nationale 1949, table 3, p. 16;

France - Ministère de la production industrielle, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1945*, Paris: Imprimerie Nationale 1947, table 6, p. 13;

France - Ministère de la production industrielle, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1942*, Paris: Imprimerie Nationale 1945, table 6, p. 13;

France - Secrétariat d'Etat a la production industrielle, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1939*, Paris: Imprimerie Nationale 1941, table 13, p. 14;

France - Ministère de la Production industrielle et du travail (Service central de l'électricité), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1938*, Paris: Imprimerie Nationale 1940, table 13, p. 17;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1935*, Paris: Imprimerie Nationale 1937, table 13, p. 17;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1934*, Paris: Imprimerie Nationale 1936, table 13, p. 67 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1927*, Paris: Imprimerie Nationale 1929, table 7, p. 13 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er juillet 1928*, Paris: Imprimerie Nationale (1930?), table 7, p. 83 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1929*, Paris: Imprimerie Nationale 1931, table 7, p. 13 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er janvier 1929*, Paris: Imprimerie Nationale 1930, table 7, p. 83 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er janvier 1931*, Paris: Imprimerie Nationale 1932, table 7, p. 100 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1932*, Paris: Imprimerie Nationale 1934, table 7, p. 116 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1933*, Paris: Imprimerie Nationale 1935, table 7, p. 24.

Column (iii)

France - Ministère de l'industrie et du commerce, Service technique de l'énergie électrique et des grands barrages, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1952*, Paris: Imprimerie Nationale 1954, p. 33, and table 8 p.52 ;

France - Ministère de l'industrie et du commerce, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1947*, Paris: Imprimerie Nationale 1949, table 3, p. 17 and table 8, p. 25;

France - Ministère de la production industrielle, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1945*, Paris: Imprimerie Nationale 1947, table 6, p. 13;

France - Ministère de la production industrielle, Service central de l'électricité, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1942*, Paris: Imprimerie Nationale 1945, table 6, p. 13, and table 13 p. 23;

France - Secrétariat d'Etat a la production industrielle, *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1939*, Paris: Imprimerie Nationale 1941, table 13, p. 14;

France - Ministère de la Production industrielle et du travail (Service central de l'électricité), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1938*, Paris: Imprimerie Nationale 1940, table 13, p. 17;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1935*, Paris: Imprimerie Nationale 1937, table 13, p. 17;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1934*, Paris: Imprimerie Nationale 1936, table 13, p. 67 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1927*, Paris: Imprimerie Nationale 1929, table 7, p. 12 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er juillet 1928*, Paris: Imprimerie Nationale (1930?), table 7, p. 83 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1929*, Paris: Imprimerie Nationale 1931, table 7, p. 12 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er janvier 1929*, Paris: Imprimerie Nationale 1930, table 7, p. 83 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique au 1er janvier 1931*, Paris: Imprimerie Nationale 1932, table 7, p. 100 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1932*, Paris: Imprimerie Nationale 1934, table 7, p. 116 ;

France - Ministère des travaux publics (Service central des forces hydrauliques et des distributions d'énergie électrique), *Statistique de la production et de la distribution de l'énergie électrique en France pour l'année 1933*, Paris: Imprimerie Nationale 1935, table 7, p. 24.

The figures for the years 1923, 1924, and 1925 were estimated assuming that ‘force motrice’ was 53.96% of total electricity consumption in those years. The figure of 53.96% is that observed for 1926. The source for total consumption of electricity in France in 1923, 1924, and 1925 is the same.

These series were then re-published in the *Annuaire Statistique*. The aggregate is likely to overestimate the consumption by the manufacturing sector as the data includes consumption of “force motrice” by the construction industry and by non industrial users. However, the magnitude of this bias is likely to be small as the bulk of electricity was consumed by the manufacturing industry.

2.1 Employment in the manufacturing sector

Data for this aggregate were recalculated by INSEE in 1961 for the years 1906, 1921, 1926, 1931, 1936, 1946, 1954. We used the dynamic of the Industrial Production Index 1913=100 as published in the *Résume Rétrospectif* in the 1938 *Annuaire Statistique* to interpolate the data for the years 1922, 1923, 1924, 1925 according to the formula:

$$L_t = L_{1921}*(1+ (\alpha_1*(Y_t- Y_{1921})/ Y_{1921}))$$

$$\text{Where } \alpha_1 = (L_{1926}- L_{1921})/L_{1921}/(Y_{1926}-Y_{1921})/ Y_{1921}$$

To interpolate the data for the years 1927, 1928, 1929, and 1930 we used the formula:

$$L_t = L_{1926}*(1+(\alpha_2*(Y_t- Y_{1926})/ Y_{1926}))$$

$$\text{Where } \alpha_2 = (L_{1931}- L_{1926})/L_{1926}/(Y_{1931}-Y_{1926})/ Y_{1926}$$

For the years 1932, 1933, 1934, 1935, 1937, and 1938 we applied the employment dynamic derived from the index number of the employed in industrial establishments with more than 100 employees (previous year =100) as published in the *Annuaire Statistique* (Tav 5 ombres indices des effectifs des établissements occupant au moins 100 personnes, par rapport aux effectifs du mois correspondant de l'année précédente).

2.3 Consumption of Electricity per Worker in the Manufacturing Sector

Having estimated the consumption of electricity by the manufacturing sector (see Table above), and combining it with these estimates of employment in the manufacturing sector, we were able to construct a series for electricity consumption in the French manufacturing sector per employee (purchased and self-generated - in ***KWh***).

Table A.5 France Employment and per caput electricity consumption in the manufacturing sector.

Year	Manufacturing employment	Electricity consumption in the manufacturing sector per employee (purchased and self-generated - in kWh).
1921	**4,841,000**	
1922	*5,027,915*	
1923	*5,109,183*	1,095
1924	*5,279,845*	1,245
1925	*5,271,718*	1,418
1926	**5,418,000**	1,544
1927	*4,746,000*	1,762
1928	*5,460,000*	1,789
1929	*5,964,000*	1,791
1930	*6,006,000*	1,882
1931	**5,334,000**	1,916
1932	*4,837,352*	1,924
1933	*4,743,428*	2,151
1934	*4,597,694*	2,232
1935	*4,394,363*	2,404
1936	**4,429,000**	2,540
1937	*4,687,702*	2,774
1938	*4,843,360*	2,676

Note: for the interpolation estimation methods of the figures in italics see above.

3. GERMANY

3.1 Electricity consumption in the manufacturing sector

We used data on industrial consumption of electricity published in the Statistical Yearbook of 1925, and 1932, and in the Statistical Handbook published in 1949. These figures were combined with manufacturing sector employment data from Hoffmann (1965). The basic assumption adopted was that the net consumption of the manufacturing sector is the total gross industrial consumption minus 3.3% of self-consumption by utilities (based on 1925 data); minus 1.5% sold by industry to utilities (based on 1930 data); minus 19.3% consumed by the mining sector (based on 1930 data). The data so calculated is presented in the second column of the Table A6.

Table A6: Employment and consumption of electricity in the German manufacturing sector

Year	Industrial gross electricity consumption (purchased and self-generated - in gigaWh).	Electricity consumption in the manufacturing sector (purchased and self-generated - in gigaWh).	Employment in manufacturing (*1000)	Electricity consumption in the manufacturing sector per employee (purchased and self-generated - in kWh).
1925	15,195	11,533	9,972	1,156.54
1926			8,782	
1927			10,183	
1928			10,463	
1929			10,101	
1930	21,056	15,982	9,116	1,753.13
1931			7,787	
1932			6,646	
1933	18,637	14,145	7,075	1,999.36
1934	22,986	17,446	8,268	2,110.11
1935	28,538	21,660	9,058	2,391.29
1936	33,169	25,175	9,767	2,577.58
1937	38,429	29,168	10,562	2,761.56
1938	45,269	34,359	11,146	3,082.65
1939	51,563	39,136	12,681	3,086.22

Sources: Statististische Reichsamt, *Statistisches Jahrbuch des Deutschen Reiches*, Berlin (1928 edn. pp. 124-125; 1932 edn. pp. 114 – 115); Länderrat des Amerikanischen Besatzungsgebiets, *Statistisches Handbuch von Deutschland 1928 - 1944*, Munich 1949, pp. 336 - 337.

3.2 Employment in the manufacturing sector

We have used the data from Hoffmann, W. G., *Das wachstum der Deutschen wirtschaft seit der mitte des 19. Jahrhunderts*, Berlin, Heidelberg and New York: Springer-Verlag 1965, Tab. 15, pp. 198 - 199.

3.3 Consumption of Electricity per Worker in the Manufacturing Sector

Electricity consumption in the German manufacturing sector per employee (purchased and self-generated - in ***KWh***) is shown in Table A.6 last column.

4. USA

4.1 Electricity consumption in the manufacturing sector

We have used the data from Du Boff (1979[original 1964]), table 22, p. 84 and the data reported in the US Department of Commerce (1975): *Historical Statistics of the U.S.: Colonial Times to 1970*, Washington D.C. This data is reproduced in column (i) of Table A.7. below.

4.2 Employment in the manufacturing sector

We have used the data from Kendrick (1961), Table D-II, pp. 465 - 466 and Table D-VII p. 488. They are reproduced in column (ii) of the table above.

Consumption of Electricity per worker in the manufacturing sector

We combined the data under column (i) and column (ii) to obtain a series for electricity consumption in the US manufacturing sector per employee (purchased and self-generated - in ***KWh***).

Table A.7. US electricity consumption and employment in the manufacturing sector.

Year	(i) Electricity consumption in the manufacturing sector (purchased and self-generated - in gigaWh).	(ii) Manufacturing Employment	Electricity consumption in the manufacturing sector per employee (purchased and self-generated - in kWh).
1902	1,300	6,384,280	203.6
1903		6,627,390	
1904		6,246,870	
1905		6,986,770	
1906		7,356,720	
1907	5,100	7,694,960	662.8
1908		6,891,640	
1909		7,684,390	
1910		8,033,200	
1911		8,033,200	
1912	9,250	8,392,580	1,102.2
1913		8,477,140	
1914		8,181,180	
1915		8,551,130	
1916		10,083,780	
1917	20,750	10,781,400	1,924.6
1918		10,992,800	
1919		10,601,710	
1920	26,913	10,580,570	2,543.6
1921	23,993	8,181,180	2,932.7
1922	27,364	8,952,790	3,056.5
1923	32,585	10,168,340	3,204.6
1924	34,967	9,534,140	3,667.6
1925	39,725	9,798,390	4,054.2
1926	46,350	10,009,790	4,630.5
1927	51,012	9,882,950	5,161.6
1928	52,699	9,914,660	5,315.3
1929	55,122	10,570,000	5,214.9
1930	53,930	9,428,440	5,719.9
1931	50,410	7,990,920	6,308.4
1932	43,504	6,754,230	6,441.0
1933	46,561	7,282,730	6,393.3
1934	50,593	8,445,430	5,990.6
1935	56,706	8,995,070	6,304.1
1936	62,949	9,745,540	6,459.3
1937	64,757	10,696,840	6,053.8
1938	58,452	9,238,180	6,327.2
1939	70,518	10,094,350	6,985.9
1940	83,276	11,024,510	7,553.7
1941	104,037	13,286,490	7,830.3
1942	122,762	15,442,770	7,949.5
1943	143,995	17,577,910	8,191.8
1944	145,015	17,239,670	8,411.7
1945	134,955	15,379,350	8,775.1
1946		14,702,870	
1947	140,947	15,421,630	9,139.6

5. JAPAN.

5.1.1 Electricity consumption in the manufacturing sector

The data on electricity consumption for manufacturing is reported as Table 10-5 http://www.stat.go.jp/english/data/chouki/10.htm.

The data was originally published in the "Electricity Enterprises Handbook" edited by the Federation of Electric Companies of Japan under the supervision of the Agency for Natural Resources and Energy. The data covers the period from 1930.

5.2 Employment in the manufacturing sector.

The number of workers in the manufacturing industry for the period 1920 to 1942 is reported in Umemura, M., Akasaka, K., Minami, R., Takamatsu, N., Arai, K., Itoh, S., 'Manpower', in Ohkawa, K., Shinohara, M., and Umemura, M. (eds.), *Estimates of long-term statistics of Japan since 1868*, V. 2, Tokyo: Toyo Keizai Shinposha 1988, Table 19, p. 256. This data is estimated on the basis of annual survey data on establishments with more that five employees up to 1938 and on all the establishments from 1939.

Table A.7. Japan: electricity consumption and employment in the manufacturing sector.

Year	(i) Electricity consumption in the manufacturing sector (gigaWh)	(ii) Manufacturing Employment (000)	Electricity consumption in the manufacturing sector per employee (purchased and self-generated - in kWh).
1930	3099.00	3741.4	828.298
1931	3097.00	3664.2	845.2089
1932	3989.00	3951.0	1009.621
1933	5132.00	4203.1	1220.991
1934	6232.00	4651.8	1339.69
1935	7629.00	4969.2	1535.249
1936	8874.00	5008.6	1771.749
1937	10562.00	6031.2	1751.224
1938	11340.00	6422.5	1765.681
1939	12120.00	7001.7	1731.016

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