The Yanks of Europe? Two technological paths in German manufacturing, 1907-1936

Joost Veenstra & Pieter Woltjer*
University of Groningen

Abstract

America's lead over Europe from the late nineteenth century onwards has often been contributed to differences in initial conditions, trapping Europe in a labour-intensive and low productive technological path. However, in the case of German manufacturing, this analysis does not align with qualitative evidence obtained from the German metal-engineering industry, which shows that German manufacturers actively copied or imported American machinery. On the basis of labour productivity comparisons in 1907/09 and 1936/35 we show that a limited number of German manufacturing industries managed to compete with their transatlantic counterparts, suggesting that these industries pursued an American technological path. Although labour in German manufacturing was located predominently in traditional industries, which remained stagnant between 1907 and 1936, the industries set up during the Second Industrial Revolution laid the foundation for Germany's industrial expansion in the twentieth century.

1 Introduction

From the late nineteenth century onwards, the US forged ahead of Europe in terms of productivity levels. In the years to follow, Europe failed to narrow the transatlantic productivity gap, which hoovered roughly around a 2:1 ratio.[1] Europe's inability to catch-up has traditionally been explained by local circumstances, i.e. factor and resource endowments as wel as demand patterns, which favoured a labour-intensive way of producing.[2] In Europe, natural resources were scarce, while skilled labour was in ample supply, which provided an incentive to economize on fixed capital in the form of machinery.[3] In contrast, the US was well endowed with natural

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[1]S. N. Broadberry, *The Productivity Race: British Manufacturing in International Perspective, 1850–1990*, (Cambridge: Cambridge University Press, 1997), 3; S. Broadberry and D. Irwin, 'Labor productivity in the United States and the United Kingdom during the nineteenth century', *Explorations in Economic History*, Vol. 43 (2006), 265.

[2]H. J. Habakkuk, *American and British Technology in the Nineteenth Century. The Search for Labour-saving Inventions*, (Cambridge: Cambridge University Press, 1962).

[3]P. Temin, 'Labour scarcity in America', *Journal of Interdisciplinary History*, Vol. 1 (1971), 162;A. Field, 'On the unimportance of machinery', *Explorations in Economic History*, Vol. 22 (1985), 379.

resources, while skilled labour was relatively expensive. Therefore, machinery was substituted for skilled labour, resulting in a capital-intensive production process. Furthermore, as the American demand for goods was to a large extent homogenous, manufacturers could standardize production methods, implement high throughput systems, and thereby raise productivity levels.[4] This advantage was denied to European countries, which faced heterogenous markets characterized by a demand for customized goods. Thus, local circumstances determined the initial choice of technology. Technological progress is subsequently directed towards the particular technological path a country has chosen, leading to lock-in effects.[5] Authors such as Broadberry and David argue that even when American technology developes so rapidly it becomes superior at all relative factor prices, Europe will not adopt American technology.[6]

Recently, Richter and Streb presented evidence of transatlantic technology transfer in the machine-tool industry during the late nineteenth and early twentieth centuries. They quote contemporary industry periodicals, which report a good many cases where German manufacturers imported American machinery and incorporated these technologies in their own production process.[7] As an explanation for these technology transfers, Richter and Streb refer to Aghion, who argues that countries distanced far away from the productivity frontier can catch-up by applying an investment-based growth strategy.[8] This concept builds upon Gerschenkron's idea of 'appropriate' economic institutions and Abramovitz' 'social capabilities' to encourage technology adoption.[9] Provided that the necessary capabilities and resources – mainly primary and secondary education – are available, countries distanced far away from the frontier can catch-up quickly by importing or imitating advanced technologies. As the level of schooling rose from the 1850s onwards, German manufacturers were induced to duplicate American machinery.

The implementation of American technology in the German machine-tool industry seems difficult to reconcile with the idea of technological lock-in driven by local circumstances. Especially since the qualitative data points at the adoption of unadjusted frontier technologies. Imported machinery was often applied in its original form: "*Information coming from Germany indicates that a number of American machine-tools are (...) made without the slightest alteration.*"[10] The difference between these two seemingly opposing strands of literature stems, in part, from the level of analysis. Richter and Streb obtained information on the level of industries. In contrast, the persistent gap between the US and Europe observed by Broadberry is based on manufacturing-level data, hiding the developments of underlying industries. Could it be that within the German manufacturing sector, industries developed along different technological paths? Perhaps not all manufacturing industries got stuck on a labour-intensive path,

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[4] S. Broadberry, 'Technological leadership and productivity leadership in manufacturing since the Industrial Revolution: implications for the convergence debate', *Economic Journal*, Vol. 104 (1994), 291.

[5] P. A. David, *Technical Choice, Innovation and Economic Growth. Essays on American and British Experience in the Nineteenth Century*, (Cambridge: Cambridge University Press, 1975), 66

[6] Broadberry, 'Technological leadership', 297; David, *Technical Choice*, 68.

[7] R. Richter and J. Streb, 'Catching-up and falling behind. Knowledge spillover from American to German machine tool makers', *FZID Discussion Paper* (2009), 1-2.

[8] P. Aghion, 'Higher education and innovation', *Perspektiven der Wirtschaftspolitik*, Vol. 9 (2008), 31; D. Acemoglu, P. Aghion and F. Zilibotti, 'Distance to frontier, selection, and economic growth', *Journal of European Economic Association*, Vol 4 (2002), 39; J. Vandenbussche, P. Aghion and C. Meghir, 'Growth, distance to the frontier and composition of human capital', *Journal of Economic Growth*, Vol. 11 (2006), 98.

[9] A. Gerschenkron, *Economic backwardness in historical perspective, a book of essays*, (Cambridge, 1962), 113, 116; M. Abramovitz, 'Catching-up, forging ahead and falling behind', *Journal of Economic History*, Vol. 46 (1986), 387.

[10] Richter and Streb, 'Catching-up and falling behind', 1.

but instead succeeded in following the 'American example'. In this paper we study the apparent contradiction between the qualitative and quantitative literature by measuring the distance to the frontier for German industries in the benchmark years 1907/09 and 1936/35. As a measure for distance to the frontier we use German/US comparative labour productivity levels, which have not been constructed before. Furthermore, as we specifically look at German productivity developments and the cross-country results are influenced by the US, we also present a Germany 1907/1936 comparison.

The German/US labour productivity comparisons show that in a number of manufacturing industries Germany indeed managed to close-in on the US. Clearly, the 2:1 persistent transatlantic gap did not apply to all German manufacturing industries. This observation challenges the idea of a single technological path for the entire manufacturing sector and, in combination with the evidence of technology transfer between the US and Germany, questions the technological lock-in hypothesis. The German comparison over time points out that only relatively modern industries – set up during the Second Industrial Revolution – improved labour productivity levels substantially over the first half of the twentieth century. These modern industries lay the foundation for Germany's industrial expansion in the second half of the twentieth century, when structural changes pushed labour towards the high productive elements of the manufacturing sector. In contrast, most traditional industries stagnated or even declined over time.

2 Methodology

Studies of comparative economic performance of nations have a long history. Arguably the best-known comparison of long-run productivity performance is the work of Angus Maddison.[11] It is characterized by a wide coverage in terms of countries and time-span, the use of a transparent methodology, and the exclusive reliance on national time series produced by statistical offices or researchers of these countries. National income and output series at constant prices are tied together at a certain benchmark year in order to compare the long-run trends in GDP per capita. Maddison based his comparative efforts on benchmark estimates of real GDP for a single benchmark year, using 1990 *ppps*. It is well-known however, that problems of interpretation arise when time series of different origin are projected from a benchmark into distant periods. Indeed, these so-called *long-span projections* have recently been increasingly criticized through confrontations with new benchmark studies for earlier years, which raises the issue of comparability between benchmark estimates of real GDP and national time series.[12]

In addition, the basis for the German *long-span projections* – the Historical National Accounts, constructed during the 1960s under the supervision of Hoffmann – have been subjected to growing criticism as well.[13] Particularly Hoffmann's procedure for estimating output growth in industry during the inter-war period is considered to be questionable. Scholars have tried to overcome these problems both by correcting for flaws in the original Hoffmann time series and by

[11] A. Maddison, *Monitoring the world economy, 1820-1992*, (Paris, 1995); A. Maddison, *The World Economy: a Millennial Perspective*, (Paris: Organisation for Economic Cooperation and Development, 2001).

[12] L. Prados de la Escosura, 'International Comparisons of Real Product, 1820–1990', *Explorations in Economic History*, 37 (2000).

[13] W. Hoffmann, *Das Wachstum der Deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts*, (Berlin, 1965); A. Ritschl, 'Spurious Growth in German Output Data, 1913–1938', *European Review of Economic History*, Vol. 8 (2004); A. Ritschl, 'The Anglo-German industrial productivity puzzle, 1895-1935: a restatement and a possible resolution', *Journal of Economic History*, Vol. 68, Nr. 2 (2008).

estimating direct benchmark estimates for earlier years.[14] Still, in terms of methodology as well as data sources, these new benchmark estimates and output indices leave room for improvement.

The direct estimates of labour productivity at the industry level that are available for Germany on the eve of the First World War, are nearly all based on the comparison of physical quantities of output, relying on a methodology proposed in 1948 by Rostas.[15] Data availability for the post-War period has allowed a more sophisticated methodology, based on the calculation of real net or gross output at the industry level using relative producer prices. This procedure was first applied by Paige and Bombach in an Anglo-American comparison for 1950.[16] The methodology behind these industry-of-origin benchmarks was subsequently further refined and used in a host of international benchmark comparisons for the post-War period; most notably the International Comparison of Output and Productivity (ICOP) project by Maddison and van Ark.[17] Recently however, the extended ICOP methodology has also been applied to international comparisons for the period preceding the Second World War.[18] These historical industry-of-origin studies not only prove that it is feasible to apply modern techniques for earlier periods, but they also stress the advantages of these methods over the earlier quantity based benchmark comparisons.

Although the basic concepts behind the available benchmark techniques are similar, there are some marked differences between the ICOP *unit value approach* and the earlier *quantity approach* as utilized by, among others, Rostas and Broadberry.[19] In principle the methodological differences between both methods are limited, and the quantity approach can easily be rewritten to approximate a basic version of the unit value approach. In practice however, the outcomes of these methods can deviate substantially. Particularly the necessity to assign labour to individual commodities, instead of industries within the quantity approach, limits this methodology's ability to estimate productivity for industries producing a wide array of heterogeneous products. In addition, the ICOP approach sets itself apart by its ability to take variations in input prices and the ratio of intermediate inputs to gross output into account. It can be extended via the double deflation technique and it is possible to adopt alternative weighting schemes through the stratified sampling methodology.

[14] R. Fremdling, 'German industrial employment 1925, 1933, 1936 and 1939. A new benchmark for 1936 and a note on Hoffmanns tales', *Jahrbuch für Wirtschaftsgeschichte*, Vol. 2 (2007); Idem, 'German machine building: a new benchmark before World War I', *Sonderdruck aus: Jahrbuch für Wirtschaftsgeschichte*, Vol. 2 (2009); Ritschl, 'Spurious Growth in German Output Data'.

[15] L. Rostas, *Comparative Productivity in British and American Industry*, (Cambridge: Cambridge University Press, 1948).

[16] D. Paige and G. Bombach, *A Comparison of National Output and Productivity of the United Kingdom and the United States*, (Paris: Organisation for European Economic Co-operation, 1959).

[17] A. Maddison, 'Ultimate and proximate growth causality: a critique of Mancur Olson on the rise and decline of nations', *Scandinavian Economic History Review*, Vol. 2 (1988); B. van Ark, *International Comparisons of Output and Productivity: Manufacturing Productivity Performance of Ten Countries from 1950 to 1990*, (Groningen: Groningen Growth and Development Centre, 1993).

[18] R. Fremdling, H. de Jong and M. Timmer, 'British and German Manufacturing Productivity Compared. A New Benchmark for 1935/36 Based on Double Deflated Value Added', *The Journal of Economic History*, Vol. 67, Nr. 2 (2007); H. de Jong and P. Woltjer, 'Depression Dynamics: a New Estimate of the Anglo-American Manufacturing Productivity Gap in the Interwar Period', *Economic History Review*, Vol. 64 (2011); J. P. Dormois, 'Episodes in Catching-Up: Anglo-French Industrial Productivity Differentials in 1930', *European Review of Economic History*, 8 (2004).

[19] Rostas, *Comparative Productivity in British and American Industry*; Broadberry, *The Productivity Race*.

2.1 ICOP approach

The section below, will demonstrate the basic ICOP methodology in a simple single industry, n country, m product framework. Note that this procedure is suited both for the benchmarking of two or more countries at a single year *and* the comparison of output and/or productivity for a single country over time. In the latter case, the subscript n denotes time instead of space.

The first step in the calculation of labour productivity is the matching of products into unit values (p). The unit values – which represent the local average price of this product – can be obtained by dividing output ($v_{k,n}$) by the respective quantity ($q_{k,n}$) for commodity k of country n; as shown in equation (1) below. Next, product specific unit value ratios (uvr) for all country-pair combinations are derived by dividing the unit value for country i by the corresponding unit value of country j; see equation (2).The subscript i represents the numerator country, whereas the subscript j represents the base country.

$$p_{k,n} = \frac{v_{k,n}}{q_{k,n}} \tag{1}$$

$$uvr_{k,i,j} = \frac{p_{k,i}}{p_{k,j}} \tag{2}$$

The $uvrs$ can then be aggregated to the industry level. For an industry which holds m products, the respective $uvrs$ are weighted according to their share in total matched output, as in equation (3). The resulting aggregated $uvrs$ are generally referred to as purchasing power parities (*ppp*). For each country-pair combination, two *ppps* are estimated where the respective countries each act as the numerator and base consecutively. When expressing the relative price level in terms of i's currency per unit of j's currency, the i,j-th entry represents the Laspeyres *ppp*, whereas the inverse of the j,i-th entry represents the Paasche *ppp*.[20] Throughout this paper, we will use the geometric mean of the Laspeyres and Paasche price indices, the Fisher price index, as the currency conversion factor for our productivity comparisons; see equation (4).

$$ppp_{i,j} = \sum_{k=1}^{m} \left(uvr_{k,i,j} \cdot \frac{v_{k,j}}{\sum_{k=1}^{m} v_{k,j}} \right) \tag{3}$$

$$ppp^F_{i,j} = \sqrt{ppp_{i,j} \cdot (ppp_{j,i})^{-1}} \tag{4}$$

The resulting *ppps* can in turn be used to convert either countries output per unit of labour to the other countries' currency (6). Below, and throughout most of this paper, we use gross output (*go*) as the measure of output, as in (5). Alternatively, when available, value added (*va*) can also act as the measure of output.[21]

[20] As v is equal to $p \cdot q$, $ppp_{i,j}$ can be expressed as $\frac{\sum p_i \cdot q_j}{\sum p_j \cdot q_j}$, while the inverse of $ppp_{j,i}$ is given by $\frac{\sum p_i \cdot q_i}{\sum p_j \cdot q_i}$.

[21] van Ark, *International Comparisons of Output and Productivity*, 28–29.

$$lp_n = \frac{go_n}{emp_n} \tag{5}$$

$$L^F_{i,j} = \frac{lp_i}{lp_j \cdot ppp^F_{i,j}} \tag{6}$$

2.2 Methods compared

In the quantity approach, labour productivity ($lp_{k,n}$) for product k of country n is defined as the ratio between the physical quantity produced ($q_{k,n}$) and the employment used to produce this particular product ($emp_{k,n}$), see equation (7). Unfortunately, employment at the commodity level is rarely available in historical sources. The product specific employment can be estimated however, by disaggregating the employment at the industry level (emp_n) by the share of commodity k's production value ($v_{k,n}$) in total gross output (go_n) for that particular industry; as in equation (8). Product specific comparative labour productivity ratios ($l_{k,i,j}$) for all country-pair combinations can then be obtained by dividing labour productivity of country i by the labour productivity of country j, see equation (9).

$$lp_{k,n} = \frac{q_{k,n}}{emp_{k,n}} \tag{7}$$

$$emp_{k,n} = emp_n \cdot \frac{v_{k,n}}{go_n} \tag{8}$$

$$l_{k,i,j} = \frac{lp_{k,i}}{lp_{k,j}} \tag{9}$$

The estimations based on both approaches will deviate as the result of a number of methodological dissimilarities and data limitations. The primary methodological differences between the two methods is that the quantity approach implicitly relies on the products output value as a measure of output in labour productivity, whereas modern international comparisons generally opt for value added. The use of product value or gross output in international benchmark comparisons introduces a systematic bias as a result of variances in the share of inter-industry deliveries in the value of production. These variations can occur as a result of differences in production methods, the types of materials used, and the amount of imported materials, but can also be caused by differences in industry classifications between the countries under comparison.[22] Another major shortcoming of the quantity approach is its inability to estimate labor productivity for more complex industries that produce a broad range of heterogeneous products. For these industries it is simply not possible to aggregate the quantities produced to a single measure or to assign labour to the various products. The assignment of labour used to produce a single good, as in equation (8), is economically less sensible when the share of output for that good only comprises a small fraction of the total production value in that industry.

In addition, the ICOP framework allows for several extensions which serve to improve the quality of the international benchmark estimates. The primary extension is the application of the double deflation technique, which does not only take relative prices for gross output into account

[22] Fremdling, de Jong and Timmer, 'British and German manufacturing Productivity Compared', 360.

(as above), but also compensates for relative price differentials for intermediate inputs.[23] Double deflation is generally considered to be the preferred approach for sector comparisons of output and productivity, and recent studies have shown that this adjustment could be of particular importance for benchmark studies that examine the turbulent inter-war years.[24] As governments put in place increasingly restrictive foreign trade regimes and tight currency controls during this period, the internal price level and ratios between input and output prices tended to deviate substantially.[25]

Another extension to the unit value framework is the stratified sampling approach, which introduces an alternative weighting scheme. The stratified sampling theory proposes that the process of aggregation of the relative price ratios can be made more precise if a heterogeneous population (the products matched) is divided into more homogeneous sub-populations, referred to as strata. These strata usually take the form of industries, the output of which can be used as alternative weights to aggregate the price ratios.[26]

3 Sources

For this study we apply the ICOP methodology and calculate single and, where possible, double deflated *ppps* on the basis of average factory-gate prices, as reported in the official manufacturing production censuses. The majority of these surveys contain detailed information on quantities and values of produced items, average prices, gross output, intermediate input and employment, enabling us to construct labour productivity comparisons bottom-up. As noted in the introduction, we will perform multiple benchmark studies. First, we determine the comparative level of German labour productivity against the US for the years 1907/09 and 1936/35. Following this, we attempt to establish the relative growth of the German manufacturing sector directly by benchmarking output per worker in 1936 against productivity in 1907.

For 1909 US we based our analysis on the *Thirteenth Census of the United States* published by the US Bureau of Commerce.[27] For 1935 US we relied primarily on the *Biennial Census of Manufactures 1935* and the *Sixteenth Decennial Census of the United States*.[28] For Germany we used the comprehensive archival records of the *Industrial Census of 1936*, which contains considerably more detailed and accurate information than the published version of the census.[29] Unfortunately, for pre-WWI Germany a census of manufactures is absent. In order to reconstruct

[23] Paige and Bombach, *A Comparison of National Output and Productivity*, 82.

[24] Fremdling, de Jong and Timmer, 'British and German manufacturing Productivity Compared'.

[25] Fremdling, 'German industrial employment', 352.

[26] For an elaborate description of the stratified sampling theory see: M. P. Timmer, 'On the Reliability of Unit Value Ratios in International Comparisons', *Groningen Growth and Development Centre Memorandum*, Vol. 31 (1996); and, Idem, *The Dynamics of Asian Manufacturing: a Comparative Perspective*, (Eindhoven: Eindhoven Centre for Innovation Studies, 1999), 21.

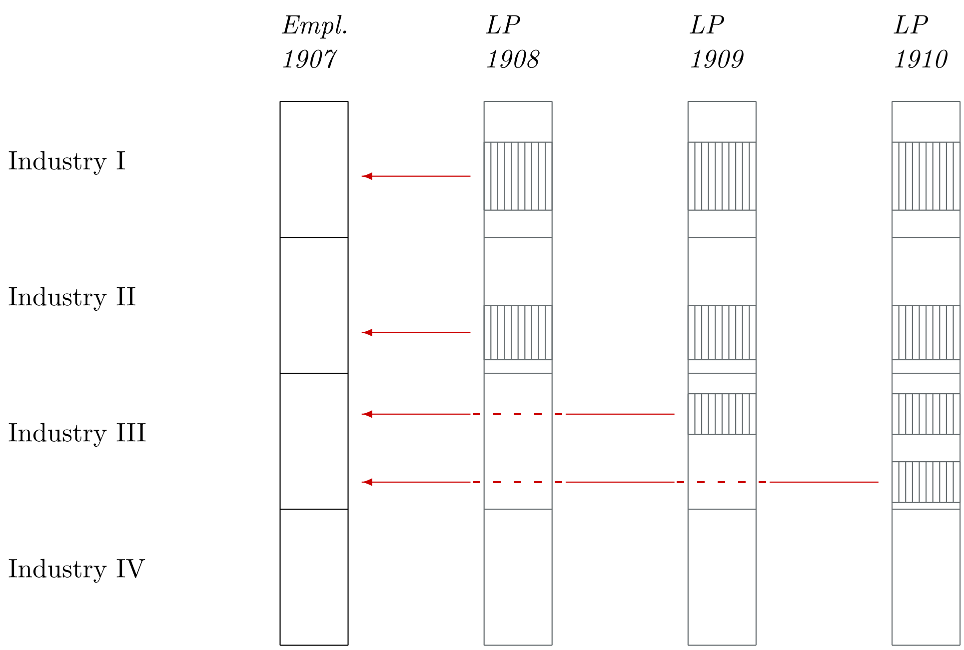
[27] United States Department of Commerce: Bureau of the Census, *Thirteenth Census of the United States Taken in the Year 1910*, Volume X: Manufactures, (Washington D.C.: United States Government Printing Office, 1913).

[28] Idem, *Biennial Census of Manufactures 1935*, (Washington D.C.: United States Government Printing Office, 1938); Idem, *Sixteenth Decennial Census of the United States*, Volume Manufactures, (Washington D.C.: United States Government Printing Office, 1940).

[29] Reichsamt fur Wehrwirtschaftliche Planung, *Die Deutsche Industrie. Gesamtergebnisse der amtlichen Productionsstatistik. Schriftenreiche des Reichsamt fur wehwritschaftliche Planung, Heft 1*, (Berlin: Verlag fur Sozialpolitik, Wirtschaft und Statistik, 1939); for a detailed discussion of this source see: R. Fremdling, H. de Jong and M. P. Timmer, 'Censuses Compared: a New Benchmark for British and German Manufacturing 1935/1936', *Groningen Growth and Development Centre Memorandum*, Vol. 90 (2007).

labour productivity levels, we combined data from several sources. We mainly relied on the industrial surveys covered by the *Vierteljahrshefte zur Statistik des deutschen Reichs*.[30] For a limited number of manufacturing and mining industries, both gross output and employment is reported for the years between 1908 and 1911. However, for the purpose of aggregation, we need the structure of the manufacturing sector in either output or employment shares. As the *Vierteljahrshefte* does not provide a manufacturing-wide coverage, we used the *Berufs- und Betriebszählung* of 1907.[31] On the basis of the occupational census we calculated employment shares for the entire manufacturing sector in Germany. Subsequently, we used the data obtained from the *Vierteljahrshefte* as a proxy for labour productivity levels in 1907, as depicted in figure 1. Furthermore, for a number of industries, such as *food & kindred*, the *Vierteljahrshefte* does not contain any data. For these industries we derived gross output from the *Statistisches Jahrbuch für das Deutschen Reich* and employment from the *Berufs- und Betriebszählung*.[32]

Figure 1: Using 1908-10 labour productivity levels as a proxy for 1907



Although, for the pre-WWI period, we designated the year 1907 as base for our benchmark comparison, the choice of the German benchmark years was at least partly determined by the availability of the production censuses listed above. Whenever possible, we took care to select relatively stable years on the eve of the First World War. Figure 2 shows that the level of real GDP at the selected census years for both countries was above the long-run trend, and

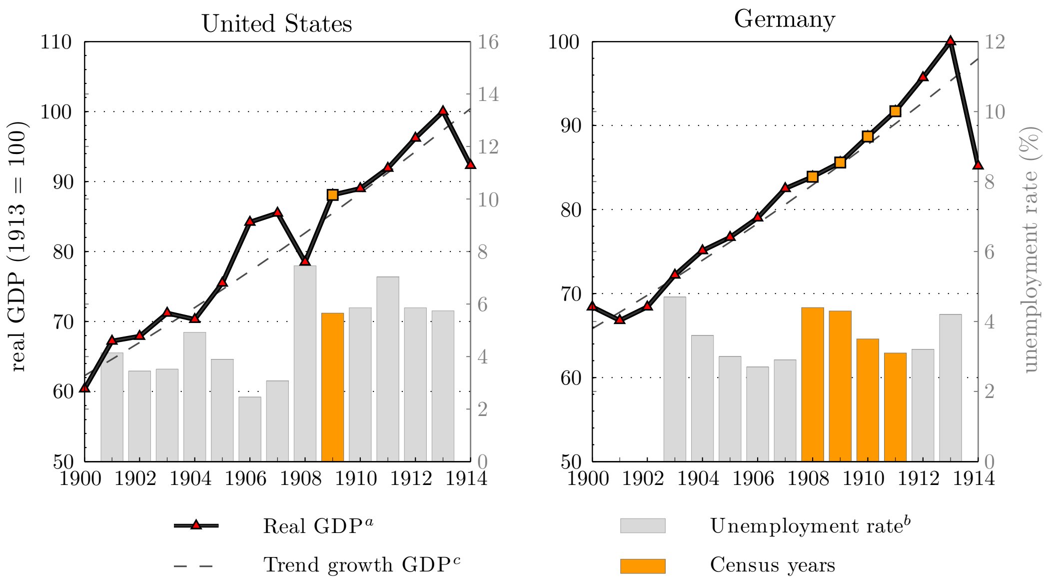
[30] Kaiserlichen Statistischen Amte, Chap. *Ergebnisse der deutschen Produktionserhebungen* In 'Vierteljahrshefte zur Statistik des Deutschen Reichs: Ergänzungsheft', (Berlin, 1913).

[31] Statistik des Deutschen Reichs, *Berufs- und Betriebszählung, Band 213: Betriebsstatistik Abteilung I & II*, (1907).

[32] Kaiserlichen Statistischen Amte, Chap. *Gewerbe* In 'Statistisches Jahrbuch für das Deutschen Reich', (Berlin, 1912).

that the unemployment rate at that point in time was relatively low or stable. This is an essential requirement for our analysis, as we strive to determine the level of *potential* productivity differentials between the countries under comparison. We thus want to exclude the effects of business cycles and capacity under-utilization as much as possible; which, we are convinced, is the case for the selected census years.[33]

Figure 2: Peak and census years, 1900–1913



[a] Source: Maddison, 'Historical Statistics of the World Economy: 1–2008 AD', Table 2: GDP Levels, retrieved: 23 March 2011.

[b] Sources: [US] Weir, 'A Century of U.S. Unemployment, 1890–1990', 341–343; [GER] Pierenkemper, 'The Standard of Living and Employment in Germany', 58–59.

[c] The basic long-run trend growth is fitted as a least-squares polynomial of degree 2, for the period 1870–1913.

4 Results

Table 1 presents our new estimates of German/US comparative labour productivity levels for manufacturing industries in 1907/09 and 1936/35. For the sake of compatibility, we have recasted the original industrial nomenclature for both benchmark years into the Standard Industrial Classification, introduced in the US in 1947. Looking at the comparative productivity levels at the manufacturing level, we see why Broadberry described the gap between the US and Europe as persistent. Between both benchmark years, the German manufacturing sector showed no signs of closing-in on the frontier. It should be noted that the pre-WWI benchmark suffers

[33] See de Jong and Woltjer, 'Depression Dynamics' for an elaborate discussion of the business cycle and capacity utilization effects and a sensitivity analysis for the interwar period.

from a low coverage and its total manufacturing estimate is biased upwards as a consequence of *textile mill products*' large employment share in the total sample of benchmarked industries. Because of these compositional effects, we attach more importance to the industry-level results. Here, the comparisons show that it is impossible to speak of a common productivity path for the entire German manufacturing sector. Particularly, *textile mill products*, *chemicals & allied products*, and *primary metal industries* showed a strong performance. Both *textile mill products* and *chemicals & allied products* had a small advantage over America in 1907. Although these industries lost their lead in 1936, their performance dropped not far below US levels. The *primary metal industries*, in contrast, resembles a classic case of catch-up, closing the gap with the US between 1907 and 1936. All other industries lagged far behind the productivity frontier, both in 1907/09 and 1936/35. Especially the continual poor performance of *transportation equipment* stands out in this respect.

Table 1: German/American comparative productivity, ca. 1909 and 1935 (US = 100)

Description	1907/09	1936/35	Description	1907/09	1936/35
Nondurable products	90	49	Durable products	61	46
Food & beverages	69	45	*Lumber*	...	49
Tobacco	32	...	*Furniture*	...	...
Textiles	94	74	*Stone, clay & glass*	67	48
Apparel	...	49	*Primary metal*	65	93
Paper	...	52	*Fabricated metal*	...	48
Printing	...	...	*Machinery (ex. electrical)*	...	49
Chemicals	123	81	*Electrical machinery*	...	49
Petroleum	43	56	*Transportation equipment*	29	25
Rubber	...	42	*Instruments*	...	25
Leather	55	50	*Miscellaneous*	...	...
MANUFACTURING	78	47	MANUFACTURING	78	47

Sources: see text, chapter 3.

As mentioned, going down from a manufacturing level to industries improves our analysis of German growth developments. In table 1 we presented comparative labour productivity levels for manufacturing industries. Data availability allows a further breakdown of a number of those industries, which is shown in table 2 for 1907/09 and 1936/35. In the case of the prewar benchmark, it should be noted that the comparison of the *chemicals* industry is based only on sulphuric acid. This means that our estimate of comparative labour productivity does not include inorganic chemicals, such as dyestuffs and fertilizers, as well as organic chemicals, such as coal tar distillation products. Of course, the limited coverage of the *chemicals* industry leaves room for improvement. When we look at *primary metals* we see that *iron & steel* performed particularly well, while *nonferrous metals* did much worse in Germany. The difference between the underlying industries in the *petroleum* sector is even larger. In *petroleum refining* Germany lagged far behind the US. In *cokes* on the other hand productivity levels were quite good. This is hardly surprising considering the difference in resource endowments between the US and

Germany. America was petroleum abundant, while Europe had to rely mainly on imports for pertroleum based products. America's economy shifted to a petroleum basis much earlier than Europe, where coal remained the primary focus of the chemical industry until well into the twentieth century.[34] These specialization patterns persist in the interwar period, as can be seen in the second column of table 2.

Table 2: German/US labour productivity on a lower level of aggregation

Description	07/09 US=100	36/35 US=100
33 Primary metal	65	93
∘ *331 Iron & steel*	82	103
∘ *333 Nonferrous metals*	43	69
28 Chemicals & allied products	123	81
∘ *281 Sulfuric acid*	123	...
29 Petroleum and coal products	43	56
∘ *291 Petroleum refining*	25	30
∘ *293 Coke industry*	90	122

Sources: see text, chapter 3.

Table 3 below shows the comparison of German labour productivity levels between 1907 and 1936. The already mentioned German time-series difficulties pursuaded us to construct the intertemporal comparison. This way, we completely sidestep the Hoffmann discussion and come up with our own estimates, consisting of two benchmark years. As compared to the Hoffmann series as well as revisions thereof proposed by Ritschl and Broadberry and Burhop, our total manufacturing estimate is less optimistic about the growth of labour productivity over the period between 1907 and 1936. Again, the coverage of the 1907 benchmark is limited and the total manufacturing estimate should therefore not be taken as representative for industries not included in the comparison. The industry-level results do not suffer from such drawbacks. What catches the eye is a very distinct difference between traditional and modern industries (although we make this distinction with caution). Only the latter improved their productivity performance over time, while the former stagnated without exception. Remarkably, whereas *transportation equipment* showed a persistent poor performance as compared to its US counterpart, productivity levels almost quadrupled in Germany between 1907 and 1936. This implies that growth in the US *transportation equipment* industry was even more impressive during the interwar years. Given the fact that the automobile industry was 'the most spectacular American success story of the interwar period', Germany's backwardness in *transportation equipment* should not too swiftly be understood as a comparative failure.[35]

[34] R. R. Nelson and G. Wright, 'The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective', *Journal of Economic Literature*, Vol. 30 (1992), 1946.
[35] Ibid., 1945.

Table 3: German 1907/1936 comparative productivity (1936 = 100)

Description	1907/36	Description	1907/36
Nondurable products	116	Durable products	79
Food & beverages	118	*Lumber*	...
Tobacco	...	*Furniture*	...
Textiles	109	*Stone, clay & glass*	118
Apparel	...	*Primary metal*	79
Paper	...	*Fabricated metal*	...
Printing	...	*Machinery (ex. electrical)*	...
Chemicals	51	*Electrical machinery*	...
Petroleum	65	*Transportation equipment*	26
Rubber	...	*Instruments*	...
Leather	188	*Miscellaneous*	...
MANUFACTURING	100	MANUFACTURING	100

Sources: see text, chapter 3.

Table 4: German employment shares, ca. 1907 and 1936 (%)[a]

<table>
<tr><th>Description</th><th>1907</th><th>1936</th><th>Description</th><th>1907</th><th>1936</th></tr>
<tr><td>Nondurable products</td><td>56</td><td>44</td><td>Durable products</td><td>44</td><td>55</td></tr>
<tr><td>Food & beverages</td><td>13</td><td>7</td><td>Lumber</td><td rowspan="2">9</td><td>2</td></tr>
<tr><td>Tobacco</td><td>3</td><td>3</td><td>Furniture</td><td>3</td></tr>
<tr><td>Textiles</td><td>14</td><td>15</td><td>Stone, clay & glass</td><td>10</td><td>6</td></tr>
<tr><td>Apparel</td><td>11</td><td>4</td><td>Primary metal</td><td rowspan="2">14</td><td>9</td></tr>
<tr><td>Paper</td><td>2</td><td>3</td><td>Fabricated metal</td><td>5</td></tr>
<tr><td>Printing</td><td>3</td><td>3</td><td>Machinery (ex. electrical)</td><td>3</td><td>10</td></tr>
<tr><td>Chemicals</td><td>3</td><td>4</td><td>Electrical machinery</td><td>2</td><td>5</td></tr>
<tr><td>Petroleum</td><td>0</td><td>1</td><td>Transportation equipment</td><td>3</td><td>8</td></tr>
<tr><td>Rubber</td><td>0</td><td>1</td><td>Instruments</td><td>1</td><td>2</td></tr>
<tr><td>Leather</td><td>7</td><td>4</td><td>Miscellaneous</td><td>2</td><td>5</td></tr>
<tr><td>MANUFACTURING</td><td>100</td><td>100</td><td>MANUFACTURING</td><td>100</td><td>100</td></tr>
</table>

[a] May not sum to total due to rounding. Sources: see text, chapter 3.

Increasing labour productivity levels in manufacturing or even entire economies have often been explained by structural changes.[36] Aggregate productivity levels benefit from shifts of labour towards high productive industries. From this perspective, labour productivity in manufacturing can increase without a corresponding growth of productivity levels in the underlying industries. For German manufacturing we studied changes in employment shares between 1907 and 1936, as shown in table 4. Over the interwar period, labour shifted from nondurable to

[36] Broadberry, *The Productivity Race*.

durable industries. Table 3 already pointed out that productivity levels in German manufacturing only increased, on average, in durable industries. Moreover, the shift from nondurable to durable manufactures was mainly driven by increasing labour shares of modern and fast growing industries, such as *machinery (ex. electrical)*, *electrical machinery*, and *transportation equipment*. Employment thus moved towards the more productive elements in German manufacturing.

Table 5: German/UK comparative productivity, 1907/09 and 1936/35 (UK = 100)

Description	1907/09	Description	1936/35
Textile	143.7	*Textile*	76.2
Leather	125.3	*Leather*	47.1
Primary metals	142.4	} *Iron and steel*	175.1
		Nonferrous metals	103.9
Motor vehicles	95.8	*Engineering*	106.1
Food & beverages	76.0	*Food & beverages*	77.8
Chemicals	108.8	} *Chemicals*	125.5
Petroleum and coke	111.3		
Cement	131.4	*Clay and building materials*	105.7

Sources: Fremdling, de Jong and Timmer, 'British and German manufacturing Productivity Compared', 353.

In the introduction we hinted at two coexisting technological paths within German manufacturing. Industries pursued either a British or an American technological paradigm. In terms of labour productivity, this implies that a number of German industries hoovered around US levels, clearly outperforming the UK, while another part of German manufacturing remained stuck on British level. Table 5 presents the results of German/UK benchmarks for 1907/09 and 1936/35. The interwar comparison stems from Fremdling, de Jong and Timmer.[37] For the pre-WWI period, we have recasted the latest revision of Broadberry and Burhop's comparison into the SIC classification.[38] In addition, for particular industries we deviated from the methods used by Broadberry and Burhop; we have consistently used value approach as often as we could.

In comparison with the Broadberry and Burhop data, two figures stand out in particular, most notably Germany's exceptionally strong performance in textiles before WWI. Here, Broadberry and Burhop point at a British lead over Germany of about 20%. For a large part the difference stems from a smaller employment number in our calculations, pushing German productivity levels upwards. As mentioned before, for some German prewar industries, we are forced to combine output data from the industrial surveys with employment data from the occupational census. We have done so for the textile industry and, subsequently, adjusted the employment number from the occupational census downwards in line with the coverage of firms in the industrial surveys. Broadberry and Burhop also report employment data obtained from the occupational census, but we have been unable to replicate those numbers. If we look at post-WWII German-UK comparisons, it is clear that Britain was specifically productive in textile weaving and not in

[37] Fremdling, de Jong and Timmer, 'British and German manufacturing Productivity Compared', 353.

[38] S. Broadberry and C. Burhop, 'Resolving the Anglo-German industrial productivity puzzle, 1895-1935: a response to professor Ritschl', *Journal of Economic History*, Vol. 68, Nr. 3 (2008), 392.

spinning. As our pre-WWI output sample only includes spun goods and twist, we are likely to overestimate German comparative productivity. For 1936, woven products – such as cloth – are included, which could explain the lower German/British level.

In addition, the estimate for leather catches the eye. We already showed that between 1907 and 1936 the German leather industry received some heavy blows. However, around 1910 the German leather industry performed at a meagre 70% of the UK, according to Broadberry and Burhop. Looking at the data of these scholars, we see that we use the same output and employment numbers. Yet whereas the former apply a quantity approach, i.e. comparing tons of output, we chose gross output as a measure of productivity. The quantity approach assumes that all products compared are homogenous. In the case of Broadberry and Burhop we have checked this by calculating an implicit PPP, which turned out to be 36 Mark/£. As the exchange rate stood at 20 Mark/£, it is likely that the basket of German leather goods used for the comparison are of different – in this case, higher – quality than those of the UK. The value approach uses product-specific UVRs, which allows us to pool heterogenous products. We used a PPP of 19 Mark/£ – reassuringly close to the official exchange rate – to deflate German output, leading to a much higher German/British productivity level.

Notwithstanding the time inconsistencies for textiles and leather, particular patterns already seen in the German/US comparisons reappear in table 5. Most notably, the German *primary metal industries (iron & steel and nonferrous metals)* were far superior to their British counterparts. Also in *chemicals* Germany outperformed the UK, although – as pointed out above – that particular comparison suffers from compositional effects. The lack of data on inorganic chemicals biases the estimate downwards. The interwar benchmark covers all chemical industries, thereby leading to a larger German/UK productivity gap. Apart from these industries, Germany and the UK were roughly on par in both 1907 and 1936.

5 Strong performance despite initial conditions

Although the Rothbarth-Habakkuk thesis offers an attractive answer to the gap on manufacturing level, the benchmark results persuade us to tread the transatlantic gap with caution. The fact that some German industries performed roughly on par with their US counterparts challenges in particular the teleological nature of the initial-conditions approach. That is, the literature has described America's lead over Europe from the late nineteenth century onwards as foreordained.[39] US resource endowments acted as a benevolent Providence, inevitably setting the stage for America's edge over Europe.[40] In contrast, conditions in the latter were less favourable to growth, sentencing Europe to an inferior productivity path. Many German manufacturing industries in our benchmarks do indeed show a persistant backwardness, but certainly not all.

The German textile, iron & steel, and chemical industries do not conform to the theory of a particular European path characterized by low productivity levels. From this we infer that for those industries initial conditions did not prevent Germany from catching-up with the productivity frontier. If country-specific conditions constrained growth at all, their effects in aforementioned industries appear to have been minimal. We can think of several reasons why

[39]N. Rosenberg, Chap. Why in America? In 'Exploring the black box. Technology, economics, and history', (1994) 112.

[40]Ibid. 112.

particular industries could escape the initial-conditions trap. For instance, because the degree to which industries rely on raw materials differs, some industries were affected more than others. However, the importance of natural resources in the *iron & steel* as well as the *textile* industries is undeniable, both in the form of raw materials and as fuel. That brings us to consider a second possibility. Factor costs in the 'successfull' German industries might not have deviated from their American counterparts as much as the Rothbarth-Habbakuk thesis suggests.

With regard to the second suggestion, the literature provides information on the costs of intermediate inputs during the pre-WWI period. Bob Allen accounted for price differences between German, American, and British iron products by studying the costs of materials used and the efficiency of production.[41] Around 1910, the price of used raw materials (ore and scrap) in Germany was lower than in both the US and UK.[42] Fuel (blast furnace coke) was more expensive as compared to the US, but cheaper than in Britain. In line with our benchmark results, Allen shows that productivity in Germany was comparable to the US and higher than in the UK.[43] Low production costs in Germany were the consequence of low material and labour costs as well as high effeciency levels.

The lead of Germany and the US over Britain in 1910 was, however, not traditional. Until at least the 1880s, labour productivity in British ironworks lay above those in its German and American counterparts.[44] In the following three decades this situation was reversed. It has been suggested that the US has used obsolete prodution technologies until halfway through the nineteenth century. The relative abundance of charcoal, for instance, delayed the switch to the 'modern' coke-fueled blast furnaces.[45] Nevertheless, when new technologies found their way across the Atlantic, they were swiftly improved upon. Most importantly, the Bessemer process – originally introduced in Britain during the 1850s – was adopted and subsequently further developed in the US during the 1860s, outperforming British steel-producing technologies. As a consequence, the flow of technology transfer was reversed by 1880, when European manufacturers started to copy American designs.[46]

This very pronounced difference between modern and traditional industries could indicate that technological lock-in effects mainly played a role for branches set up before the 1870s. These industries were encouraged to organize according to British blueprints, as the UK constituted the productivity frontier until at least the 1850s. Shifting the technological basis of entire industries decades or even centuries after their time of birth would be a very costly and time consuming event. In contrast, modern industries were free from such path dependencies and, therefore, could directly apply technologies from the new frontier, i.e. the US.

The distinction between German industries set up before and during the Second Industrial Revolution was not pronounced in the German/US comparisons. Some of the modern industries performed relatively good, while some did not. A likewise story goes for the traditional industries. Although most of these persistently lagged behind the US, *textiles* ranked among the top three of strong performing industries.

[41] B. Allen, 'International competition in iron and steel, 1850-1913', *Journal of Economic History*, Vol. 39 (1979) 911.

[42] Ibid. 932. Actually, British iron ore mined in the East Midlands and Cleveland was at least as cheap as the German ore from West-Phalia. However, for some reason Britain mainly used the more expensive Spanish ore.

[43] Ibid. 931.

[44] Ibid. 927.

[45] C. Hyde; D. Jeremy, editor, Chap. Iron and steel technologies before 1914 In 'International technology transfer. Europe, Japan and the USA, 1700-1914', (1991) 52.

[46] Ibid. 68.

6 Concluding remarks

In this paper we argue that the German manufacturing sector was actually driven by two coexisting technological paths. Contrary to the Rothbarth-Habakkuk thesis, this suggest the German manufacturing sector was not bound by limited factor and resource endowments or heterogeneous demand patterns. Particularly those industries established during the Second Industrial Revolution were, in specific cases, able to adopt American technologies and thus distance themselves from the labour-intensive production process typical for Europe. These findings are in line with qualitative evidence which show that it was indeed commonplace in these industries to import or copy American machinery.

Given the very strong US performance in manufacturing throughout the late nineteenth and twentieth century, the interest of German entrepreneurs in American technological and managerial innovations is perhaps not all that surprising. Whereas the current empirical debate centers almost exclusively around German industrial performance in relation to the United Kingdom, we shift attention to the transatlantic productivity gap. The relative labour-productivity differentials between Germany and the US provide key insights into the mechanics and technological basis of the former's manufacturing sector. In this paper we provide three benchmark comparisons, two German/American comparisons of labour productivity in 1907/09 and 1936/35, and a direct German comparison between the years 1907 and 1936. We apply the ICOP methodology – a more sophisticated method than has thus-far been applied for pre-WWI comparisons – which allows us to directly measure the comparative productivity levels between both countries and time periods at the industry level.

The productivity levels presented above challenge the 2:1 persistent productivity gap suggested by Broadberry. Our results show that the comparative German/American productivity estimate for *total manufacturing* obscures the underlying dynamic nature of the individual German industries. Although performance in particularly the traditional industries (e.g. *apparel*, *leather* and *lumber*) conforms to the 2:1 ratio and mirrors British productivity, the performance of particularly the *textiles*, *chemicals* and *primary metal* industries fell only slightly below American levels. The comparison of German labour productivity levels between 1907 and 1936 reveals a very pronounced difference in growth trajectories between the traditional industries and those industries linked to the Second Industrial Revolution; in particular it underscores the strong performance in *chemicals* and *steel*. The inter-temporal comparison also highlights strong growth in the German *transportation equipment* industry, which qualifies the persistent poor performance in this sector as compared to its American counterpart.

These findings emphasize it is unlikely German manufacturing was tracking a single technological path, but instead suggest that a number of German manufacturing industries were indeed pursuing an American paradigm. This leads us to question the technological lock-in hypothesis. The pronounced difference between modern and traditional industries could indicate that technological lock-in effects mainly played a role for branches set up before the 1870s. Whereas these industries were organized almost exclusively according to British blueprints, the modern industries of the Second Industrial Revolution could directly adopt technologies from the then technology leader, i.e. the US. It were these modern industries which lay the foundation for Germany's industrial expansion in the twentieth century.

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