A TALE OF TWO TAILS: PLANT SIZE VARIATION AND COMPARATIVE LABOR PRODUCTIVITY IN U.S. AND GERMAN MANUFACTURING IN THE EARLY 20th CENTURY

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Abstract
This paper presents a German/U.S. comparison of labor productivity in mining and manufacturing for two benchmark years, 1909 and 1936/35. German manufacturing productivity had a level of ca 56 per cent of the U.S. level in 1909, and around 50 per cent in 1935. Variation across industries was large. Next we analyze for 1909 whether the scale of production has been a decisive factor in the differences in performance between Germany and the U.S. American data on state level show no direct relationship between the average plant size and labor productivity. We do find a positive relationship between labor productivity and the skewness of the distribution of plant size. In turn, skewness is strongly correlated with the number of plants established in a state. From this we draw the tentative conclusion that skewness provides a measure of plant-concentration and captures external economies of scale, flexibility and competition, driving the positive relation with labor productivity. With respect for the transatlantic labor-productivity gap, these findings suggest that the comparatively low average establishment size in Germany did not necessarily convey a disadvantage. More important may have been the setting in which small German establishments operated that kept them from attaining U.S. levels of labor productivity. We conjecture that Germany’s poor average productivity performance in manufacturing was a combined effect of low wages and heterogeneous demand patterns.

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A Tale of Two Tails: Plant Size Variation and Comparative Labor Productivity in U.S. and German Manufacturing in the Early 20th Century

1. Introduction

Germany's rapid economic development from the late nineteenth century onwards has traditionally been described as an example of catch-up growth (see e.g. Gerschenkron 1962, 16; Landes 1969, 236). In particular the rapid transformations in the new, science-based industries of the second industrial revolution, such as engineering, chemical production, and metal manufacturing, have received attention (Braun 1990, 20). To which degree these developments propelled Germany to the vanguard of industrial development is still a topic of debate, as demonstrated by the discussion recently held between Broadberry and Burhop, and Ritschl, who did not reach consensus over the question whether or not Germany had surpassed Britain in levels of manufacturing labor productivity by the turn of the twentieth century (Broadberry and Burhop 2007; Ritschl 2008). It has not been attempted to compare Germany with the U.S., which is a surprise given the latter's well-established lead over Europe in manufacturing; if German growth genuinely resulted from a catch-up process, i.e. the “benefits of backwardness”, than the universal productivity leader US – and not Britain – seems the appropriate point of reference (Broadberry 1997a).

This paper presents a German/U.S. comparison of labor productivity in mining and manufacturing for two benchmark years, i.e. 1909 and 1936/35. The results of this exercise are confronted with two strands of literature, each highlighting a different aspect of the German growth experience. First, it has been argued that low relative labor costs in Europe discouraged the substitution of machinery for skilled labor, which in turn constrained the adoption of labor-productivity enhancing technology (Habakkuk 1962; David 1975, 66; Temin 1971, 162; Field 1985, 379). Secondly, it has been suggested that the small scale of European production negatively affected labor productivity. Large-scale production and standardization was limited, because producers in Europe faced a smaller domestic market characterized by a demand for customized goods (Rostas 1943, 58-59; Chandler 1990, 47; Landes 1969, 247; Broadberry 1994, 291). Evidence in support of such theories are based mainly on the case of Britain. The question is whether the British constraints to labor-productivity growth applied also to Germany.

Having matched British performance, did Germany subsequently encounter the same barriers for further growth that have prevented the UK from catching-up to the U.S.? This should not necessarily have been the case. Chandler pointed at similarities between the German system of manufacturing with the U.S., such as the managerial system (Chandler 1992). Also, the unique institutional setting in which German producers operated, in particular the cartel-tariff system, has been associated with labor-productivity
benefits, which may have counteracted some of the ails that European countries suffered from (Hannah 1995, 207-208; Kinghorn 1996, 109; Levenstein 2006, 85).

In addition to questions of relative performance and catch-up, this paper addresses the issue of labor-productivity movements within Germany too. During the first decades of the twentieth century the U.S. economy showed an unprecedented growth spurt. By just comparing Germany's performance with America the growth record of German industries between 1909 and 1936 may easily remain unnoticed (Field 2003). For both years novel methodologies for constructing productivity comparisons are taken on board to allow for the most accurate analysis possible. This involves the application of an industry-of-origin approach to the benchmark estimates, which, among other things, entails a breakdown of manufacturing into various industries to provide the level of detail needed to map out an economy's productivity profile.

We combine our findings with new data on the distribution characteristics of plant size in the U.S. on state level, and Germany. Central to the line of argument pursued here is the idea that the technologies of the second industrial revolution favored large-scale production to induce efficiency advantages. The U.S. adopted standardization and high-throughput production technology, usually associated with high levels of capital intensity, more widely than the European countries (Rostas 1943, 58-59; Chandler 1990, 47; Landes 1969, 247). European markets were smaller and typically specialized in customized production (Broadberry 1994, 291). From this line of reasoning it follows that manufactures of consumer goods must have suffered more from heterogeneous demand than the producers of basic goods. We find that strong performing German industries are involved in the production of predominantly basic goods. This could suggest that these industries performed well due to their large scale of production relative to industries producing consumer goods, assuming that labor productivity and establishment size are positively related. Using U.S. data on the state level, we explore this potential relation for 1909.

2. The transatlantic labor-productivity gap
The methodology and data described in appendix 1 enables us to compare labor-productivity levels between German and U.S. manufacturing industries. This is necessary because the extent to which Germany lagged behind the global productivity leader is not immediately evident from other studies. In the literature German/UK and U.S./UK comparisons are presented for prewar and interwar years. Until now, direct German/U.S. comparisons were not available. The size of the pre-WWI gap between Germany and the UK before WW1 is not undisputed. Both Steven Broadberry and Carsten Burhop, and Albrecht Ritschl have presented German/UK benchmarks for 1907, reporting a productivity ratio in manufacturing
of 1.08 and 1.28, respectively (Ritschl 2008, 549; Broadberry 2008, 932). Contingent on the choice between these benchmarks, Broadberry and Irwin's estimate of a 2:1 American lead over Britain in 1909/10 implies a German/U.S. productivity ratio of either 0.54 (via Broadberry and Burhop) or 0.63 (via Ritschl); a difference which is quite sizable for this type of research (Broadberry and Irwin 2006, 261).

<table>
<thead>
<tr>
<th>Industry</th>
<th>PPP (Ger/U.S.)</th>
<th>1909</th>
<th>1936/35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>7.18</td>
<td>6.19</td>
<td>6.66</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>4.33</td>
<td>3.49</td>
<td>3.89</td>
</tr>
<tr>
<td>Food and kindred products</td>
<td>4.19</td>
<td>2.87</td>
<td>3.47</td>
</tr>
<tr>
<td>Textile mill products</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
</tr>
<tr>
<td>Tobacco manufactures</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Paper and allied products</td>
<td>4.59</td>
<td>4.53</td>
<td>4.56</td>
</tr>
<tr>
<td>Chemical and allied products</td>
<td>3.64</td>
<td>2.83</td>
<td>3.21</td>
</tr>
<tr>
<td>Petroleum and coal products</td>
<td>6.63</td>
<td>6.05</td>
<td>6.33</td>
</tr>
<tr>
<td>Rubber products</td>
<td>7.71</td>
<td>7.71</td>
<td>7.71</td>
</tr>
<tr>
<td>Leather and leather products</td>
<td>4.86</td>
<td>5.42</td>
<td>5.13</td>
</tr>
<tr>
<td>Stone, clay, and glass products</td>
<td>4.13</td>
<td>4.12</td>
<td>4.12</td>
</tr>
<tr>
<td>Primary metal products</td>
<td>3.58</td>
<td>3.22</td>
<td>3.39</td>
</tr>
<tr>
<td>Transportation equipment</td>
<td>4.82</td>
<td>5.03</td>
<td>4.92</td>
</tr>
</tbody>
</table>

Sources: see appendix 1

Our approach compares the gross output by industries between countries using an industry-specific conversion factor or purchasing power parity (PPP). The listed Laspeyres, Paasche, and Fischer versions differ markedly between manufacturing industries and the official exchange rate would function poorly for the purpose of converting industrial output. On the total output level, however, the 1909 Fischer PPP for industry closely resembles the official exchange rate, which signals that the latter reflects fairly accurately the average price ratio between Germany and the US. This no longer holds for the interwar period, when the official exchange rate overvalued the Reichsmark with considerable margin. In this case, the use of the exchange rate to convert Reichsmark to U.S. Dollar would introduce a bias in the comparison in favor of German productivity.

Looking at the PPPs presented in table 1, for several industries the Laspeyres and Paasche PPPs vary substantially, specifically in 1936/35. This is an indication of structural differences between the countries under comparison. The deviation between the Laspeyres and Paasche PPPs stems from the use of,
respectively, base-country (U.S.) or non base-country (German) weights for the process of aggregation and variation between the two is evidence of dissimilar production structures. A clear example is the case of the petroleum and coal industry in 1936/35; the early adoption of petroleum-based production techniques in the U.S. led to a large gap in output prices relative to Germany.

Table 2: German/U.S. comparative labor productivity per employee and per hour worked, 1909 and 1936/35 (US=100)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Per employee</th>
<th></th>
<th>Per hour</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1909</td>
<td>1936/35</td>
<td>1909</td>
<td>1936/35</td>
</tr>
<tr>
<td>Mining</td>
<td>40</td>
<td>29</td>
<td>44</td>
<td>26</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>57</td>
<td>52</td>
<td>56</td>
<td>47</td>
</tr>
<tr>
<td>Food and kindred products</td>
<td>55</td>
<td>43</td>
<td>55</td>
<td>41</td>
</tr>
<tr>
<td>Tobacco manufactures</td>
<td>30</td>
<td>35</td>
<td>30</td>
<td>34</td>
</tr>
<tr>
<td>Textile mill products</td>
<td>90</td>
<td>111</td>
<td>86</td>
<td>103</td>
</tr>
<tr>
<td>Paper and allied products</td>
<td>53</td>
<td>52</td>
<td>53</td>
<td>46</td>
</tr>
<tr>
<td>Chemical and allied products</td>
<td>80</td>
<td>105</td>
<td>82</td>
<td>96</td>
</tr>
<tr>
<td>Petroleum and coal products</td>
<td>42</td>
<td>55</td>
<td>43</td>
<td>50</td>
</tr>
<tr>
<td>Rubber products</td>
<td>50</td>
<td>46</td>
<td>51</td>
<td>43</td>
</tr>
<tr>
<td>Leather and leather products</td>
<td>66</td>
<td>57</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>Stone, clay, and glass products</td>
<td>51</td>
<td>54</td>
<td>51</td>
<td>48</td>
</tr>
<tr>
<td>Primary metal products</td>
<td>67</td>
<td>103</td>
<td>64</td>
<td>88</td>
</tr>
<tr>
<td>Transportation equipment</td>
<td>30</td>
<td>24</td>
<td>30</td>
<td>21</td>
</tr>
</tbody>
</table>

Sources: see appendix 1

The conversion of industrial output with the PPPs reported in table 1 enables us to make a comparison of German and U.S. labor-productivity levels in 1909 and 1936/35. The results of these comparisons are listed in table 2. Because of the data constraints discussed in appendix 1, comparative productivity for 12 pre-WW1 industries could be calculated (11 manufacturing industries and mining). Although for 1936/35 it was possible to provide full-manufacturing coverage, for reasons of consistency and comparability table 2 includes an estimate based on the same selection of industries as studied for the year 1909. The employment coverage of the prewar comparison amounts to 34% for Germany and 47% for the U.S. In 1936/35 the coverage of the prewar industry-sample was 32% and 33%, respectively.²

The lack of full-coverage data for the pre-WW1 period may introduce a bias in the estimates. Indeed, on the aggregate level, a comparison between the sample and full-coverage results for 1936/35, presented in

²For Germany 1909 95% of mining employment is covered. All employment is taken into account for U.S. 1909, U.S. 1935 and Germany 1936.
table 3 below, shows that the former overstate Germany's performance by about 10%. The difference is accounted for by two effects. First, the performance in some German industries is overestimated by the sample data. For textiles, chemicals and, to a lesser extent, primary metals the total-industry results show a much poorer performance on the part of Germany. This indicates that the production activities covered by the 1909 sample displayed a high performance level, a finding that helps explain the strong performance in some parts of German manufacturing, an issue to which we will return later. Second, several industries are excluded by the sample data and these tended to perform relatively weak.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Per employee</th>
<th></th>
<th>Per hour</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample</td>
<td>All</td>
<td>Sample</td>
<td>All</td>
</tr>
<tr>
<td>Mining</td>
<td>29</td>
<td>29</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>52</td>
<td>46</td>
<td>47</td>
<td>41</td>
</tr>
<tr>
<td>Food and kindred products</td>
<td>43</td>
<td>45</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td>Tobacco manufactures</td>
<td>35</td>
<td>35</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Textile mill products</td>
<td>111</td>
<td>74</td>
<td>103</td>
<td>69</td>
</tr>
<tr>
<td>Apparel products</td>
<td>. . .</td>
<td>49</td>
<td>. . .</td>
<td>39</td>
</tr>
<tr>
<td>Lumber and wood products</td>
<td>. . .</td>
<td>49</td>
<td>. . .</td>
<td>46</td>
</tr>
<tr>
<td>Paper and allied products</td>
<td>52</td>
<td>52</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Chemical and allied products</td>
<td>105</td>
<td>72</td>
<td>96</td>
<td>66</td>
</tr>
<tr>
<td>Petroleum and coal products</td>
<td>55</td>
<td>56</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>Rubber products</td>
<td>46</td>
<td>41</td>
<td>43</td>
<td>39</td>
</tr>
<tr>
<td>Leather and leather products</td>
<td>57</td>
<td>50</td>
<td>55</td>
<td>48</td>
</tr>
<tr>
<td>Stone, clay, and glass products</td>
<td>54</td>
<td>48</td>
<td>50</td>
<td>43</td>
</tr>
<tr>
<td>Primary metal products</td>
<td>103</td>
<td>93</td>
<td>88</td>
<td>79</td>
</tr>
<tr>
<td>Fabricated metal products</td>
<td>. . .</td>
<td>48</td>
<td>. . .</td>
<td>42</td>
</tr>
<tr>
<td>Machinery (excl. electrical)</td>
<td>. . .</td>
<td>49</td>
<td>. . .</td>
<td>40</td>
</tr>
<tr>
<td>Electrical machinery</td>
<td>. . .</td>
<td>49</td>
<td>. . .</td>
<td>43</td>
</tr>
<tr>
<td>Transportation equipment</td>
<td>24</td>
<td>25</td>
<td>23</td>
<td>22</td>
</tr>
</tbody>
</table>

Sources: see appendix 1

The top rows of tables 2 and 3 report the comparative performance on the aggregate level and shows that Germany tracked America at considerable distance, both in 1909 and 1936/35. Despite this large potential for catch-up growth, German levels of productivity were still low at the end of the interwar period.³ The idea of catch-up is old and can be found in the works of, for instance, Gerschenkron1962, 113, 116 and Abramovitz1986, 387. For more recent frontier analysis see, for example, Acemoglu2002, 39 and Vandenbussche2006, 98.
U.S. extended its lead and the German/U.S. productivity ratio dropped from 57% to 52%, which might not come as surprise given the turbulence in Germany since 1914.

So far we have looked at gross output per employee in Germany and the US. There are, however, good reasons to adjust for working hours. Over the interwar period both the U.S. and European countries saw a rapid drop of hours worked per year. Both the increased bargaining power of labor unions, and the effects of the Great Depression have led to a shortening of the working week and an increasing number of holidays. Since the change in hours worked was larger for the U.S., adjusting for hours will affect the labor-productivity comparisons. For the U.S., total annual hours worked per worker per year dropped from 2,718 in 1909 to 1,817 in 1935; a decrease of 33%. The corresponding figures for Germany show a less pronounced drop from 2,723 hours in 1909 and 2,073 in 1936. Table 2 reports the comparative labor-productivity levels corrected for hours worked. Compared to the output per employee results the correction for differences in working hours hardly matters for the year 1909, but makes a big difference for the interwar period and reinforces Germany’s poor productivity performance vis-à-vis the U.S.

The new benchmark results call for a moderate revision of German industry's competitiveness relative to the U.S. First, before WW1 German industry was somewhat stronger than implicitly indicated by Broadberry and Burhop, but certainly not as strong as suggested by Ritschl. Second, the considerable drop in comparative performance over the interwar period when labor input is measured by hours worked questions the stationary 2:1 ratio attributed to the transatlantic productivity gap in Broadberry's work, a conclusion also drawn by de Jong and Woltjer (2011) for the case of the U.S. and the U.K. Nevertheless, the findings on the aggregate level broadly align with the traditional view on the 'productivity race', in which the U.S. enjoyed a commanding lead over Europe throughout the first half of the twentieth century (Broadberry 1997a, 34).

Whereas German manufacturing on average dropped far behind the U.S., comparative performance across manufacturing industries ranged from very poor to impressively strong. Variation in comparative performance between industries can be explained as an economy’s productivity profile. Broadberry, for instance, has pointed at Britain's characteristic comparative advantage in light industries, where the productivity gap with the U.S. was smaller than on the level of total manufacturing (Broadberry 1997a, 26-27). There is more than one story to be told for German manufacturing industries, too. Classified according to their distance to the frontier, German industries can be grouped in two categories. First, many

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4The correction for hours worked is based on data from Huberman2004 and Huberman2007. In addition, several primary sources have been used, i.e. StatJahrbuch, Hoffmann1965, CensusUS1910VIII, ILO1939 and Matthews1982.
industries failed to keep up with the U.S. and performed at a level half that of their American counterparts, or even less. At the low end of this group are tobacco manufacturing and the transportation-equipment industry, while paper production and leather performed somewhat better. A second group is formed by industries that managed to keep up with the U.S. This was a small group constituted by textiles, chemicals and primary metals.

When we probe deeper and dissect the manufacturing sector on the SIC 3-digit level, the pronounced variation between comparative levels of performance persists. For instance, a breakdown of primary metals in 1909 points out that the iron & steel industries in Germany were not inferior to the U.S. A low efficiency in nonferrous metals, however, depresses the productivity level for German primary metals as a whole. Similarly, the large gap between Germany and the U.S. in petroleum and coal production was caused by a low level of productivity in German petroleum refining. In coke production Germany was no less efficient than America. The comparative performance of chemical industries in 1936/35 varied, too; while the German paint production performed at a third of the U.S. level, Germany enjoyed an advantage over America of about 2:1 in the fertilizer industry. In short, the range of German industrial performance relative to the American frontier was large.

In spite of the observed variation in comparative labor productivity between industries, the pattern of strong versus weak performers persisted over time. Leather manufacturing, paper production, petroleum refining, and transportation-equipment industries all persistently trailed the U.S. at a large distance. At the other end of the spectrum textiles, primary metals and chemicals, all of which already did well in 1909, improved their comparative performance. The recurrence in 1936/35 of a productivity profile similar to the case of 1909 suggests that the level of comparative performance was dictated by long-run growth determinants, despite the turbulence of the period.

The common characteristic shared by all three industries that managed to approach U.S. levels of labor productivity was that they produced mainly basic, standardized goods. A large part of the primary-metals industry's output was processed further in the fabricated-metals, (electrical-) machinery or transportation-equipment industries. The textile industries studied for 1909 concern spinning activities producing yarn and thread, which was subsequently used in weaving or apparel industries. The chemical products included in the prewar sample, in particular sulfuric acid and potassium compounds, formed the intermediate inputs needed for the production of fertilizers. Indeed, for textiles, chemicals as well as primary metals the 1936/35 comparison shows that the prewar industry sample displays a level of labor

See J. Veenstra (2014), ch. 2.
productivity well above the average for the industry as a whole (see table 5). Conversely, many of the industries facing a particular large gap to the U.S. involved the production of predominantly consumer goods, the food & drink and transportation equipment industries being prime examples.

3. Labor-productivity growth in interwar Germany

Although the productivity gap with the U.S. hardly changed between 1909 and 1936/35, German industries did not necessarily lack technical progress. Conditional on the rate of productivity growth in the U.S., a German industry could rapidly increase productivity levels and still fail to catch-up. Table 4 provides an overview of productivity growth in German manufacturing industries between 1909 and 1936. As with the German/U.S. comparisons, the results are obtained through application of a methodology where industry-specific PPPs are constructed on the basis of prices calculated from the census (see appendix 1). Because it concerns a single-country intertemporal comparison, the purchasing power parity is interpreted as a domestic price index and used to convert nominal to real output, i.e. 1909 Goldmark into 1936 Reichsmark. The labor-productivity difference between 1909 and 1936 is expressed in average per annum growth to get an accurate estimate of the pace of change.

<table>
<thead>
<tr>
<th>Industry</th>
<th>PPP change 1909/1936</th>
<th>Employees</th>
<th>Hours</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>0.94</td>
<td>2.2</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.94</td>
<td>0.6</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Food and kindred products</td>
<td>0.66</td>
<td>-1.2</td>
<td>-0.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Tobacco manufactures</td>
<td>. . .</td>
<td>1.7</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Textile mill products</td>
<td>0.76</td>
<td>-0.5</td>
<td>0.8</td>
<td>-0.05</td>
</tr>
<tr>
<td>Paper and allied products</td>
<td>1.11</td>
<td>1.5</td>
<td>2.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Chemicals and allied products</td>
<td>1.16</td>
<td>1.7</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Petroleum and coal products</td>
<td>0.85</td>
<td>0.8</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>Rubber products</td>
<td>2.01</td>
<td>1.6</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Leather and leather products</td>
<td>0.99</td>
<td>-0.5</td>
<td>0.6</td>
<td>-0.3</td>
</tr>
<tr>
<td>Stone, clay, and glass products</td>
<td>1.01</td>
<td>2.4</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Primary metals products</td>
<td>0.91</td>
<td>0.7</td>
<td>1.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Transportation equipment</td>
<td>2.07</td>
<td>5.7</td>
<td>6.8</td>
<td></td>
</tr>
</tbody>
</table>

Sources: see text.

Providing new estimates on German growth is also important because there are doubts about the reliability of the output and employment data of the German Historical National Accounts (HNA) by Walther
Hoffmann, which have been constructed in the 1960s. The critique on Hoffmann's series is directed toward his use of income data to estimate output growth. Because the productivity to wage ratio changed, the use of the latter as a proxy for output leads to spurious growth (Ritschl 2004). As the quality of the time series has been called into question, extrapolating backwards from known labor-productivity levels in the interwar period could potentially lead to inaccurate estimates. New estimates of labor-productivity growth in German manufacturing are therefore necessary (Hoffmann 1965; Fremdling 1988).

Our intertemporal comparison does not suffer from the problems associated with the time series and, therefore, offers a convenient alternative. Table 4 also reports the average annual growth rate of output per employee in German industries between 1909 and 1936 calculated on the basis of Hoffmann's data. The intertemporal productivity comparison corresponds reasonably well with his estimates. The growth rates observed for mining, textiles, leather and metal production differ little between the calculations of Hoffmann and our own. A major exception is the case of the building materials industry, which compared with the stone, clay, and glass industry shows a relatively low rate of growth. This discrepancy is driven by the composition of the industries, which differs between Hoffmann's and our classification. The growth of the stone, clay, and glass industry is driven mainly by cement production, a process that underwent rapid change over the interwar years.

Our new results provides more detail as compared to Hoffmann's estimates. For example, whereas in case of the latter the food & kindred industry is combined with tobacco, our estimation makes a distinction between the two and shows that the -0.3 average annual growth rate displayed by Hoffmann's series is the result of a decline in output per employee levels in food & kindred, which is in turn partly offset by an increase in tobacco production. The same applies to chemical industries; whereas the benchmark distinguishes between chemical and petroleum production, the time series do not allow for such a breakdown.

The present estimation adjusts for differences in working hours between the prewar and interwar period. In Germany the total number of hours worked on an annual basis decreased by 25%. Taking account of this reduction in labor input leads to an upward adjustment of labor-productivity growth. As a result, the food, textiles and leather industries no longer display a negative rate of labor-productivity growth, as implied by Hoffmann.

Table 4 shows that some industries experienced rapid growth while others appeared to stagnate or even decline. With respect to the former, the common characteristic of fast-growing industries appears to have
been the early stage in the life-cycle. In particular ‘new’ industries developed rapidly, the transportation equipment industry being a prime example. The latter’s fast-paced growth is reflected by the price ratio between 1909 and 1935. The price level dropped sharply between 1909 and 1936, a characteristic feature of rapidly developing industries. Rubber, which through the production of tires was closely related to the motor-vehicles industry, and chemicals & allied belong to this category too. Industries starting (chemicals, motor vehicles, tires, petroleum) or extensively modified (primary metals, tobacco) during the late nineteenth century succeeded in raising productivity levels. In contrast, the industries with stagnating productivity growth (e.g. food & kindred, textiles and leather) were in a later stage of their life-cycle.6

The results presented in table 4 shed new light on the comparative German/U.S. productivity levels. Germany’s relatively favorable comparative performance in textiles over the interwar period now looks less impressive knowing that the relatively small productivity gap resulted from a lack of any significant progress in both countries. On the other hand, Germany’s performance vis-à-vis the U.S. in emerging industries, e.g. chemicals & allied, and industries still in development, such as primary metals, looks quite favorable. Furthermore, the large and persistent productivity gap in the transportation-equipment industry might be understood best as an extraordinary success of the early expansion of the U.S. motor vehicle industry, rather than a German failure.

Table 5: Employment shares Germany and the U.S., 1907 and 1936/35 (in %)

<table>
<thead>
<tr>
<th></th>
<th>GER 1907</th>
<th>GER 1936</th>
<th>U.S. 1909</th>
<th>U.S. 1935</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Food &amp; tobacco</td>
<td>16</td>
<td>8</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Textiles &amp; apparel, leather</td>
<td>31</td>
<td>24</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Wood &amp; furniture</td>
<td>9</td>
<td>5</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>Paper &amp; printing</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>(Petro)chemicals &amp; rubber</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Metals</td>
<td>14</td>
<td>17</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>Machinery &amp; engineering</td>
<td>7</td>
<td>20</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>17</td>
<td>12</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

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

Germany’s development is reflected by the fast labor-productivity growth in several industries displayed in table 4, but can also be deduced from changes in the employment structure. Table 5 reports the

6Although these industries modernized, too. In textiles, for instance, the ring spindle gradually replaced the mule and the food industries witnessed the introduction of new techniques that conserved products for a longer time. Broadberry 2008, 158, 161.
employment shares on the industry level in 1909 and 1936/35 for both Germany and the U.S. In Germany the combined share of modern industries – i.e. (petro)chemicals & rubber and machinery & engineering – almost tripled from 9% in 1909 to 26% in 1936. In the U.S. the same industries employed 12% of labor in 1909 and, like Germany, 26% in 1936. Moreover, in Germany the share of food & kindred, a low-productive industry, rapidly declined, while several other first generation industries, such as wood production, developed similarly. The combined share of textiles and apparel remained stable over the years (from 24% in 1909 to 23% in 1936), but it did likewise in the U.S. (21% and 22%, respectively). Even though the move of labor toward modern industries did not lead to catch-up growth, the German manufacturing sector was restructuring between 1909-1936 in a pattern not dissimilar to the US.

From the results presented in this section, we can draw three conclusions. First, the German manufacturing sector was characterized by high cross-industry variation in comparative performance, a feature not captured by total-industry estimates. Several industries performed on par with their U.S. counterparts. There is no evidence of catch-up, as most industries faced an increasingly large gap vis-à-vis the U.S. Secondly, although there was a relative decline in competitiveness, German industry did not stagnate. However, there is no relationship between the rate of growth over time and the distance toward the U.S. frontier. For example, labor productivity in the transportation-equipment industry increased at an unprecedented rate, but the same industry in the U.S. simply performed even better. In contrast, the textile industry failed to improve labor-productivity levels over time, but was able to deliver a strong comparative performance all through the period of study. Thirdly, from this we infer that the drivers of growth and catch-up were not necessarily the same across industries. It mattered whether an industry was at the forefront of the second industrial revolution or not.

4. Labor productivity and plant size distribution

The benchmark comparisons show a number of German industries that either managed to close-in on the U.S. or displayed fast productivity growth over the interwar period. These industries stand out sharply against the backdrop of comparative stagnation in German manufacturing. The wide-spread range of comparative industrial performance suggests that factors other than Europe’s self-destruction were at play, a belief that is strengthened by the identical productivity profiles in 1909 and 1936/35. This persistence supports the notion that comparative performance was determined by factors present throughout the entire period of study.

In this section we explore the possibility that Germany’s comparatively low level of labor productivity stems from one such persistent feature of German manufacturing, namely the abundance of relatively
Small establishments. Central to the line of argument pursued here is the idea that the technologies of the second industrial revolution favored large-scale production to induce efficiency advantages. Large establishments (factories or plants) obtain scale economies by standardizing production lines. Empirically, there are two ways of looking at this issue. First, the average establishment size in the U.S. and Germany may indicate the degree to which modern production units have been adopted in both countries.

This is only part of the story, however. In times of rapid technological change, elements of backwardness and modernity are likely to coexist as the replacement of the old stock of production technology proceeds stepwise. It may therefore warrant studying the full distribution of establishment size, rather than looking at the mean of the distribution only. If new technology of the second industrial revolution was indeed operated efficiently with large-scale production, this will show up in the distribution of establishments over establishment size; the distribution of plant size may be bi-modal, with one peak containing traditional, small establishments and another with modern, large establishments. In this section we therefore study the average plant size as well as the full distribution of establishments over size classes.

Table 6: Share of workers employed in establishments employing over 50 workers (%)

<table>
<thead>
<tr>
<th>Description</th>
<th>U.S. 1909</th>
<th>Germany 1907</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textiles</td>
<td>93</td>
<td>38</td>
</tr>
<tr>
<td>Paper and printing</td>
<td>67</td>
<td>51</td>
</tr>
<tr>
<td>Lumber</td>
<td>81</td>
<td>22</td>
</tr>
<tr>
<td>Leather</td>
<td>90</td>
<td>25</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>99</td>
<td>98</td>
</tr>
<tr>
<td>Food</td>
<td>67</td>
<td>13</td>
</tr>
<tr>
<td>Ceramics</td>
<td>85</td>
<td>55</td>
</tr>
<tr>
<td>Chemicals</td>
<td>85</td>
<td>70</td>
</tr>
</tbody>
</table>


Average establishment size in German manufacturing was smaller than in the U.S., as Kinghorn and Nye show for the pre-WW1 period (Kinghorn and Nye 1996, 99). Table 6 reports for several manufacturing industries the share of industrial employment working in establishments with over 50 employees. The picture is the same across the board; the employment share working in large-scale establishments is in each and every case lower in Germany. Nevertheless, the size of the gap varied between industries. The difference is almost non-existent in iron & steel and quite small for chemicals as well. In contrast, if the share of employment working in large-scale establishments provides an indicator of industrial
development, the German textile, lumber, leather, and food industries lagged substantially behind; in these industries the share of workers employed in establishments with over 50 workers was 3, 4, or – in the case of the food industry – even 5 times smaller than in the US.

The large percentages of employment in both U.S. and German iron & steel manufacturing may relate to Hannah’s observations regarding giant plants (>1,000 workers) in Germany and the U.S. Hannah states that giant production units were particularly representative for ‘modern’ industries. In chemicals, shipbuilding, and electrical manufacturing Germany counted more giant plants than the U.S. (Hannah 2008, 68). The opposite conclusion applies to tobacco and automobiles. With the exception of electrical engineering, the presence of giant plants or the lack thereof corresponds well to the comparative productivity levels presented in this research; chemicals performed on par with the U.S., while the transportation-equipment industry and tobacco manufacturing trailed the American frontier at considerable distance. Moreover, following Kinghorn and Nye, Hannah underlines Germany’s overall smaller average establishment size in manufacturing and suggests it might have been the bulk of small workshops that drove Germany’s low overall labor productivity (Hannah 2008, 72).

Table 7: Distribution of employment over establishment-size classes in German manufacturing industries, 1907 (in %)

<table>
<thead>
<tr>
<th>SIC</th>
<th>Industry</th>
<th>≤ 50</th>
<th>51-1000</th>
<th>≥ 1001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textiles</td>
<td>Total</td>
<td>28</td>
<td>72</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Cotton spinning</td>
<td>31</td>
<td>69</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Linen spinning</td>
<td>18</td>
<td>82</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Jute spinning</td>
<td>7</td>
<td>93</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Silk spinning</td>
<td>51</td>
<td>49</td>
<td>0</td>
</tr>
<tr>
<td>Chemicals</td>
<td>General chemicals</td>
<td>29</td>
<td>58</td>
<td>13</td>
</tr>
<tr>
<td>Petroleum and coal</td>
<td>Total</td>
<td>21</td>
<td>79</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Petroleum</td>
<td>66</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Coke</td>
<td>18</td>
<td>82</td>
<td>0</td>
</tr>
<tr>
<td>Stone, clay and glass</td>
<td>Cement</td>
<td>12</td>
<td>84</td>
<td>4</td>
</tr>
<tr>
<td>Primary metals</td>
<td>Total</td>
<td>15</td>
<td>59</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Iron &amp; steel</td>
<td>5</td>
<td>55</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Cast iron</td>
<td>30</td>
<td>60</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Nonferrous metals</td>
<td>9</td>
<td>82</td>
<td>9</td>
</tr>
<tr>
<td>Transportations equipment</td>
<td>Motor vehicles</td>
<td>21</td>
<td>50</td>
<td>29</td>
</tr>
</tbody>
</table>

May not sum to total due to rounding. Sources: Kaiserlichen Statistischen Amte, “Gewerbliche Betriebsstatistik,” in Berufs- und Betriebszählung, Statistik des deutschenReichs (Berlin, 1907).
So far as the data of Kinghorn and Nye go (table 6), the small share of employment working in large-scale establishments reported for the German textile industry is difficult to reconcile with the comparatively strong labor-productivity performance it delivered in both 1909 and 1936/35. This puzzle can be explained by table 7, which reports for several industries covered by the labor-productivity comparisons the distribution of employment over establishment-size classes. For 1909 the textile industries included in the comparison concern spinning activities and table 7 shows that in these industries the employment share working in establishments with over 50 employees was much higher than the 38% reported by Kinghorn and Nye for the whole of textiles. In cotton spinning, which was the largest spinning industry in terms of employment, this share amounted to 69%. The other textile industries, i.e. jute, linen and silk spinning, employed 93, 82 and 49% of total labor in large-scale establishments, respectively. Clearly, the spinning industries not only displayed above average labor-productivity levels, as the 1936/35 comparison testifies, they were also characterized by relatively large establishments. For the other two strong performers, i.e. iron & steel and chemicals, the employment share working in large establishments differs not between the industry sample of the comparisons and Kinghorn and Nye's data.

In the previous section we found that strong performing German industries are involved in the production of predominantly basic goods, which possibly explains why in these industries the share of employment working in large establishments was comparable to the U.S. This suggests that these industries performed well due to their large scale of production relative to industries producing consumer goods. Continuing on this line of thought, while modern elements were clearly present in turn-of-the-century Germany, its overall poor performance in manufacturing may have been driven by the abundance of small workshops and handicraft workers. Germany’s inability to catch-up with U.S. labor-productivity originated from market conditions that prevented less efficient firms from losing market share and profit to the more efficient ones (Melitz, 2003). Except, perhaps, for industries that produced basic goods and did not face heterogeneous customer demand. It should be noted, however, that this hypothesis relies entirely on the notion that the size of establishments was positively related to labor productivity. But did it?

In the remainder of this paper we introduce a preliminary exploratory analysis of the relation between labor productivity and establishment size for the U.S. in 1909. We do this for two industries, i.e. cotton and primary metals (iron and steel). Ideally, this analysis is based on micro level data that provide for single establishments the number of employees, the produced output, the use of materials and the value of the capital stock. In the absence of such data we rely on the variation across U.S. states. Given the number of U.S. states in 1909, this strategy yields a maximum of 46 observations per industry. At the state level, the U.S. census provides information on labor productivity and establishment size, as well as a number of
other variables, among which capital intensity, that can be used as controls in a formal statistical treatment of the data. Importantly, the data not only provides the mean establishment size in each state, but also supplies the distribution of plant size. If the use of new or old technology depends on the size of establishments, information on the full distribution of establishments is needed to study the relation with labor productivity, rather than the average establishment size only.

For Germany we have data on the country level only, which makes it impossible to repeat the same research strategy as applied to the U.S. Nevertheless, we do have the distribution of German manufacturing establishments over establishment-size classes. So based on our findings for the U.S., we can conclude whether or not establishment size mattered for labor productivity and, given the differences between the German and U.S. distribution of establishments over plant-size classes, if that may explain part of the transatlantic labor productivity gap.

We derive the U.S. distribution of establishments over establishment-size classes from the U.S. census of manufactures of 1909. The census reports the number of manufacturing establishments and the number of wage earners per establishment-size class. There are nine bins, ranging from establishments with 0 wage earners to those with more than 1,000. The census includes all establishments that annually produce $500 or more. This potentially excludes the smallest, 1-person establishments. For example, in the cotton industry, with an average annual wage of $343, many 1-person establishments may not be accounted for in the census. In other industries with higher wages this is much less of a worry. For instance, in the foundry industry, blast furnaces and rolling works the average annual wage was $522, $626 and $571, respectively. It is unlikely that the census excluded many establishments in these industries.

The German distribution of establishments over establishment-size classes we collect from the German occupational census of 1907. With twelve establishment-size bins, the German census provides more detail than we have for the U.S. In addition, the German census has no cut-off point and reports for each establishment-size class the number of proprietors, administrative staff members, technicians, laborers and family members employed in the establishment, and for all of these occupations the number of males and females.

Given the detail provided by the German occupational census, we have adjusted the German data to fit the U.S. definitions. Instead of all employment, we only count German laborers and family members to match U.S. wage earners. Moreover, we leave out all 1-person establishments to allow for the U.S. cut-off point of $500. Lastly, we aggregate both the German and U.S. data to eight establishment-size classes, i.e. 1 to
5, 6 to 20, 21 to 50, 51 to 100, 101 to 250, 251 to 500, 500 to 1,000 and 1,000+ workers. With these data we then plot the distribution of establishments over establishment-size classes and compare these between Germany and the U.S.

Figure 1. Distribution of establishment size in German and U.S. Manufacturing 1909

Figure 1 shows the distribution of establishments over establishment-size classes for the total of industries studied in the benchmark for 1909. On the horizontal axis the classes of establishment size are displayed in a log scale. The vertical axis shows the cumulative frequencies (the cumulative share of establishments). Each vertical jump in the distribution function corresponds to the average establishment size for Germany or the U.S. in each establishment-size class, starting with the class that contains establishments with 1 to 5 workers. The graph shows that much of the difference between the distributions of Germany and the U.S. can be traced back to establishments with less than 100 workers (or perhaps even less than 50 workers). The average German plant employed 33 workers; in the U.S. it was 87. Nevertheless, both countries have very small as well as very large establishments, suggesting that while the shape of the distribution differs between Germany and the U.S., both countries cover a comparable range of establishment size. Again, assuming that modern industries are characterized by relatively large size, this implies that traditional and modern elements were present in Germany just as well as in the U.S.
Zooming in on two relatively strong performing industries in Germany, cotton and primary metals (iron and steel rolling mills), we see basically the same pattern with Germany having many more plants in the
lower size classes (see Figures 2 and 3). The difference with the U.S. is larger in iron and steel (rolling mills) than in cotton. In both German industries we nevertheless find a higher concentration in lower size classes and small workshops. Is there a relation with the lower comparative labor productivity in Germany as is demonstrated by our benchmark comparisons?

To find out whether establishment size and labor productivity are related we study the U.S. data. The U.S. census allows us to study this relationship on the basis of U.S. state-level data so that we can rule out country specific causes for labor-productivity differentials like resource endowments, (human) capital intensity, market size, or market imperfections. We find that the distribution of establishments over establishment-size classes varies considerably across states. At one end of the spectrum, some U.S. states approach the German distribution closely, as is shown in Figure 4 for the iron and steel industry in Wisconsin. Also average plant size in Wisconsin is close to the German average. On the other hand, some U.S. states, such as Indiana, count only very large establishments with a corresponding large average size (see Figure 5). Appendix 2 (Figures 1 and 2) shows basically the same characteristics for the cotton industry.

Figure 4. Distribution of establishment size in German, U.S. and Wisconsin Iron and Steel (rolling mills) Manufacturing 1909

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{iron_steel_distribution.png}
\caption{Distribution of establishment size in German, U.S. and Wisconsin Iron and Steel (rolling mills) Manufacturing 1909}
\end{figure}
Is there a relationship between average establishment size and the level of labor productivity across U.S. industries? A first exploratory display of the U.S. data suggests not. Appendix 2 Figure 3 shows no correlation between both indicators in U.S. cotton and iron and steel industries across U.S. states. Average labor productivity varies a lot across states and so does average plant size, but there is no relationship between the two indicators. In a simple OLS regression and controlling for capital intensity, there is no significant positive relation between average establishment size and labor productivity. On a country level average plant size did not seem to matter for levels of labor productivity in the early 20th century.

However, if we take into account the differences in the shape of the size-distribution across states, some interesting observations can be made, particularly when we look at skewness, which is a statistical measure of asymmetry of the distribution of observations around their mean. Positive skewness means that the distribution has a long right tail relative to the mean and negative skewness implies that the distribution has a long left tail.

Figure 6 reveals that in both industries a longer right tail is associated with higher average labor productivity across the U.S. states. In a simple OLS regression where we control for capital intensity, the skewness of the distribution of establishments over establishment-size classes is positively and
significantly related to labor productivity. To be sure, a long right tail does not mean that there are many large establishments in the distribution as such. The asymmetry is measured in relation to the mean. In practice, a high positive skewness describes a distribution that is stretched out to the right side of its mean in a pronounced way. How can this be related to higher levels of labor productivity?

Figure 6. Labor productivity and the skewness of establishment size distribution in U.S. Cotton and Iron and Steel (rolling mills) Manufacturing 1909

Figure 7. Skewness and number of establishments in German and U.S. Manufacturing 1909
We observe high positive skewness mostly in U.S. states that have relatively many establishments. This is shown in Figure 7. The skewness of the establishment size distribution is associated with a larger number of establishments in both the cotton and iron and steel industries across states. How can this relationship be explained? It is highly probable that a larger number of establishments increases the likelihood that all establishment-size classes in the total population of plants will be represented. A distribution with many observations will contain for a large part relatively small plants. Remember that big and giant factories were still a relative novelty in the early 20th century. But when there are also a few big plants in the total population of plants in a state, it will contribute to the positive skewness of its distribution more than in the case when there are only few establishments.

We believe that the relation between skewness and labor productivity of the U.S. states is not just a statistical artifact or spurious. The distribution is positively skewed when there are many establishments, most of which are small but some necessarily large to push out the right tail of the distribution. This implies that a state with a positively skewed distribution is characterized by relatively many establishments in combination with firms in the larger size-classes. A large number of plants and firms means that there will be many possibilities for external economies of scale, flexibility and competition. Secondly, having a number of large, modern factories will also indicate that the challenge and response mechanism of technological advance and large scale operations is fulfilled. The skewness of the distribution captures these two advantages, and is in turn statistically related to levels of higher labor productivity (see Hannah 2013, p. 31).

5. Explaining German productivity levels

*Vertical integration: firms versus cartels*

How does Germany fit in this picture? Unfortunately we cannot make the same kind of breakdown as in the U.S. example. We can only look at Germany at the total country level. In Figures 2 and 3 we have seen that in Germany cotton and iron and steel industries were more concentrated in the lower size classes, resulting in a lower average overall plant size. But the evidence shown here suggests that average plant size as such has not been a decisive factor determining levels of labor productivity and that we should look at the structure of the market, the possibilities for external economies and the role of the firm.

In the case of firm size, being large is not always better. More specifically, as optimal firm size is determined by transaction costs, the smaller firm in Germany might simply reflect a well-integrated market that reduced the incentive for firms to extent their control over more stages of the production
chain. Country-specific conditions conducive to low transaction costs can thus limit the size of firms. The German cartels could have provided such conditions and the smaller firm size in Germany need not have been a sign of backwardness (Kinghorn and Nye 1996, 109; Hannah 1995, 207-208). Cartels offered an alternative way to attain a reduction of transaction costs. Through the control exerted by the cartel over different stages of the production chain, coordination problems could be addressed efficiently without having to integrate these production stages in one firm. Related to this, the stability offered by cartels potentially induced higher rates of investment, leading to capital deepening and productivity growth (Levenstein 2006, 85).

Although cartels are associated with a reduced intensity of competition, moving Germany away from competitive capitalism, the literature on Germany is quite positive about the effect of cartels on economic development (Kocka 1978, 564). If German cartels tended toward a monopoly control of the market, they could have closed the door on technological development, yet Burhop and Lübbers conclude that in the case of German coal-mining corporations productivity was not significantly affected by cartel membership (Burhop and Lübbers 2009, 502). Over the period 1881-1913 there is no evidence that the Rheinisch-Westphalien Coal Syndicate, one of the longest-lasting cartels, adversely influenced levels of technical efficiency. In similar vein, Kinghorn argues that German coal and iron & steel cartels around the turn of the century did not lead to true monopoly power, yet they did allow firm members to use more efficient production technologies (Kinghorn 1996a, 492). Strikingly, the top three of industries with the largest number of cartels included iron & steel, chemicals and textiles, i.e. precisely those industries that the benchmark comparisons showed to deliver a strong performance relative to the U.S. (Kocka 1978, 564).

Relative factor costs
Apart from the differences in industrial organization between Germany and the U.S. described above, Europe’s inability to catch-up in general has been explained by the Rothbarth-Habakkuk thesis. In Europe, factor and resource endowments as well as demand patterns are said to have favored a labor-intensive way of production (Habakkuk 1962). Natural resources were scarce and skilled labor was in ample supply, which provided an incentive to economize on fixed capital in the form of machinery (Temin 1971, 162; Field 1985, 379). Indeed real wage levels in Germany were only 50-60 percent of American wage levels shortly before WW1 (Williamson, 1995, 180). In contrast, the U.S. was well endowed with natural resources, while skilled labor was relatively expensive. Machinery was substituted for skilled labor, resulting in the use of capital-intensive production techniques. This way, specific American circumstances determined the initial choice of technology. Technological progress was subsequently directed toward the particular technological path a country has chosen, leading to lock-in effects (David 1975, 66). As capital-
intensive production techniques are associated with higher labor-productivity levels, Europe could not catch-up with the US.

Some remarks are in place here. Our benchmark results do not fit the Rothbarth-Habakkuk thesis exceptionally well. The German industries that performed on par with their U.S. counterparts challenge the deterministic nature of the initial-conditions approach. The relatively strong German performance in textiles, primary-metals manufacturing, and chemicals suggests that in these industries either similar production techniques (i.e. capital-to-labor ratios) were employed by both countries or that higher levels of capital intensity do not necessarily translate into higher labor-productivity levels.

Some of the cross-industry differences in performance might be explained by the variance in the degree to which industries relied on raw materials and capital-intensive production techniques. However, the importance of natural resources in, for instance, the iron & steel and the textile industries is undeniable, both in the form of raw materials and as combustibles. A more likely explanation is that these kinds of factor costs in the ‘successful’ German industries deviated only little from those in the U.S. In a case study on the pre-WW1 iron & steel industry, 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. Allen finds that in 1910 the price of used raw materials (ore and scrap) was actually lower in Germany than in both the U.S. and U.K. (Allen 1979, 932). Fuel (blast furnace coke) was more expensive as compared to the U.S., but cheaper than in Britain. In line with the benchmark results, Allen shows that productivity in Germany was comparable to the U.S. and higher than in the U.K. (Allen1979, 931). Iron production in Germany was characterized by low material costs and high efficiency levels.

Apparently, the costs of using capital in the primary-metals industry did not differ much between Germany and the U.S. Does this mean that both countries have similar production functions? In the late nineteenth century, the Bessemer process for the mass-production of steel from molten pig iron revolutionized the iron & steel industry. Although the large-scale application of the Bessemer process was introduced first in Britain, the technology was swiftly improved upon in the U.S. so that by the 1880s the coke-fueled blast furnaces developed in America formed the pinnacle of available production techniques (Hyde 1991, 52). Hyde shows that when American steel-producing technologies proved their superiority European manufacturers started to copy American designs (Hyde 1991, 68). Adoption of American technology by German entrepreneurs is observed in other turn-of-the-century industries, too. For instance,

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7 British iron ore mined in the East Midlands and Cleveland was at least as cheap as the German ore from West-Phalia, but for some reason Britain mainly used the more expensive Spanish ore.
Richter and Streb present evidence of transatlantic technology transfer in the machine-tool industry, a tradition that continued well into the twentieth century. 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 without the slightest adjustment (Richter 2009, 1-2). The implementation of American technology in German industries seems difficult to reconcile with the idea of technological lock-in driven by local circumstances.

Our new findings somehow echo Salter’s analysis of the Anglo-American productivity differences in the first half of the 20th century. He proposed to make a distinction between effects of technical progress for an individual firm or industry and the broad effects of productivity growth that have led to cheaper capital goods and faster economic depreciation of capital goods. The direct effects of technological advance in each individual firm may be determined by the speed with which changes take place, the nature of technical change (capital or labor saving) and the effects of technological advance on relative factor prices. The cheapening of capital goods, however, can be viewed as common to all industries. The much lower levels of real wages in Germany led to lower levels of replacement than in the U.S., with a slower adjustment of the capital stock and leading to a heavier left tail of smaller firms. More relatively small firms may have driven Germany’s low overall labor productivity, but the reason is that it was interacting with slower adjustments of the capital stock, due to lower wages. It also implies that the skewness of the distribution is not necessarily a reflection of low technological standards or even economic efficiency (Salter, 1969, p.41 and 73).

6. Conclusion
This paper has presented a German/U.S. comparison of labor productivity in mining and manufacturing for two benchmark years, 1909 and 1936/35. German manufacturing productivity had a level of ca 56 per cent of the US level in 1909, and around 50 per cent in 1935. Variation across industries was large, with 30 percent for tobacco and over 100 percent for textiles, chemicals and primary metals. Although German productivity has increased fast in some industrial branches, we see no strong catch up movement vis-à-vis the U.S. Traditionally, emphasis has been placed on the success of German industries during the second industrial revolution, but we find no quantitative evidence of German catch-up growth. Contingent on the level of aggregation, the German/U.S. productivity comparisons presented here justify both stories. There are no signs of catch up at the level of total manufacturing. Zooming in on the performance of underlying industries, however, several clear-cut German successes are observable, most notably in the production of chemicals, textiles, and parts of the metal industry. For instance, iron & steel industries performed comparatively strong, although non-ferrous metal production failed to keep-up with the U.S.
Next we looked at the distribution of plant size in both countries to analyze whether the scale of production has been a decisive factor in the relative poor overall performance of German manufacturing. To find out whether large establishment size and high levels of labor productivity are positively related we have focused on U.S. state-level data. We could find no direct relationship. But there is a positive correlation between labor productivity and positive skewness of the distribution of plant sizes, reflecting a large number of plants in an industry, and the level of labor productivity. Our conclusion is that a higher number of plants in an industry may indicate possibilities for external economies of scale, flexibility and competition, but also possibilities for large scale operations fueled by technological advance.

There is a striking overlap between the German industries listed in the literature as having relatively many large factories or even giant plants, many cartels, and high tariffs and those that performed strong in comparison to the U.S. According to the literature the cartel-tariff system had the potential of raising efficiency levels by encouraging large-scale production, lowering transaction costs through vertical integration, and creating a low-risk environment for investment.

The notion that these institutions provided German industries with a competitive edge certainly sits well with the benchmark results. As to why specifically these German industries managed to upscale production, a possible explanation concerns the nature of the manufactured products. It has been suggested that the smaller establishment size in Germany resulted from a domestic demand for customized goods, which hampered standardized production. However, textile spinning, iron & steel and chemical industries produced predominantly basic, rather than consumer goods. Unconstrained by heterogeneous demand patterns, large-scale production was attainable. In these industries smaller firms may well have driven Germany’s low overall labor productivity, due to lower wages, leading to slower adjustments of the capital stock. But the wide variation in plant size does not reflect low technological standards. From this perspective, the rapid productivity growth between 1909 and 1936 signifies fast technological change, while the large gap with U.S. levels of labor productivity reflects the inability to benefit fully from new developments.
Appendix 1: Methodology of productivity comparisons and a description of the data

To allow for effects of composition and to capture inter-industry variance in performance, the labor-productivity comparisons constructed in this study employ the industry-of-origin approach, which dissects the manufacturing sector into its underlying components, i.e. manufacturing industries.\(^8\) By measuring industrial inputs and output in a particular year, an industry-of-origin benchmark provides the starting point for further research that aims to explain a country’s economic performance. In addition, a benchmark estimate for the pre-WW1 period supplies a check upon time-series projections extrapolated backward from more recent benchmark estimates. Backward projections do not always accurately reflect changes in the structure of an economy (Gerschenkron 1955). A large deviation between time-series projections and direct level estimates may indicate a degree of inaccuracy on the part of the former. An additional advantage of a benchmark estimate over time-series projections is that in contrast to many time series of labor productivity, data on output and employment can be obtained from a single primary source, which guarantees internal consistency between the input and output measures (vanArk 2001).

Our estimation method starts with the measurement of gross output or value added in national prices. To convert output in a common currency we do not use the official exchange rate, but calculate industry specific purchasing power parities. This method is explained extensively in Fremdling et al (2007) and De Jong and Woltjer (2011).

The building blocks of the conversion rates are formed by product prices. As these prices are seldomly available in the statistical records, they have to be derived from data on the produced value and quantity of products. In a bilateral country comparison, these product prices – referred to as unit values – are computed for both countries as in equation (1).

\[
p_{ij} = \frac{v_{ij}}{q_{ij}}
\]  

(1)

Where \(p_{ij}\) is the unit value of product \(i\) in country \(j\), \(v_{ij}\) the output value of that product and \(q_{ij}\) the corresponding produced volume. Subsequently, identical products are selected and matched between the two countries involved in the comparison. The ratio between the unit value of the same commodity in both countries captures the product-specific relative price expressed in terms of country \(n\)’s currency per unit of the base country \(o\)’s currency, as in equation (2).

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\(^8\) See also J. Veenstra (2014), ch. 2.
\[ uvr_{no} = \frac{p_{in}}{p_{io}} \]  \hspace{1cm} (2)

With \( uvr_{no} \) as the unit value ratio (henceforth, UVR) of product \( i \), which represents the relative unit value in country \( n \) (\( p_{in} \)) compared to the unit value in country \( o \) (\( p_{io} \)). In order to derive an industry-level conversion factor, a weighted average is taken of the product-specific price ratios classified in the same industry group. The weights allotted to the UVRs for the purpose of aggregation reflect the product’s share in total industrial output (\( v_i / \sum v_i \)). The aggregated UVRs are traditionally referred to as purchasing power parities (henceforth, PPPs). The process of aggregation proceeds in three sequential steps, as described by equations (3), (4) and (5). The UVRs are aggregated, first, using base country \( o \)'s output weights and, second, using the weights of the numerator country \( n \) to get a Laspeyres (\( L^{go} \)) and Paasche (\( P^{go} \)) gross output PPP, respectively:

\[
L^{go} = \frac{\sum (v_{io} \cdot p_{in})}{\sum v_{io}} = \frac{\sum (v_{in} \cdot uvr_{io})}{\sum v_{io}} \hspace{1cm} (3)
\]

\[
P^{go} = \frac{\sum v_{in}}{\sum (v_{in} \cdot p_{io})} = \frac{\sum v_{in}}{\sum (v_{in} / uvr_{io})} \hspace{1cm} (4)
\]

In a third step the geometric average of the Laspeyres and Paasche PPPs is taken (\( F^{go} \)), which is used throughout this chapter to convert industrial output:

\[
F^{go} = \sqrt{L^{go}, P^{go}} \hspace{1cm} (5)
\]

Equations (1)-(5) provide the tools needed to express German and U.S. gross output in a common currency. Labor productivity in country \( j \) (\( y_j \)) is then expressed as in equation (6), where \( go_{ij} \) denotes gross output of product \( i \) in country \( j \) and \( l \) the labor input employed in the production process.

\[
y_j = \frac{\sum go_{ij}}{\Sigma l_{ij}} \hspace{1cm} (6)
\]

In the following analysis labor is defined initially as the number of employees involved in production and subsequently as total annual hours worked. The adjustment for hours worked takes on significance mainly for the interwar comparison, as the first half of the twentieth century saw a rapidly decreasing length of
the working week, especially in the US. (deJong2011) Combining equations (5) and (6), the level of labor productivity in country \( n \) as compared to base country \( o \) is expressed as in equation (7) below:

\[
LP = \frac{y_n/F^o}{y_o} \tag{7}
\]

Data
We employ in this study the censuses of production published by the statistical offices of Germany and the US. The pre-WW1 analysis for the U.S. is based on the Thirteenth Census of the United States published by the U.S. Bureau of Commerce.\(^9\) For 1935 U.S. we rely primarily on the Biennial Census of Manufactures 1935 and the Sixteenth Decennial Census of the United States\(^10\). The U.S. censuses provide an extensive and consistent coverage of the American manufacturing sector in both years. For interwar Germany we use the comprehensive archival records of the German production census published in Die deutsche Industrie: Gesamtergebnisse der amtlichen Produktionsstatistik (henceforth, production census of 1936). This is the first official German census of manufactures and is available in two forms; a published edition and the original archival records. The former has been to set up to hide particular manufacturing activities that were related to the war effort. The archival records of this census contain considerably more detailed information and will be used in this study.\(^11\)

Collecting data to calculate labor productivity for pre-WW1 Germany was less straightforward. The statistical offices of the U.S. and the U.K. published a census of manufactures already before WW1. For manufacturing industries these censuses report data on output, employment, installed capital, etc. and as such are ideally suited for constructing benchmarks. Because the first German census of manufacturing was not published until 1936, we had to use other sources for the prewar period. The Kaiserlichen Statistischen Amte (henceforth, Imperial Statistical Office) monitored the economy in a variety of ways from the turn of the twentieth century onwards. Using a combination of official statistical publications the industry-level data needed for the construction of benchmarks was obtained. Because it forms the weakest link in the chain of benchmarks presented here, the computation of German labor-productivity levels before WW1 requires further elaboration.

\(^10\)CensusUS1935; CensusUS1940manI; CensusUS1940manII
\(^11\)CensusGER1936; for a detailed discussion of this source see: Fremdling2007a.
Labor productivity in pre-WWI Germany

To calculate German labor-productivity levels for the prewar period, we mainly rely on information obtained from the *Vierteljahrshefte zur Statistik des deutschen Reichs* (henceforth, statistical quarterlies). In the statistical quarterlies of 1913 the results of industrial surveys for the years between 1907 and 1911 are published. The surveys report output and employment data for a number of industries. For those industries that are included, the surveys do not provide full coverage. Instead, the production of a sample of firms is reported. Partly this is due to the fact that the surveys are only sent to firms affiliated with the national health-insurance scheme for workers (Gewerbe-Unfallversicherungsgesetze). The smallest workplaces are in effect not covered and the scope of the surveys may be limited to the larger firms in German industries. This could lead to compatibility problems when comparing Germany with the US. The U.S. census of manufactures provides almost full coverage as only household industries and establishments with an annual output lower than $500 are excluded (Census U.S. 1910 VIII, 19).

Using a combination of the average firm size reported by the industrial surveys and information obtained from the occupational census, we have estimated, first, which establishment-size classes are represented by the surveys and, second, the share of total-industry employment that is covered by these establishment-size classes. The results indicate that in most industries the surveys represent all but the smallest establishment-size classes. As, in general, between 95% and 100% of the manufacturing labor force is employed in establishments-size classes represented in the surveys, there is no reason to think that the surveys introduce a structural upward bias in the German labor-productivity estimates.

Additional sources for the pre-WWI period

Another potential drawback of the statistical quarterlies is that several manufacturing industries are not included in the surveys. Data on, for instance, the food industry, electrical and mechanical engineering, or the instrument industry are not reported. For some industries important activities are omitted as well. The chemical industry is poorly represented by coal-tar distillations, potash and sulfuric acid: information on inorganic chemicals is unavailable. Furthermore, the industrial surveys only report output in the textile industry, but no employment, making it impossible to calculate labor-productivity levels. Lastly, due to their incomplete coverage, the industrial surveys do not provide a complete output structure of the manufacturing sector. Additional sources have been used to provide the weights for an analysis on the level of total manufacturing. To fill the gaps in the data of the statistical quarterlies, other publications of the Imperial Statistical Office have been used to provide data on industries like mining, and blast furnaces, sugar, tobacco, alcoholic beverages, paper, glass, and rubber.

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12*Vierteljahrshefte*1913; *Vierteljahrshefte*1914.
A potential problem is that most labor-productivity levels calculated on the basis of the industrial surveys do not refer to the same year as the weighting scheme, i.e. 1907. In fact, except for the textile and food & kindred industries, all productivity data refer to either 1908, 1909 or 1910. If the results are to be interpreted as representative for 1907, labor-productivity levels must have remained constant over this period, which seems unlikely. In this study we pursue a less stringent approach by choosing the year for which the most output data is available, i.e. 1908 or 1909, as the basis for the benchmark. This setting assumes that the composition of the manufacturing labor force has remained unaltered between 1907 and 1909. As the employment structure is much less volatile than the movement of productivity levels, projecting the 1907 structure on either 1908 or 1909 does not give great cause for concerns.\textsuperscript{13} As the prewar benchmark is used for a comparison with America and the latter's census of manufactures refers to 1909, I designated 1909 as base for the German benchmark.

\textbf{Figure 1: Peak and census years, 1900-1913}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Chart showing real GDP and unemployment rates for the United States and Germany, with census years highlighted.}
\end{figure}


\textsuperscript{13}On the basis of the industrial surveys I am able to calculate the annual change in labor productivity between 1907 and 1911 for several industries. In almost all of these industries labor productivity increased (rapidly) over the years 1908-1911. Assuming that labor productivity did not change, even in this short period, is therefore problematic. Instead, the employment share of these industries changed little.
The choice of 1909 as the prewar benchmark-year was further strengthened by movements of the business cycle. Whenever possible, we took care to avoid years which are at a peak or in a trough of the cycle. Figure 1 shows that the level of real GDP at the selected census years for both countries was above the long-run trend, and 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. Consequently, all German labor-productivity estimates originally based on data from other years are adjusted to a 1909-basis using Hoffmann's industry-level time series of output and employment.

Appendix 2: Establishment size and labor productivity

Appendix 2. Figure 1. Distribution of establishment size in German, U.S. and Pennsylvania Cotton Manufacturing 1909

14 See de Jong and Woltjer 2011 for an elaborate discussion of the business cycle and capacity utilization effects and a sensitivity analysis for the interwar period.
Appendix 2 Figure 2. Distribution of establishment size in German, U.S. and Maine Cotton Manufacturing 1909

Appendix Figure 3. Labor productivity and average establishment size in U.S. Cotton Manufacturing and Iron and Steel Manufacturing in 1909
Literature


**Primary sources**


Kaiserlichen Statistischen Amte. “Ergebnisse der deutschen Produktionserhebungen”. In Vierteljahrshefte zur Statistik des deutschen Reichs. no. 2. Berlin, 1914.


