The Yanks of Europe? Technological change and labor productivity in German Manufacturing, 1909-1936

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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 labor-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. In this paper, we reassess the productivity dynamics in Germany on the basis of a new model by Basu and Weil that emphasizes the role of technology and which predicts convergence in light of rapid capital deepening. We construct a data set on the basis of two new German/American industry-of-origin benchmarks for 1909 and 1936. By means of a data envelopment analysis, we measure the effects of capital accumulation, technological change, and efficiency change and find evidence for considerable increased capital-intensity levels in the German manufacturing sector during this period. The process of capital deepening was accompanied by a large labor-productivity growth potential which, however, did not materialize as low levels of technical efficiency stood in the way of German convergence. These findings are in line with Basu and Weil's model of localized technological change and discredit the traditional technological lock-in hypothesis.

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 well as demand

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[1] Broadberry, *The Productivity Race* p. 3; Broadberry and Irwin, 'Labor Productivity in the United States and the United Kingdom' p. 265.

patterns, which favored a labor-intensive way of producing.[2] In Europe, natural resources were scarce, while skilled labor 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 resources, while skilled labor was relatively expensive. Therefore, machinery was substituted for skilled labor, 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 heterogeneous 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 develops 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] Apart from a new lick of paint, imported American 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."[8] 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.[9] This concept builds upon Gerschenkron's idea of 'appropriate' economic institutions and Abramovitz' 'social capabilities' to encourage technology adoption.[10] 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.

The implementation of American technology in the German machine-tool industry, during the early twentieth century, seems difficult to reconcile with David's idea of technological lock-in driven by local circumstances. In this paper we contrast David's path-dependent view of technological progress with a recent theoretical model by Basu and Weil, which fits better with the qualitative evidence and offers a more appropriate framework to study the German growth experience over the interwar period. They demonstrate that, given certain conditions, convergence, both in terms of productivity and technology, is possible and indeed likely.[11]

Regardless of the fundamentally different conclusions reached by these authors, the drivers

[2] Habakkuk, *American and British Technology in the Nineteenth Century*.

[3] Temin, 'Labour Scarcity in America' p. 162; Field, 'On the Unimportance of Machinery' p. 379.

[4] Broadberry, 'Technological Leadership and Productivity Leadership in Manufacturing' p. 291.

[5] David, *Technical Choice, Innovation and Economic Growth* p. 66.

[6] Broadberry, 'Technological Leadership and Productivity Leadership in Manufacturing' p. 297; David, *Technical Choice, Innovation and Economic Growth* p. 68.

[7] Richter and Streb, 'Catching-up and falling behind' pp. 1–2.

[8] Ibid. p. 1.

[9] Aghion, 'Higher Education and Innovation' p. 31; Acemoglu, 'Directed Technical Change' p. 39; Vandenbussche, Aghion and Meghir, 'Growth, Distance to the Frontier and Composition of Human Capital' p. 98.

[10] Gerschenkron, *Economic backwardness in historical perspective, a book of essays* pp. 113, 116; Abramovitz, 'Catching-up, Forging Ahead and Falling Behind' p. 387.

[11] Basu and Weil, 'Appropriate Technology and Growth'.

behind the models are actually very similar. Both assume technology advances through learning-by-doing and both relate the level of technology as specific to a particular degree of capital intensity. In addition, both models adopt the Atkinson and Stiglitz notion of 'localized' technological change.[12] The latter implies that technological improvements are confined to a particular mix of capital and labor, or, in the more general version of the model, is restricted to a range of similar technologies. David argues that the initial choice of technology – being either capital-intensive for the US, or labor-intensive for Europe – led to distinctive rates of technical progress across the Atlantic, as the effects of a technological advances for a certain input mix were not automatically transferred to other technologies and essentially 'localized' to a specific capital-labor ratio.[13] In similar vein, Basu and Weil argue that although technology is freely available to all and instantly transferred, a country may nonetheless refrain from using a new technology until it reaches a level of development at which this technology would be 'appropriate' to its needs.[14]

David claims that the choice of technology is thus "being 'guided,' or directed in an *ex post* manner by previous myopic decisions – decisions having their objective in the minimization of current (as distinct from future) private costs of production."[15] For any country, a major shift in technology applied is therefore only feasible if relative factor prices change dramatically. Basu and Weil on the other hand claim that, regardless of static differences in factor and resource endowments or demand patterns, countries have the potential to rapidly converge in terms of labor-productivity levels if they successfully adopt the leaders', capital-intensive, production technologies. They emphasize the fact that technological change appears to be biased towards the capital-intensive technologies, and show that countries operating on a technical level far outside the range of the world's technology leader are likely to fall behind in terms of productivity growth, which will eventually induce them to adopt more capital-intensive production techniques.[16] The speed at which they are likely to converge is however not only dependent upon the size of the technology gap and the rate of capital deepening (their savings rate), but is also constrained by the effects of learning by doing and other barriers that raise the cost of adopting a higher level of technology.[17]

Several recent studies have found empirical evidence that strongly supports Basu and Weil's appropriate-technology hypothesis.[18] These studies rely on a novel framework, the data envelopment analysis (DEA), that emphasizes the role of technology and the potential for technology transfer; factors that, thus far, have received little attention in the empirical convergence literature.[19] They confirm the importance of localized innovation at the aggregate level and stress the finding that technological change is decidedly non-neutral; both for the period prior to and

[12] Atkinson and Stiglitz, 'A New View of Technological Change' p. 574.

[13] David, *Technical Choice, Innovation and Economic Growth*; Broadberry, 'Technological Leadership and Productivity Leadership in Manufacturing' p. 295.

[14] Basu and Weil, 'Appropriate Technology and Growth' p. 1027.

[15] David, *Technical Choice, Innovation and Economic Growth* p. 4.

[16] Basu and Weil, 'Appropriate Technology and Growth'.

[17] See e.g. Barro and Sala-I-Martin, 'Technological Diffusion, Convergence, and Growth'.

[18] Kumar and Russell, 'Technological Change, Technological Catch-up, and Capital Deepening'; Los and Timmer, 'The 'Appropriate Technology' Explanation of Productivity Growth Differentials'; Timmer and Los, 'Localized Innovation and Productivity Growth in Asia'; Caselli and Coleman, 'The World Technology Frontier'; Allen, 'Technology and the Great Divergence'.

[19] Bernard and Jones, 'Technology and Convergence' pp. 1037–1038.

following the Second World War.[20] They also emphasize that technical progress has been limited to high capital-labor ratios. In this paper we adopt this framework and apply it to the case of productivity and technology convergence in Germany and the United States.

The aim of this paper is threefold. First, we want to confirm whether technological change in manufacturing during the first half of the twentieth century was localized (i.e. whether the assumption of factor neutrality can be rejected). Secondly, we aim to show empirically whether German industries continued to innovate along their own labor-intensive productivity path (David's model) or, whether they actively sought to adopt American techniques (by accumulating physical capital) to benefit from the rapid technological change at the capital-intensive side of the production frontier (Basu and Weil's model). Lastly, we quantify the effects of technological change, capital deepening, and barriers to technological diffusion on labor productivity growth at the industry level for the German case. This will provide us with a novel view of the dynamics behind the trans-Atlantic labor-productivity differentials during the early twentieth century.

In this paper, our primary interest lies in the measurement of technology convergence rather than its causes, not because we think that a search for the causes of the patterns of efficiency is unimportant but because we feel uncovering the patterns comes first. Our findings should be interpreted as being complementary to existing explanations in either the neoclassical or endogenous-growth literature that model the impediments to technology transfer, as well as traditional explanations of the German growth experience during the early twentieth century; which we will consider is section 4. We explain the model and the decomposition exercise in section 2. In this section we will also, briefly, discuss the construction of a new data set; a more extensive overview of the sources and methods of the data construction can be found in the appendix. The main results are discussed in section 3. In the last section we conclude.

2 Methodology and Data

For our study of productivity dynamics in Europe and the United States we apply a data envelopment analysis (DEA) and perform a decomposition technique recently proposed by Kumar and Russell.[21] The DEA approach allows us to estimate a global production frontier, which represents the various 'best practice' production techniques observed for the entire feasible range of input combinations. By tightly enveloping data points with linear segments using mathematical programming methods, the structure of the frontier can be revealed without imposing a specific functional form on either technology or deviations from it.[22] Because of its non-parametric nature, the DEA naturally allows for any form of localized technical change, an important feature in our framework.[23] This approach also lends itself more readily to the decomposition of productivity growth as, in contrast to traditional growth-accounting exercises, it distinguishes between both the effects of (global) technological change and relative efficiency change.[24] In later sections we will show that efficiency loss, i.e. the movement away from the frontier, is a crucial factor in explaining German growth dynamics for the early twentieth century.

[20] Kumar and Russell, 'Technological Change, Technological Catch-up, and Capital Deepening' p. 529; Allen, 'Technology and the Great Divergence' pp. 4–5.

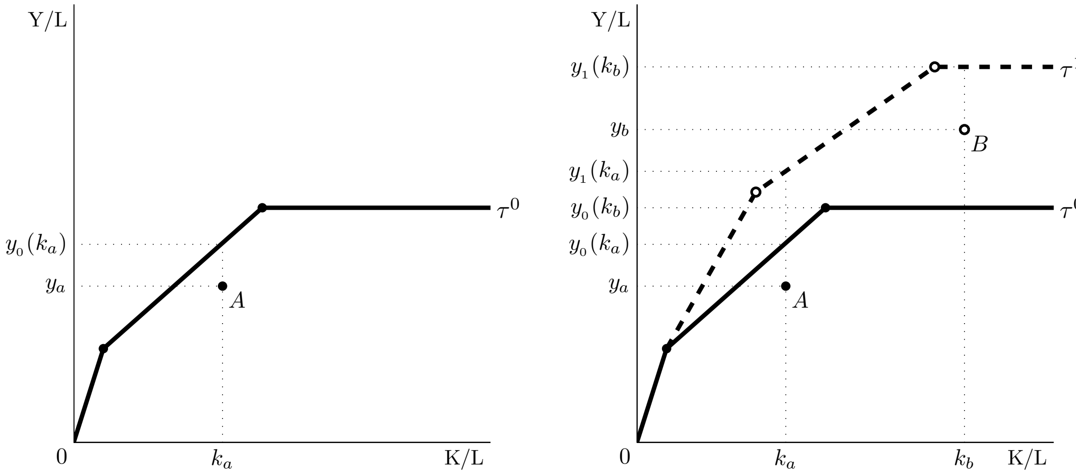
[21] Kumar and Russell, 'Technological Change, Technological Catch-up, and Capital Deepening'.

[22] Färe, Grosskopf and Lovell, *Production Frontiers* p. 12.

[23] Los and Timmer, 'The 'Appropriate Technology' Explanation of Productivity Growth Differentials' p. 522.

[24] Färe, Grosskopf and Lovell, *Production Frontiers* p. 13.

Figure 1: Illustration of Data Envelopment and Decomposition



(a) one-period (b) two-periods

2.1 Data Envelopment Analysis

The left pane of figure 1 shows a basic example of a DEA involving firms which use two inputs (K and L) to produce a single output (Y). If we assume constant returns to scale, we can represent the world production frontier in $\langle k, y \rangle$ space, where y is labor productivity and k is capital intensity (i.e. individual production techniques). The frontier (τ) is formed as linear combinations of observed extremal activities or, following Salter's definition, 'best-practice' activities.[25] Of the three observations in our example, two employ best-practice techniques and are thus located on the frontier. These frontier observations exhibit full efficiency in the Koopmans sense, who defined an activity as technologically efficient if increasing any output or decreasing any input is possible only by decreasing some other output or increasing some other input.[26] Debreu and Farrell extended this work and provided a measure of inefficiency relative to the frontier.[27] Farrell showed that the distance to the frontier can be interpreted as a measure of technical efficiency. In figure 1, observation A's vertical distance to the frontier indicates the potential for labor-productivity increase; the ratio of A's observed productivity y_a to the optimal productivity level $y_0(k_a)$ at A's capital-intensity k_a represents the Farrell efficiency index.

Färe et al. provide a formal framework for this type of efficiency measurement and show that the frontier can be estimated using a linear programming approach.[28] In our basic example we assume that all inputs and output quantities are nonnegative, and let $\left\langle Y_t^j, L_t^j, K_t^j \right\rangle \in R_+^3, t = 1, \ldots, T, j = 1, \ldots, J$, represent T observations for each of J countries. The Farrell efficiency index (θ) can be computed by solving equation (1) below for all countries at time t.

[25] Salter, *Productivity and Technical Change*.

[26] Koopmans, 'Efficient Allocation o Resources' p. 460.

[27] Debreu, 'The Coefficient of Resource Utilization'; Farrell, 'The Measurement of Productivity Efficiency'.

[28] Färe, Grosskopf and Lovell, *Production Frontiers*.

$$
\min_{\theta,\lambda^1,\dots,\lambda^J} \quad \theta \quad \text{subject to}
$$

$$
\begin{aligned}
Y_t^j/\theta &\leq \sum_k \lambda^k Y_t^k \\
L_t^j &\geq \sum_k \lambda^k L_t^k \\
K_t^j &\geq \sum_k \lambda^k K_t^k \\
\lambda^k &\geq 0 \ \forall\ k.
\end{aligned} \tag{1}
$$

The solution to the linear program for the intensity vector λ^* and efficiency index θ^* can be interpreted as follows. There is a (hypothetical) composite producer formed as a nonnegative linear combination of all J observations using the components of λ^*. This composite producer consumes no more than observation j's capital and labor, while still producing $1/\theta^*$ of j's output. The composite producer thus represents a fully efficient producer who is located on the global production frontier at j's capital and labor levels, while θ^* represents the ratio between Y^j and the output of the composite producer; in line with our example in figure 1.[29]

2.2 Decomposition

The frontier approach can be used in a decomposition of total factor productivity, a process described by Kumar and Russell as "growth accounting with a new twist."[30] They break down TFP growth into two components: (1) technological change, and (2) technological catch-up. They characterize the first component as shifts in the global production frontier, determined conceptually by the state-of-the-art, potentially-transferable, technology. The second component reflects movements toward (or away from) the frontier as countries adopt best practice technologies and reduce (or exacerbate) technical and allocative inefficiencies.[31] To decompose labor productivity growth rather than TFP growth, the effects of capital accumulation can be added, which reflect movements along the frontier.[32]

To illustrate this decomposition, we have extended our example in the right pane of figure 1 to include a second period. The example now features two frontiers, for periods 0 and 1 respectively, as well as two (inefficient) observations: A and B. Labor productivity change can be represented by the decomposition in equation (2) below.

$$
\frac{y_b}{y_a} = \underbrace{\left(\frac{y_b}{y_1(k_b)} \Big/ \frac{y_a}{y_0(k_a)}\right)}_{\text{efficiency}} \cdot \underbrace{\left(\frac{y_1(k_a)}{y_0(k_a)} \cdot \frac{y_1(k_b)}{y_0(k_b)}\right)^{0.5}}_{\text{technological change}} \cdot \underbrace{\left(\frac{y_0(k_b)}{y_0(k_a)} \cdot \frac{y_1(k_b)}{y_1(k_a)}\right)^{0.5}}_{\text{accumulation}} \tag{2}
$$

[29] Note that the minimization problem for our simple example will return $L^j = \sum_k \lambda_k^* L^k$, in which case the ratio of Y^j to the output of the composite producer will be equal to the ratio of Y^j/L^j to the composite producer's labor productivity. Also note that the Farrell efficiency index θ will take on a value between 0 and 1, where a value of 1 implies that that particular producer is fully efficient.

[30] Kumar and Russell, 'Technological Change, Technological Catch-up, and Capital Deepening' p. 529.

[31] Ibid. p. 528.

[32] Timmer and Los, 'Localized Innovation and Productivity Growth in Asia' p. 50.

The first right-hand side factor measures the change in the, previously introduced, Farrell efficiency index. A value larger than 1 represents an increase in the level of technical efficiency over time, and hence we denote this as the *efficiency* component. Timmer and Los illustrate that this factor can be interpreted as the result of learning by doing and indicates the extent to which a country has exhausted the potential of a particular technology.[33] The second factor measures *technological change* by the shift in the frontier, expressed in labor-productivity change. As we can observe the vertical shift of the frontier both at capital intensity k_a as well as k_b, we adopt a 'Fisher ideal' decomposition and report the geometric average of the two measures. The last factor, which we label *accumulation*, is a Fisher index of the potential change in labor productivity resulting from a shift in the capital-labor ratio. This component thus represents the average productivity gains or losses as a result of the movement along both frontiers.

2.3 Extensions of the Basic Model

For our analysis, we have made a number of additions to the basic framework described above. First we adopt an 'intertemporal' approach, in line with the empirical analysis of Los and Timmer.[34] Instead of estimating the frontier at time t based solely on observations from this period, we also include all observations prior to period t in our reference production set. Los and Timmer argue that there are two important reasons to adopt the intertemporal approach:

> "First, because the production frontier is constructed sequentially, it can never shift inward and hence 'technological regress' cannot occur. The possibility of 'technological regress' seems awkward and hard to defend from a knowledge perspective on technology, as it would involve 'forgetting'. Second, a crucial element in the [Basu and Weil] model is the possibility for countries to use knowledge that was generated by technology leaders in the past. Labor-productivity levels of past technology leaders should be attainable for latecomers."[35]

A potential problem is that frontier techniques observed for the first year in our sample, 1909, are dominated by unobserved combinations in the past. In that case, part of what would be interpreted as frontier movements would in fact be assimilation of knowledge associated with these unobserved appropriate techniques. To accommodate this problem, we extended our data set backwards by 10 years by including two additional periods for the US, 1899 and 1904 respectively.

Secondly we address the issue of aggregation. So far, the level of aggregation in the frontier analysis literature has been highly macroeconomic. Kumar and Russell for the post-WWII period and Allen for the nineteenth and early twentieth century, for instance, rely on a global production frontier for the total economy.[36] Bernard and Jones show that sectoral measures of productivity growth and convergence can look very different from aggregate results.[37] Convergence in terms of labor productivity driven by technology diffusion typically occurs at the level

[33] Timmer and Los, 'Localized Innovation and Productivity Growth in Asia' p. 52.

[34] Los and Timmer, 'The 'Appropriate Technology' Explanation of Productivity Growth Differentials'; for a discussion of the time component in data envelopment analysis, see Tulkens and Vanden Eeckaut, 'Non-parametric Efficiency, Progress and Regress Measures'.

[35] Los and Timmer, 'The 'Appropriate Technology' Explanation of Productivity Growth Differentials' pp. 522–523.

[36] Kumar and Russell, 'Technological Change, Technological Catch-up, and Capital Deepening'; Allen, 'Technology and the Great Divergence'.

[37] Bernard and Jones, 'Technology and Convergence' p. 1043.

of products or industries, rather than at the total economy level. As pointed out by Timmer and Los, "Convergence at the industry level might not be reflected in macroeconomic statistics when countries differ in their industrial composition or experience different patterns of structural change."[38] Broadberry indeed observes substantial differences in the sectoral composition between Germany and the US for the early twentieth century.[39] Hence, we break up the manufacturing sector into 20 industry-groups and estimate a separate global production frontier for each.

2.4 Data

For our analysis of the German-American labor-productivity differentials, we have constructed a new data set of industry-specific real value added, employment and horsepower statistics. Our (unbalanced) panel observes 10 years for the US, spanning the period 1899 to 1939, and 2 years for Germany, 1909 and 1936 respectively. The set includes data for approximately 105 separate industries, and in total consist of nearly 1,250 observed input-output combinations. The basic source for US industries is the *Census of Manufactures*, while the primary German data is drawn from multiple industrial surveys, statistical yearbooks, employment censuses as well as the archival records of the 1936 *Industrial Census*. This section will, very briefly, describe the basic methods behind the construction of the data set; a full description of sources and methods can be found in the appendix.

As a first step in the construction of our data set, we have reclassified the industrial data for both countries and all years to the 1945 US Standard Industrial Classification (SIC).[40] Generally, an industrial classification groups establishments primarily engaged in the same line or similar lines of economic activity which, in the case of manufacturing, is either defined in terms of the products made (demand side) or the processes of manufacture used (supply side).[41] The SIC scheme places primary emphasis on the latter, whereas the original, German and US classifications rely heavily on the former. The supply-side grouping of businesses – i.e. the categorization according to the way in which inputs are transformed into outputs, mainly depending on the technology used – fits neatly into our DEA framework.

To make the German output data directly comparable to the US, we subsequently constructed two new industry-of-origin benchmarks; for 1909 and 1935/36 respectively. We calculated Purchasing Power Parities (PPP) at the industry level on the basis of producer prices, using the procedures first set out by Paige and Bombach and nicely exposited in the work of van Ark.[42] The price data for the interwar benchmark was collected from the American 1935 Census of Manufactures as well as the German Industrial Census of 1936.[43] For the 1909 benchmark, US price data was again taken from the Census of Manufactures. For Germany, manufacturing-wide

[38]Timmer and Los, 'Localized Innovation and Productivity Growth in Asia' p. 48.

[39]Broadberry, *The Productivity Race* pp. 63–73.

[40]For an overview of the SIC, see United States Department of Commerce: Bureau of the Census, *Census of Manufactures 1947, Vol. II: Statistics by Industry* pp. 862–914.

[41]Kendrick, *Productivity trends in the United States* pp. 405–406.

[42]Paige and Bombach, *A Comparison of National Output and Productivity*; van Ark, *International Comparisons of Output and Productivity*.

[43]The sources and methods used were identical to those described in the recent 1935/36 British-German benchmark by Fremdling et al. and the 1935 British-American benchmark by de Jong and Woltjer. Fremdling, de Jong and Timmer, 'British and German Manufacturing Productivity Compared'; de Jong and Woltjer, 'Depression Dynamics'.

production censuses did not become available until after the First World War. For our early Benchmark we rely on data obtained from industrial surveys, which reported output and prices for a sample of industries between 1907-1912. The resulting PPPs enabled us to convert German value added into nominal Dollar values for both 1909 and 1936.

Nominal value added, for both the US and Germany, was then converted to constant prices (with a 1929 base) by applying price deflators at the industry level. We calculated deflators on the basis of Fabricant's indices of physical output and nominal output series.[44] Subsequently, we reclassified these deflators to fit the SIC, and incorporated the modifications and extensions to the indices of production proposed by Kendrick.[45] Lastly, we expressed the employment measure in terms of hours worked and adjusted our capital measure to exclude the power of electric motors run by current generated in the same establishment, in order to prevent duplication. The necessity of the hours adjustment has been stressed by de Jong and Woltjer who observe a substantial drop in the average hours of work for the interwar period, particularly in the US.[46]

Our data set thus includes a single measure of output (value added in constant 1929 Dollars) and two inputs (hours worked and horsepower capacity), similar to the example listed above. We also assume constant returns to scale in our analysis.[47] As previously noted, we estimate a separate frontier for approximately 20 industry groups, distinguished by the SIC as industries that are similar in their use of inputs, outputs or production techniques. These industry groups are referred to as two-digit industries; a denotation which indicates their level of aggregation as being one step above the three-digit level, the level of aggregation of our data set. In the estimation of the frontiers we pool all the observations that belong to the same two-digit industry, implicitly assuming that these observations share a production function at this level of aggregation. For a small number of two-digit industries this assumption appeared to be violated, in which case we estimate more than one separate frontier for that respective group.[48]

3 Results

The main findings of this paper can be summarized in three points. First, in terms of capital-intensity levels Germany converged on the US between 1910 and 1935. Secondly, technological change at the frontier was decidedly non-neutral and biased toward capital. Technical progress has been limited to high capital-labor ratios, which as a consequence operated at higher levels of labor productivity. Furthermore, because of the bias in technological progress capital-intensive techniques continuously pulled further ahead between 1899 and 1939. If frontier technology was freely available to follower countries, the latter had a clear incentive to adopt capital-intensive production techniques. Thirdly, German manufacturing industries did exactly so between 1910 and 1935 and created a large growth potential as a result. However, the created potential for growth was not realized. Despite the process of rapid capital deepening, low levels of efficiency

[44] Fabricant, *The Output of Manufacturing Industries* pp. 123–321; 605–639.

[45] Kendrick, *Productivity trends in the United States* pp. 416–421; 467–475.

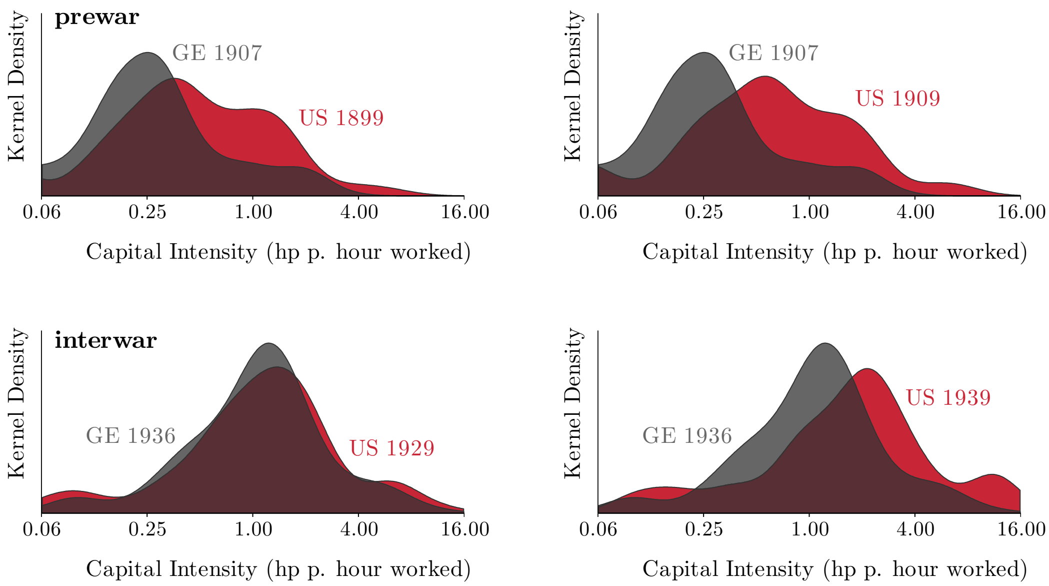
[46] de Jong and Woltjer, 'Depression Dynamics' pp. 485–488.

[47] Färe et al. show that the flexible nature of the DEA would allow us to relax the constant-returns-to-scale assumption, this does come at a cost of greatly increased data requirements however. A sensitivity check for a sub-sample of our data, on the basis of variable returns to scale, demonstrates that this assumption does not significantly alter our findings; we therefore feel confident using it. Färe, Grosskopf and Lovell, *Production Frontiers* pp. 32–37.

[48] A notable example is the *chemicals and allied products* industry.

stood in the way of German catch-up in terms of labor-productivity levels. These findings are in line with Basu and Weil's model of localized technological change (and not David's concept of technical lock-in).

Figure 2: Distribution of employment over production techniques



Source: see appendix.

3.1 On the level of total manufacturing

Figure 2 captures the convergence of capital-intensity levels between the US and Germany. In figure 2 the distribution of manufacturing employment over available production techniques is depicted. For Germany data is presented only for the benchmark-years 1909 and 1936. Capital-intensity data for the US can be found for 1909, too. The US census of 1935 did not include information on applied horse power and data for 1929 and 1939 are used instead. The overlap between the density plots of Germany and the US shows that the gap in capital-intensity levels had narrowed considerably between 1909 and 1936. Although the US retained a lead over Germany, capital deepening proceeded at a higher rate in Germany than it did in the US. Dissimilarities between production techniques used in American and German manufacturing industries disappeared to a large extent. While before WWI both countries clearly tracked different technical paths, such a distinction is no longer evident for the interwar period. The comparatively high rate of capital deepening in Germany implies that initial conditions did not stand in the way of capital-intensive production.

To measure the effect of the adoption of American-like production techniques on German manufacturing, German labor-productivity growth between 1909 and 1936 is decomposed ac-

Table 1: Decomposition of labor-productivity growth for manufacturing (ln %)

	Germany 1909–1936	**US** 1909–1935
Accumulation	1.9	0.8
Technological change	1.4	1.9
Efficiency	-1.5	0.2
Average annual labor-productivity growth	1.8	2.9

Sources: see appendix.

cording to Kumar and Russell's decomposition described in section 2. On the basis of the decomposition results – presented in table 1 – two conclusions can be drawn. First, Germany had created an enormous growth potential due to the increased capital intensity in manufacturing. Technological change was biased toward capital, so labor-productivity levels at the frontier were persistently higher for relatively capital-intensive production techniques. By 1936 Germany had moved into that range of high capital-intensity levels. The potential reward for this process of capital deepening was an annual labor-productivity growth of 1.9%. Furthermore, as the rate of technological change at the frontier was higher for capital-intensive production techniques, which Germany had adopted by the 1930s, the potential gains from technological progress at the frontier had increased, too. This added another 1.4% to the potential annual growth rate in Germany, which together with the accumulation effect amounted to 3.3%.

The second point brought forward by table 1 is that in reality German manufacturing grew with an annual average rate of only 1.8%.[49] The large unrealized potential, i.e. the difference between potential growth and actual growth, is captured by the substantial decline in the efficiency level in table 1. Similar production techniques in Germany did not operate at the same level of performance as they did in the US. Although the analysis does not provide an explanation as to why German industries did not reap the fruits of increased capital intensity, it does show that the persistent transatlantic productivity gap over the interwar period cannot be explained by the use of different production techniques. While the labor-productivity gap did not narrow and even increased somewhat in the 1930s, Germany rapidly closed with the US in terms of capital-intensity levels. These dynamics are very much in line with Basu and Weil's model of localized technological change, a point to which the next section will return.[50]

Growth dynamics in the US over this period were very different. The value of the efficiency component close to zero shows that the relative distance of American industries to the frontier did not change over time. As American industries constituted the frontier, as already established in the literature, the zero efficiency score indicates that the movement of the frontier as captured by the DEA was representative for US total manufacturing.[51] Because of the unchanged position relative to the frontier, movement along the frontier (capital deepening) and shifts of the frontier

[49] Growth rate for total manufacturing Germany is based on Hoffmann, *Das Wachstum der Deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts*. See section 2

[50] Basu and Weil, 'Appropriate Technology and Growth'.

[51] Allen, 'Technology and the Great Divergence'

(technological change) directly translated into labor-productivity growth. Whereas the created potential in Germany resulted mostly from capital deepening, technological change was the main driver of growth in the US. As de facto only American industries formed the frontier, the gains in US labor productivity were achieved through a process of innovation rather than accumulation. The exhibited growth rates over this period were unprecedentedly high, as already observed and accurately described by Field and Gordon.[52]

The German paradox in table 1 is evident. Manufacturing industries rapidly created growth potential as a result of increased capital intensity, yet they did not reap the benefits from this process of transformation. But for the lack of efficiency, German manufacturing would have grown at a rate almost twice as high as it actually did (3.3% instead of 1.8%). The gap between potential and realized growth was large. However, there are reasons to believe that German capital-intensity levels are overestimated. In the DEA capital-intensity levels of 1933 are used as a proxy for 1936. Germany was still in the midst of the Great Depression in 1933 and in order to save on production costs labor had been laid off. Although the employment census of 1933 only reports regularly-used horse power – and thus partly adjusts for capacity utilization – the high unemployment rate might have temporarily inflated capital-intensity levels.

Table 2: Decomposition of labor-productivity growth for industries (ln %)

Industry	**Efficiency**	**Technology**	**Accumulation**
28 Chemicals and allied	-3.9	2.5	2.7
33 Primary metals	-2.0	1.3	1.4
22 Textiles	-1.7	3.2	0.2
30 Rubber	-0.9	2.4	3.1
37 Transport. equipment	-0.6	4.1	2.7
29 Petroleum and coal	-0.1	2.2	1.6
32 Stone, clay, and glass	0.4	2.6	0.9
31 Leather	1.1	1.2	0.9

Sources: see appendix.

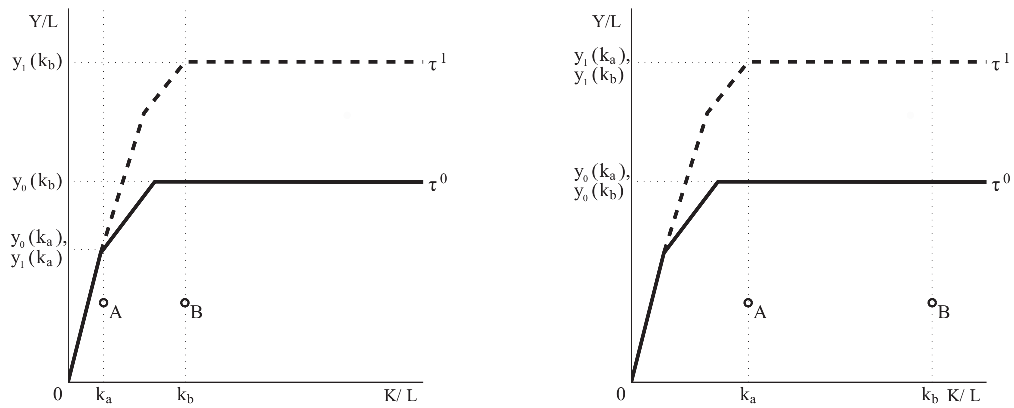
Using a lower-bound estimate of 1936 capital-intensity levels has little impact on the interpretation of the results, however. The lower-bound estimate is obtained by dividing applied horse power in 1933 by 1936 employment. This procedure underestimates 1936 capital-intensity levels because it incorporates the rise in employment between 1933 and 1936 but does not take into account any increase in the stock of machinery. A lower capital-intensity level reduces the rate of capital deepening between 1909 and 1936 and decreases the created potential for labor-productivity growth accordingly. As the realized rate of growth remains the same, it follows that the inefficiency in German manufacturing is smaller than the previously recorded 1.5%. However, even when we use the lower-bound estimate and capital-intensity levels in 1936 are underestimated, the unrealized growth potential due to inefficiencies was still 1.0% per year.

[52] Field, 'The Most Technologically Progressive Decade'; Gordon, 'One Big Wave?'.

3.2 On the level of manufacturing industries

Going down to a more detailed level of analysis, a similar decrease of technical efficiency between 1910 and 1935 is observed for manufacturing industries in Germany.[53] Table 2 presents the decomposition of labor-productivity growth and points out that in terms of efficiency almost all industries lost ground relative to the frontier. The lack of efficiency captures the difference between realized growth and created growth potential. In many industries, the potential for growth was large due to the process of capital deepening that took place in Germany between 1910 and 1935. In particular in chemicals & allied, primary metals, rubber, transportation equipment, and petroleum & coal the accumulation effect was substantial, signifying a move along the frontier toward the range of production techniques associated with relatively high labor-productivity levels.

Figure 3: The effect of capital deepening on labor productivity



(a) Large accumulation effect

(b) No accumulation effect

In contrast, the contribution of capital deepening to labor-productivity growth in the stone, clay, & glass industry, the leather industry, and the textiles industry was relatively small. It should be noted, however, that a low accumulation effect does not necessarily reflect a low rate of capital deepening. In fact, capital-intensity levels were roughly stagnant only in the case of textiles. Figure 3 explains why. The accumulation effect equals the average gain in labor productivity due to a shift along the frontier over time, i.e. the geometric average of $\frac{y_0(k_b)}{y_0(k_a)}$ and $\frac{y_1(k_b)}{y_1(k_a)}$. In spite of a high rate of capital deepening, the created growth potential due to the move from k_a to k_b in the right pane figure 3 is zero. This happened in the stone, clay, & glass industry and the leather industry; capital intensity in 1910 had (just barely) reached the level from which onwards the effect of further capital deepening on labor productivity was marginal only.

[53]Due to a lack of data, only for a limited number of industries labor-productivity growth over the interwar period can be calculated. For the decomposition of total manufacturing labor-productivity growth Hoffmann's time series of output and employment are extrapolated backwards from the level of labor productivity in 1936 German manufacturing. For the pre-WWI period a manufacturing-wide census of production is not published and output and employment for only a handful of industries is reported by industrial surveys. Capital intensity for both total manufacturing and the sample of industries is obtained from the prewar and interwar employment censuses, which go down to SIC 3-digit level.

Table 2 also shows that technological progress at the frontier for German capital-intensity levels proceeded at a high rate across the board, as table 1 already pointed out. In most industries the magnitude of created growth potential due to technological change was largely determined by the rate of capital deepening; as the upward movement of the frontier was larger for capital-intensive techniques, a move from low to high capital-intensive techniques increased the growth potential due to technological change. Progress was embodied in increasingly more labor-saving technology. However, at a certain point industries that move along the frontier run into diminishing returns to capital-intensity. If in the left pane of figure 3 an industry was positioned at point k_b already in period B, the marginal productivity of capital intensity between period A and B would equal zero. This was the case for the textiles industry, the stone, clay, & glass industry, and the leather industry.

As already pointed out, of these three industries capital-intensity levels remained roughly stable only in textiles between 1910 and 1935. In contrast, the stone, clay, & glass and the leather industries appear to have overshot the target and accumulated too much capital, because the returns to the additional investment in capital intensity beyond point k_b (in the left pane of figure 3) did not lead to gains in labor productivity. This overshooting was not uncommon in German manufacturing. Several other industries, e.g. tires, pig iron, and coke also ended up in 1936 with a capital-intensity level much higher than was minimally required to obtain the growth potential they had created. This explains why the low-bound estimate, which was used to allow for possible overestimation of capital intensity in 1933, had a limited effect on the results: a decrease of capital-intensity level has little impact on the creation of growth potential as by 1936 some industries had long since passed the point where an increase in capital intensity still translates into labor-productivity growth.

The over-accumulation of capital is counter-intuitive and seemingly at odds with notions of cost minimization. A possible reason as to why some industries overshot and apparently ended up with too much capital is the bias in technological change toward capital. As frontier dynamics were located in a range of production techniques increasingly more capital intensive, industries at point k_b in the left pane of figure 3 will in future no longer fully benefit from technological change at the frontier. In the next period industries positioned to the right of k_b have a larger growth potential than those still at k_b. Given an average asset lifetime of machinery of twenty years, taking into account the capital bias in technological change when purchasing new capital is advantageous to labor-productivity growth.

Not all German industries studied in this paper over-accumulated capital. The growth trajectory of, for instance, inorganic chemicals, organic chemicals, nonferrous metals, and iron & steel foundries is more accurately described by the situation depicted in the left pane of figure 3. Between 1910 and 1935 capital deepening moved industries from a point where the frontier did not shift – k_a or a point to the left of k_a – to the range of production techniques where over time technical efficiency increased – a point anywhere between k_a and k_b. Capital-intensity levels of their American counterparts tended to be higher on average, but these German industries had increased capital intensity just enough to still benefit from technological change at the frontier. It should be noted, however, that in both scenario's the effect of capital deepening on labor-productivity growth was very similar. Germany did not realize the growth potential it had created as a result of capital deepening.

4 Interpretation

The move toward American-like production techniques occurred in a time of persistently large German-American labor-productivity differences. German industries rapidly increased capital-intensity levels but this process of modernization did not lead to catch-up growth. We are certainly not the first to study Germany's inability to close the transatlantic productivity gap in the first half of the twentieth century and consider the analysis applied in this paper to be complementary to previous work discussing the constraints to German labor-productivity growth. The non-parametric growth decomposition presented in this paper uncovers the large discrepancy between created growth potential and realized growth, a main feature of German economic development, and the existing literature can provide a better understanding of the impediments to technical efficiency in German manufacturing. Although it is not in our intent to offer an exhaustive overview of the literature, this section does aim to link the key mechanisms of our model to the realities of interwar Germany.

4.1 Frontier awareness

The labor-productivity difference between American and German industries for given capital-intensity levels can be interpreted as a technical-efficiency gap only if technological knowledge generated at the frontier was immediately available to all other countries. Prerequisite to technological spillover is an awareness of production techniques used at the frontier. Not before new technology is known to follower countries frontier production techniques can be adopted. Economic historians have long since emphasized the prominence of technology transfer.[54] Ultimately, the diffusion of frontier technology hangs on local conditions. In the model used in this paper, follower countries can use the technology of the leading country not before it has reached a sufficiently high level of development.[55] In the case of Germany 'frontier awareness' translates into a knowledge of American production techniques among German industrialists. Indeed, such an America-centered orientation is well documented in the literature on interwar Germany.

American influences on German entrepreneurship were limited before the 1920s. From the 1890s onwards, the scientific management of labor as proposed by Frederick Taylor gained a strong foothold in the minds of American producers. Proponents of Taylorism traveled to Germany, too, but found their message difficult to sell; partly because of working-class opposition for fear of reform at the cost of the laborer and partly because Germany's successful industrial development before 1914 did not create a necessity for new concepts.[56] In the 1920s the situation was different. WWI, the repair payments demanded at Versaille, and the hyperinflation of the early 1920s had left the German economy weakened in general and technological backward in particular.[57] Change was needed and by that time an attractive alternative to Taylorism was offered by Ford's achievements in the Detroit motor-vehicle industry. Rather than improving performance by rationalizing only on the factor input labor, Fordism stressed the importance of both labor and technology in the production process.[58] As a consequence, the Fordist approach to production appealed strongly to German entrepreneurs and set the example for future

[54]Bernard and Jones, 'Technology and Convergence' p. 1038.
[55]Basu and Weil, 'Appropriate Technology and Growth' p. 1027.
[56]Nolan, *Visions of Modernity* p. 45.
[57]Ibid..
[58]Ibid. p. 48.

development in Germany:

> "With the end of Germany's acute postwar dependency and instability, America came to be seen as an economic model. In the words of one observer: 'One seeks to learn from her, to study her organization, management, and technology."'[59]

The economic-growth literature has often emphasized the importance of investment-based strategies for follower countries.[60] Provided that the necessary capabilities and resources are available (Gerschenkron's idea of 'appropriate' economic institutions and Abramovitz' 'social capabilities') countries distanced far away from the frontier can catch-up quickly by importing or imitating advanced technologies.[61] From this perspective, the strong German orientation on America does not come as a surprise. Apart from the theoretical notions of modern economic-growth models, however, perhaps a more decisive incentive to follow the American example was provided by the realities of the interwar period. In 1924, after the damage suffered by the economy between 1914–1924 was revealed, industrialists and entrepreneurs sought ways to recover. At the time America showed an unprecedented growth record.[62] More importantly, the growth experience of the US was not just a theoretical possibility discussed in academic debate. Right in front of everyone's eyes the US demonstrated the feasibility of fast economic growth. What better way forward for Germany than to follow the American example?

> "For industrialists, (...) Fordist productivism offered a possible solution to the economic problems of low productivity, inefficient technology, lack of standardization, and the resulting high costs that plagued the economy as a whole. (...) Rationalization, at least in the first instance, was defined by all in technological and productivist terms. A shared perception of the problems of German production led to a shared belief that there was no better place to start learning alternative production methods than from Ford, the embodiment of American technological leadership, efficiency, and cost cutting."[63]

Many German entrepreneurs traveled to the US to study first hand the organization of American manufacturing industries. Although the extensive application of machinery and the high level of efficiency at which American manufacturing operated never failed to impress the visitors, many Germans felt that the American example could not be repeated in Germany. Market size, demand patterns, and wage structures differed just too much between the US and Germany. Nevertheless, it was argued that the principles of American production technology could be isolated and implemented in Germany as well.[64] The literature has, indeed, pointed out that in the 1920s German manufacturing industries deployed imitating activities to catch-up with their American competitors. Richter and Streb, for instance, quote contemporary sources reporting that American machine tools were copied by German engineers without any modification to

[59] Nolan, *Visions of Modernity* pp. 23–24.

[60] Aghion, 'Higher Education and Innovation' p. 31; Acemoglu, 'Directed Technical Change' p. 39; Vandenbussche, Aghion and Meghir, 'Growth, Distance to the Frontier and Composition of Human Capital' p. 98.

[61] Gerschenkron, *Economic backwardness in historical perspective, a book of essays* pp. 113, 116; Abramovitz, 'Catching-up, Forging Ahead and Falling Behind' p. 387.

[62] Field, 'The Most Technologically Progressive Decade'.

[63] Nolan, *Visions of Modernity* p. 38.

[64] Ibid..

the original design.[65] In the mid-1920s, the American trade commissioner listed over sixty US machine-tool producers whose export suffered from German firms duplicating their products.[66] These cases are clear examples of technology transfer from the US to Germany.

4.2 Delayed catch-up

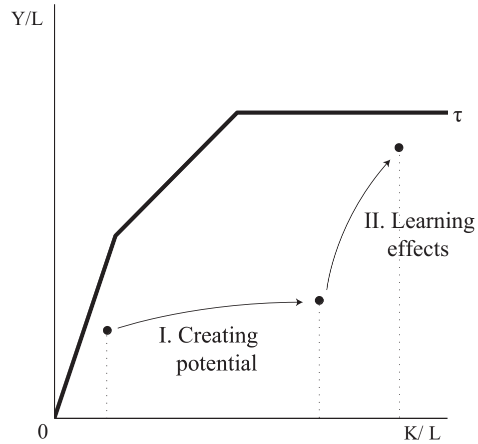
In spite of their infatuation with the US, the German rationalization movement could not match the pro-America rhetoric employed by German engineers, entrepreneurs, and labor unions. The implementation of new technology was hindered in two major ways. First, the short time between the hyperinflation and the Great Depression offered little room for extensive revisions to the production process. When the depression hit Europe in 1929 Germany had enjoyed relative stability for less than a decade and many long-term projects slowed down, stalled, or were canceled all together.[67] Germany never reached the level of mechanization displayed by the forerunners of American industrial development such as Ford. Secondly, by the 1930s it became evident that due to the emphasis on production and productivity, i.e. supply-side factors, the productive capacity of industries had expanded much faster than demand. In effect, many industries were overcapitalized and had excess capacity that was left unused.[68] As the new direction of technological development and industrial organization was ill-matched to meet demand patterns, the success of the modernization process was less than what was hoped for.

The incomplete process of mechanization in German manufacturing and the associated implementation problems fit well with the results of our analysis presented in the previous section. In terms of capital-intensity levels Germany converged on the frontier, but America retained a lead all through our period of study. Furthermore, our results also point out that in the short run the gains of modernization were very small indeed. In contrast to the literature, however, we do not necessarily understand the lack of catch-up growth as a failure on the part of Germany. Previous applications of the intertemporal DEA-approach in the field of development economics led to findings not dissimilar to ours. For a sample of Asian countries in the period between 1975–1992, Timmer and Los show that the created potential due to capital deepening was large, too.[69] Moreover, the country that created the largest potential, i.e. Korea, experienced an increase of its relative distance to the worldwide frontier over time. Korea grew 3.8 percentage point less than the 9.3% annual growth potential it had created. Instead of interpreting the negative value for efficiency as a failure, Timmer and Los conclude that these findings suggest a sequence in which countries first create opportunities for growth by rapidly increasing capital intensities and subsequently learn to operate the new technology at its full potential.[70]

Timmer and Los' interpretation of the Korean growth experience is a two-stepped approach to catch-up. Follower countries go through two sequential phases of development in order to close with the frontier, as depicted in figure 4. If the initial phase of catch-up – the accumulation of new production technology – involves an extensive transformation of the production process, in the short run efficiency levels are likely to be very low. Only after the economy has adjusted to the new situation and has 'learned' to operate the new technology at its full potential, the

[65] Richter and Streb, 'Catching-up and falling behind' p. 1.
[66] Ibid. p. 17.
[67] Nolan, *Visions of Modernity* p. 132.
[68] Ibid..
[69] Timmer and Los, 'Localized Innovation and Productivity Growth in Asia' p. 58.
[70] Ibid. p. 60.

Figure 4: Catch-up in two sequential steps



labor-productivity gap to the frontier can be narrowed. The time lag between creating potential and moving toward the frontier therefore depends on the scope of capital deepening. For the case of Germany, this implies that the implementation problems that German engineers and industrialists encountered in the 1920s and 1930s were not signs of failed industrialization. Instead, they were features of progress and inextricably linked to the initial phase of catch-up growth.

Unfortunately, we are unable to study the effects of learning in Germany over a longer period. Data on the late 1930s and 1940s are, of course, distorted by the armaments race, WWII, and the reconstruction period in the war's aftermath. What is known, though, is that between 1950 and 1980 Germany rapidly closed the productivity gap with America. In 1980 German levels of value-added per hour worked were at 91% of those in the US.[191] Furthermore, the process of capital deepening picked up again after 1950 and continued until by 1980, as with the productivity gap, America had lost its lead over Germany.[71] It is not suggested here that the high rate of capital deepening over the interwar period provided the foundation for the German postwar growth miracle. Too much has happened between the 1930s and 1950s to make such a connection. We do like to point out, however, that the dynamics that propelled Germany to the frontier in the postwar period should, perhaps, not necessarily be understood as a development strictly confined to the post-1950s.

5 Conclusion

This paper set out to study the growth experience of German manufacturing over the interwar period. Qualitative evidence presented in the literature is difficult to align with David's model of path-dependent technological progress, which economic historians have used to explain the persistent transatlantic labor-productivity gap between 1850 and 1950. Labor-abundant and

[191] van Ark, *International Comparisons of Output and Productivity*.

[71] Ibid. p. 121.

resource-scarce European countries were supposedly trapped on a labor-intensive technological path that limited the scope for productivity growth. However, during the 1920s German industries actively copied and duplicated American, capital-intensive, technology; which contradicts the existence of a European-specific technological path.

In this paper we reassessed the productivity dynamics in German manufacturing on the basis of Basu and Weil's model of appropriate technology that predicts convergence in light of capital deepening. By means of a DEA we decomposed labor-productivity growth in effects of capital accumulation, technological change, and efficiency change. David's model implies stable capital-intensity levels over the period 1909–1936, but the DEA reveals very different dynamics. German manufacturing industries had a high rate of capital deepening, rapidly adopting new, 'American', production techniques. Although in terms of capital-intensity levels the US retained a lead, the gap was narrowed considerably. Moreover, due to the combined effect of increased capital-intensity levels and capital-biased technological change at the frontier, Germany had created a large labor-productivity growth potential.

The convergence in capital intensity occurred at a time when German entrepreneurs and industrialists increasingly looked to America as the example for industrial development. Frontier awareness, i.e. knowledge of production techniques used at the frontier, was a prerequisite to technological spillover and abundantly present among German industrialists in the late 1920s and early 1930s. However, in spite of their infatuation with the US, the German modernization movement could not match the pro-America rhetoric employed by German engineers, industrialists, and entrepreneurs. The DEA shows that low levels of technical efficiency stood in the way of realizing the created growth potential.

In contrast to the traditional literature on the transatlantic productivity gap, however, we do not interpret the small gains in labor productivity as a failure on the part of Germany. Following Basu and Weil's appropriate-technology model, the decrease of relative efficiency is understood as a feature of progress inextricably linked to the first phase of catch-up growth, i.e. creating potential by capital deepening. Only after an economy has adjusted to the new situation and exhausts the full potential of the new technology, the labor-productivity gap to the frontier can be narrowed. This process was interrupted by WWII, delaying the second phase of catch-up, i.e. the learning effect, but we nevertheless do suggest that capital deepening during the interwar period was a first step on the road to convergence.

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A Note on US Data and Methods

The basic source of output, employment and capital data for US industries is the *Census of Manufactures*. Data on total employment, value added and total horsepower employed is available in the quinquennial censuses between 1899 and 1919 and the biennial censuses of 1923 to 1929 and 1939.[72] The section below will define the basic variables, discuss the comparability of the figures between different census years, and clarify the industry classification.

A.1 Basic sources

Nominal value added is derived directly from the census figures as the net of the total value of products minus the cost of materials, purchased fuel and electric energy and contract work. No attempt was made to adjust for inventory revaluations or fully account for maintenance work and repairs; but evidence presented by Fabricant suggests that these adjustments would only marginally affect gross value added for the years in our sample.[73] We calculated deflators at the industry level on the basis of the Fabricant indices of physical output and nominal output series.[74] Subsequently, we reclassified these deflators to fit the 1947 industry classification, which constitutes the basis for both the Kendrick series and our own (see section A.3 below).[75] Lastly, we incorporated the modifications and extensions to the indices of production proposed by Kendrick.[76] Nominal value added was converted to constant prices (with a 1929 base) by applying the price deflators at the two-digit SIC level.

We define employment as the sum of wage earners, salaried officers and employees.[77] We exclude all proprietors and firm members as we wish to limit our analysis to *manufacturing*

[72]United States Department of Commerce: Bureau of the Census, *Thirteenth Census of the United States, Vol. VIII: Manufactures*; Idem, *Fourteenth Census of the United States, Vol. VIII: Manufactures*; Idem, *Fifteenth Decennial Census: Manufactures, Vol. I: General Report*; Idem, *Sixteenth Decennial Census: Manufactures, Vol. I: Statistics by Subjects*.

[73]Fabricant, *The Output of Manufacturing Industries* pp. 340–350.

[74]Ibid. pp. 123–321; 605–639; 1939 physical output was derived from United States Department of Commerce: Bureau of the Census, *Census of Manufactures 1947, Indexes of Production* p. 1.

[75]For the computation of the aggregate price indices we maintained the Marschall-Edgeworth formula with 1909, 1919 and 1929 as base-years.

[76]Kendrick, *Productivity trends in the United States* pp. 416–421; 467–475.

[77]The category 'salaried officers and employees' includes all superintendents, managers and clerical workers.

personnel whose activity directly contributes to the value added reported in the census. In censuses prior to 1935, manufactures were instructed to report all personnel employed in both production activities and in auxiliary activities such as maintenance, shipping, warehousing, etc. at the same location. Our employment figures thus invariably include a number of employees engaged in these kinds of non-manufacturing activities. This distinction is complicated further by the 1939 schedule that asked employers to report separate figures for their manufacturing and non-manufacturing personnel, based either on- or off-site. Although it is difficult to establish to what extent this change in definition affects the comparability of the employment figures between the censuses, Fabricant concludes that "the implicit Census definition of factory employment has given rise to no serious ambiguities in the data."[78] For 1939 we included all non-manufacturing personnel – but still excluding proprietors and firm members – in our employment totals, which is comparable to the definition applied by Kendrick for this year.[79]

The census employment figures were converted to total hours worked on the basis of industry-specific average annual hours of work obtained from various sources. For the inter-war period we relied on data by Inklaar et al., who provide detailed estimates of average hours of work for wage earners, for all census years.[80] We extended their dataset to include the census years prior to World War I. The censuses of 1909 and 1914 provide industry specific data on prevailing hours of labor per week; no data is available for the years 1899 and 1904, we used the 1909 average hours instead.[81] We normalized our industry-specific weekly hours over the total manufacturing figures provided by Jones, using census wage earners as weights.[82] Lastly, we converted the prewar estimates to annual average hours worked, based on the 1900 estimate of American vacation and holidays by Huberman and Minns.[83]

Capital intensity is defined as the sum of the horsepower capacity of prime movers and the horsepower rating of motors driven by purchased electric energy, divided by our measure of employment. Our definition coincides with the census measure of primary power; which also excludes the power of electric motors run by current generated in the same establishment to prevent duplication. The census years 1921 and 1931 to 1937 were entirely excluded from our sample as data on power equipment was either not collected or incomplete for these years. Although it is likely that rates of capacity utilization have changed during this period – partly as a result of the shift from the use of prime movers towards electric motors – we were unable to adjust for these.

A.2 Scope and continuity

During this period the scope of the activities covered by the Census has changed somewhat. Prior to 1919, the Census exempted all establishments with an annual production valued at less than $500; for the years since 1919 this limit was raised to $5,000. In the 1921 Census report

[78] Fabricant, *Employment in Manufacturing* p. 173.

[79] Kendrick, *Productivity trends in the United States* p. 434.

[80] Inklaar, de Jong and Gouma, 'Did Technology Shocks Drive the Great Depression?' pp. 852–854. These figures relate exclusively to wage earners, however this group comprises the bulk of our employment measure, and any deviations in hours worked between wage earners and salaried officers and employees are bound to be small compared to the annual fluctuations observed during this period.

[81] United States Department of Commerce: Bureau of the Census, *Thirteenth Census of the United States, Vol. VIII: Manufactures* pp. 316–319; Idem, *Abstract of the Census of Manufactures 1914* pp. 482–489.

[82] Jones, 'New Estimates of Hours of Work per Week' p. 375.

[83] Huberman and Minns, 'Days and Hours of Work in Old and New Worlds' p. 546.

this resulted in a 21.6 percent reduction in the number of establishments covered. However, the comparability of the figures since 1919 were not appreciably affected as, according to the United States Bureau of the Census, "99.4 percent of the total wage earners and 99.7 of the total value of products reported at that census [1919, red.] were contributed by the establishments reporting products to the value of $5,000 or more."[84] In addition, from 1904 onwards, the Census of Manufactures was confined to establishments conducting work under the *factory system*, thus excluding neighborhood industries and hand trades. For 1899 we relied on reclassified figures provided in the 1909 census. The adjusted figures omit all non-factory establishments for 1899 and are thus fully comparable to the statistics for subsequent census years.[85]

Over the course of our period several major industries engaged in activities no longer considered as manufacturing were excluded from the Census.[86] We followed this convention and withdrew these industries from our sample. Over the various censuses numerous changes were made to the classification of industries and products, inevitably resulting in discontinuities and breaks in the series. Fabricant discusses the continuity of the census value added and employment data over the period 1899–1939 at length.[87] Overall, predominantly smaller industries were affected by the changes across the various census years, thus limiting the overall impact on the coherence of the dataset. Where necessary we have combined related industries into aggregate groupings to ensure continuity.[88]

A.3 Standard industrial classification

In our analysis we rely on the industrial classification laid out in the 1947 Census of Manufactures.[89] The census classification was derived from the 1945 *Standard Industrial Classification* (SIC), which was the first attempt to standardize the collection and reporting of data across different agencies while maintaining consistency over a longer time-frame.[90] The industrial classification groups establishments primarily engaged in the same line or similar lines of economic activity which, in the case of manufacturing, is generally defined in terms of the products made (demand side) or the processes of manufacture used (supply side).[91] The SIC scheme places primary emphasis on the latter, whereas the original, prewar, census classifications relies heavily

[84] United States Department of Commerce: Bureau of the Census, *Sixteenth Decennial Census: Manufactures, Vol. I: Statistics by Subjects* p. 2.

[85] Idem, *Thirteenth Census of the United States, Vol. VIII: Manufactures* pp. 507–517; both the 1899 and 1904 data were taken from the 1909 Census report.

[86] Important industries that were dropped are motion picture production, manufactured gas, automobile repairing, and railroad repair shops. See e.g. Kendrick, *Productivity trends in the United States* p. 404.

[87] Fabricant, *The Output of Manufacturing Industries* pp. 605–639; Idem, *Employment in Manufacturing* pp. 179–230.

[88] E.g. Cigarettes (211) and Cigars (212) were combined into an aggregate industry group, as well as Flat Glass (321) and Pressed and Blown Glassware (322).

[89] United States Department of Commerce: Bureau of the Census, *Census of Manufactures 1947, Vol. II: Statistics by Industry* pp. 862–914.

[90] The differences between the 1947 Census and the 1945 SIC are minor; for a detailed discussion see Ibid. pp. 931–933.

[91] Kendrick, *Productivity trends in the United States* pp. 405–406.

on the former.[92] The supply-side grouping of businesses – i.e. the categorization according to the way in which inputs are transformed into outputs, mainly depending on the technology used – fits neatly into our productivity analysis. Although the SIC has undergone several revisions (the latest in 1987), we explicitly chose to use the 1947 vintage as the introduction of new products and production techniques over time make the later classifications less applicable to the period preceding the Second World War.

Following the standard industrial classification, the manufacturing division comprises approximately 450 industries in 1939, which are included in 127 industry groups and 20 major groups.[93] These major groups are commonly referred to as two-digit industries and are broken down into three-digit industries (i.e. industry groups), which in turn are separated into four-digit industries.[94] We restrict our analysis to the three-digit level, moderately modified to ensure continuity, leaving us with 105 observations for each of the 10 census years. We generally estimate a frontier at the two-digit level, implicitly assuming that industries share a production function at this level of aggregation. As previously noted, the SIC groups industries according to a similarity in their inputs, outputs or use of production techniques, giving credence to the assumption of a joint production function. For a number of two-digit industries this assumption was violated, in which case we estimate two or more frontiers for that respective group.[95]

B Note on German Data and Purchasing Power Parities

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.[96] 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.[97]

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

[92] Although in many respects the SIC resembles the prewar census classifications, there have been a number of important changes that highlight the shift from a demand-side to a supply-side oriented classification. Notably in metals, the prewar censuses grouped establishments according to whether they produced ferrous or nonferrous products. The 1945 SIC reclassified these industry groups according to whether the production process was mainly associated with primary production (e.g. refining, smelting, rolling, etc.) or the production of finished metal products (e.g. nails, wire, hardware, etc.), regardless of the type of metal from which the end-product consisted.

[93] United States Department of Commerce: Bureau of the Census, *Census of Manufactures 1947, Vol. II: Statistics by Industry* p. 915.

[94] Carter et al., *Historical Statistics of the United States, Vol. 4: Economic Sectors* p. 4.

[95] The most notable example is *chemicals and allied products* (28).

[96] Maddison, *Monitoring the World Economy*; Idem, *The world economy*.

[97] Prados de la Escosura, 'International Comparisons of Real Product'.

to growing criticism as well.[98] 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 estimating direct benchmark estimates for earlier years.[99] 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 labor 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.[100] 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.[101] 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.[102] Recently however, the extended ICOP methodology has also been applied to international comparisons for the period preceding the Second World War.[103] 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.[104] 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 labor 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.

B.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

[98] Hoffmann, *Das Wachstum der Deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts*; Ritschl, 'Spurious Growth in German Output Data'; Ritschl, 'The Anglo-German industrial productivity puzzle'.

[99] Fremdling, de Jong and Timmer, 'British and German Manufacturing Productivity Compared'; Fremdling, 'Sonderdruck aus: Jahrbuch für Wirtschaftsgeschichte Vol. 2 [2009]'; Ritschl, 'Spurious Growth in German Output Data'.

[100] Rostas, *Comparative Productivity in British and American Industry*.

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

[102] Maddison and van Ark, 'Comparison of Real Output in Manufacturing'; van Ark, *International Comparisons of Output and Productivity*.

[103] Fremdling, de Jong and Timmer, 'British and German Manufacturing Productivity Compared'; de Jong and Woltjer, 'Depression Dynamics'; Dormois, 'Episodes in Catching-Up'.

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

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 (3) 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 (4).The subscript i represents the numerator country, whereas the subscript j represents the base country.

$$p_{k,n} = \frac{v_{k,n}}{q_{k,n}} \tag{3}$$

$$uvr_{k,i,j} = \frac{p_{k,i}}{p_{k,j}} \tag{4}$$

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 (5). 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*.[105] 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 (6).

$$ppp_{i,j} = \sum_{k=1}^{m} \left(uvr_{k,i,j} \cdot \frac{v_{k,j}}{\sum_{k=1}^{m} v_{k,j}} \right) \tag{5}$$

$$ppp^{F}_{i,j} = \sqrt{ppp_{i,j} \cdot (ppp_{j,i})^{-1}} \tag{6}$$

B.2 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. For 1909 US we based our analysis on the *Thirteenth Census of the United States* published by the US Bureau of Commerce.[106] For 1935 US we relied primarily on the *Biennial Census of Manufactures 1935* and the *Sixteenth Decennial Census of the United States*.[107] For Germany we used the comprehensive

[105] 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 $\frac{\sum p_i \cdot q_i}{\sum p_j \cdot q_i}$.

[106] United States Department of Commerce: Bureau of the Census, *Thirteenth Census of the United States, Vol. VIII: Manufactures*.

[107] Idem, *Biennial Census of Manufactures 1935*; Idem, *Sixteenth Decennial Census: Manufactures, Vol. I: Statistics by Subjects*.

archival records of the *Industrial Census of 1936*, which contains considerably more detailed and accurate information than the published version of the census.[108] Unfortunately, for pre-WWI Germany a census of manufactures is absent. For the construction of unit values, we relied on the industrial surveys covered by the *Vierteljahrshefte zur Statistik des deutschen Reichs*.[109]

Table 3: German/US purchasing power parities in 1909 and 1935

SIC	Description	*ppp*	
		1909	1935
19	SMALL ARMS AND AMMUNITION	–	2.54
20	FOOD AND KINDRED	–	4.35
22	TEXTILES	3.10	3.47
23	APPAREL AND RELATED	–	3.58
24	LUMBER AND WOOD PRODUCTS	–	6.26
26	PAPER AND ALLIED	–	3.64
28	CHEMICALS AND ALLIED	3.22	3.03
29	PETROLEUM AND COKE	6.25	2.84
30	RUBBER PRODUCTS	3.68	4.20
31	LEATHER PRODUCTS	5.40	4.23
32	STONE, CLAY, AND GLASS	3.94	2.84
33	PRIMARY METALS	3.34	2.81
34	FABRICATED METALS	–	3.56
35	MACHINEREY (EXCEPT ELECTRICAL)	–	3.54
36	ELECTRICAL MACHINERY	–	3.61
37	TRANSPORTATION EQUIPMENT	4.98	3.99
38	INSTRUMENTS AND RELATED	–	5.38

[108] Reichsamt fur Wehrwirtschaftliche Planung, *Die Deutsche Industrie*; for a detailed discussion of this source see: Fremdling, de Jong and Timmer, 'Censuses Compared'.
[109] Kaiserlichen Statistischen Amte, 'Vierteljahrshefte zur Statistik des Deutschen Reichs: Ergänzungsheft'.