The Cutting Edge of Modernity: Machine Tools in the United States and Germany 1930-1945

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Abstract:
This paper aims to examine the difference between US and European manufacturing before and during the World War II, focusing on the key technology in the metal-working sector: machine tools. We present a new data set covering the installed capacity of metal-working tools in the United States and Germany for the period 1930-1945. The existing literature is heavily dependent on assumptions about the different type of machine tools in use on either side of the Atlantic. So far, systematic comparison has been limited to case studies. This is the first attempt to quantify the differences in this key technology for the entirety of metal-working in both economies. The enormous detail of the statistical sources we have uncovered allows us to combine aggregation and a degree of specificity, which exceeds that of any previous case study. In the German case, the original data is divided into well over a hundred sub-categories. For comparative purposes, we have identified 19 major classes of machines, which aggregate over 50 sub-categories. Our results suggest the need for a far more nuanced understanding of metal-working than the dichotomous picture of American mass manufacture, reliant on special-purpose tools, and European craft manufacturing employing general-purpose machinery. For 1930, we find a remarkable similarity in machine to worker ratios between Germany and the United States. There are differences in certain key areas. However, the US stock of metal-working tools is not yet distinguished by a clear commitment to mass production technology. For the period after 1935, until the early 1940s, our data suggest a remarkable degree of convergence. The American stock stagnated. In some areas, there was disinvestment. And the average age of machinery rose dramatically. By contrast, Germany entered a period of rapid catch-up, which appears to have continued into the early years of the war. By 1940, German metal-working came close to matching its American counterpart in terms of the number of workers employed and the quantity and types of machines installed. German machines were, on average, far younger. This process of catching-up, however, was dramatically reversed during World War II. Over a period of no more than four years the American stock expanded by over eighty percent and growth was markedly concentrated in key categories of mass production equipment. It appears that it was only in this period that mass production machinery came to truly dominate US metal-working. German investment, albeit moving in the same direction, failed to match the new intensity of American commitment to mass production in some key machinery classes.
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The Cutting Edge of Modernity: Machine Tools in the United States and Germany 1930-1945[1]

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Introduction:

Machine tools are at the heart of industrial metal-working. Different types of tool are widely believed to be characteristic of different systems of industrial production. In this paper we present a new data set, which allows a detailed comparison of the stocks of metal-working machine tools in place in the two largest industrial economies of the interwar period: Germany and the United States. The results of this comparison add further fuel to recent arguments over one of the classic questions in modern economic history: how to characterize and explain the differences between European and North American industry.

Machine tools have long served as one of the symbols of the gulf that separates American from European industry. When the first examples of new American tools began to arrive in Europe in the late 19th century they appeared to encapsulate all the differences between production on either side of the Atlantic. American industry broke with the classic European dependence on the general purpose lathe operated by skilled craftsmen. The American industry introduced new types of tools for metal cutting such as milling machines and grinders. They produced ever more specialized tools suited for the production of particular parts in large quantities. And they produced tools that could be operated by semi-skilled and unskilled workers simply by moving a set of levers. They systematically applied and developed the power of electrical motors to the problem of metal cutting: a development which was itself forced by the introduction of the first generation of high performance tool steels. By the 1890s manufacturers in Britain, the traditional home of modern machine

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tools - but above all in Germany - began actively to respond to the American challenge. By World War I the geographical hierarchy of the machine tool industry, the hub of engineering, was set for most of the twentieth century: America in the lead, followed by Germany, with Britain a distant third.

In the historical literature this multi-faceted process of innovation has been encapsulated in a simple dichotomous distinction. On the one hand, American production technology is characterized by its supposed dependence on special purpose machine tools, dedicated to the mass production of interchangeable parts, with the minimum use of skilled labour. On the other hand, European production technology is characterized as being heavily reliant on a combination of skilled craft labour working with more traditional, general purpose machines, typified perhaps by the so-called engine lathe, the most flexible of all tools. There is no doubt that this stereotypical distinction was a common place amongst engineering writers on both sides of the Atlantic. It underpinned the analysis, for instance, of the investigative teams of the United States Strategic Bombing Survey (USSBS) which visited Germany in 1945. Its place in present day academic discussion has been consolidated above all by the work of the social scientists Sabel and Piore and the historians Zeitlin and Tolliday. In a series of highly influential discussions in the 1980s they founded a distinction between mass production and so-called flexible specialization on the difference in tool types in use in America and in the traditional industrial communities of Europe such as the English Midlands, or Northern Italy.

More recently, Stephen Broadberry, in his highly influential account of the *Productivity Race* has grafted the Sabel-Zeitlin-Piore model onto the neoclassical account of European and American industrialization. For Broadberry, the divergence in industrial technology is originally explained by differences in factor proportions. Abundant natural resources in nineteenth-century America combined with scarce labour to make optimal those production technologies which were capital intensive. By contrast, European producers remained wedded to technologies, which were heavily reliant on skilled labour, used less capital and economized on resource inputs. Once these different technologies were adopted they were reinforced by the pattern of consumer demand and by strategies of local-learning and adaptation. The result was two different technological paradigms, which Broadberry describes in language borrowed directly from Sabel, Zeitlin et al: "With mass production (in the US), standardised products are produced with special purpose machinery, requiring a relatively unskilled shopfloor labour force, whilst with flexible production, customised products are produced with general purpose machinery, requiring a highly skilled shopfloor labour force." (Broadberry, 1997, p. 1).

There have of course been many case studies of American and European industry and some industrial comparisons, in the case of metal-working, above all concentrated on motor vehicles. For the 1960s and 70s there are a number of comparisons which do attempt to quantify differences in metal-working technology between the US and Europe. However, for the first half of the century there is no equivalent. To our knowledge the only attempt in this direction was undertaken by the USSBS in the immediate aftermath of World War II. Using captured German material and data supplied by the US War Production Board, the USSBS compiled the following remarkable table.

Table 1. USSBS comparison of machine tool stocks

	US STOCK	GERMAN STOCK	US ANNUAL ADDITIONS	GERMAN ANNUAL ADDITIONS
Jan-1940	942,000	1,177,600		
Jan-1941	1,053,500	1,305,800	111,500	128,200
Jan-1942	1,246,500	1,437,800	193,000	132,000
Jan-1943	1,529,386	1,554,900	282,886	117,100
Jan-1944	1,770,935	1,656,800	241,549	101,900
Jan-1945	1,882,841	1,737,100	111,906	80,300

Source: USSBS Report 55, p. 3.

According to the USSBS there was little doubt that Germany had started the war with more installed machine tools than the United States. From 1941 onwards machine tools were treated as a top priority of the Allied war effort and by 1945 the number of tools in the US finally exceeded that in Germany, though never by a substantial margin. By itself this finding posed some serious questions for the conventional assumption that American industry was more capital intensive. Given the relative size of the two economies one could be excused in expecting the US machine tool stock to vastly exceed that of Germany. How could the larger and more capital intensive US metal-working sector have broadly the same number of machine tools than its supposedly smaller and labour intensive German counterpart during World War II? From this point of view the USSBS table is indeed puzzling. However, according to the USSBS the figures for the quantities of units installed were misleading. The essential difference was to be found in the age and type of machines installed. For the USSBS, the astonishing abundance of machine tools in German industry was accounted for by the tendency of German managers to regard machine tools 'as an investment, another form of "money in the bank", and since in Germany a universal machine ten years old, if it was in good repair, was about as useful as the universal machine fresh off the production line, there was a much slower turnover of the inventories of machine tools.'[2] Accumulating vast stocks of machine tools made sense because the machines were not rendered obsolete by rapid technical change. By contrast, US manufacturers, according to the USSBS, aimed to replace their specialized tools just as soon as they had paid for

2 USSBS *Report 55*, p. 2.

themselves. Old machines were rapidly scrapped to make way for the latest generation of technology. Thus, when war came, Germany had an abundant stock of general-purpose machines easily adaptable to war production. The US, by contrast, was forced into a major investment program both to retool and to increase total capacity. The implication being that the US stock during the war was more modern, more mass-production oriented, and, therefore, more productive.

The USSBS account of American and German industry has been highly influential. It was taken up, for instance, by Alan Milward in his well known comparative study of the economics of World War II. On the authority of the USSBS he claimed that, by contrast with other combatants, there was very little innovation in German manufacturing technology during the war because German industry was so well supplied with general purpose machine tools that could be easily adapted for wartime production.[3] The general strategy adopted by the USSBS in explaining its rather counter-intuitive findings, is echoed in the way in which growth accountants seek to reconcile discordant estimates of capital stock for Europe and America. European figures are inflated by the assumption of longer asset lives and the heavier weight given to non productive capital such as buildings. Once adjusted to concentrate on the truly productive element and standardized to a common age, the conventional story of US advantage in terms of capital intensity and industrial technology can be sustained.

On closer inspection, however, the claims made by the Survey do not appear to be particularly solidly founded. The Survey did have access to a large amount of quite detailed information on the German machine tool stock. However, they did not carry out a systematic analysis of its composition. More importantly, the comparison with the US, which underpinned their entire analysis, was never supported with any data beyond the table already cited. The relative youth of American tools was simply assumed. The claim that American industry did indeed employ predominantly special purpose machinery was axiomatic.

Recently, the familiar characterization both of American and German metalworking technology has been challenged on both sides of the Atlantic. On the one hand, Philip Scranton has undertaken a compelling re-examination of common place assumptions about American industry.[4] Using a combination of case studies and aggregative analysis he has demonstrated that the stereotypical mass production model applied to only a minority of American industry even in the 1920s. For the metal-working sectors, his figures for 1923 imply that only 12.2 percent of value added was contributed by out-and-out mass production industries, 47.1 percent was accounted for by "specialty" producers and 33.7 percent by industries involved in a mixture of flexible "specialty production"

[3] Milward, *War, Economy and Society,* pp. 189-190.
[4] P. Scranton, *Endless Novelty*.

and "bulk production".[5] Even allowing for the dramatic development of US manufacturing in the 1920s, Scranton's figures imply that there must in fact have been a large market for flexible, "European-style" machine tools, even in the US. On the other hand, for the Weimar Republic and Nazi Germany we have the detailed studies of the development of German machine tool technology by Thomas von Freyberg and Tilla Siegel.[6] They too highlight the inadequacy of the familiar dichotomy between European and American manufacturing technology. Far from being locked into a static tradition of general-purpose machinery, Freyberg and Siegel show how German metalworkers struggled to adapt American technology to European circumstances. In some cases, German firms simply took on American technology, abandoning classic general-purpose machines, such as "engine" lathes, in favour of single-product special purpose tools. More common, however, was a strategy of compromise involving an array of machines that combined "American" design elements with the flexibility necessary to respond to shifting market conditions.[7]

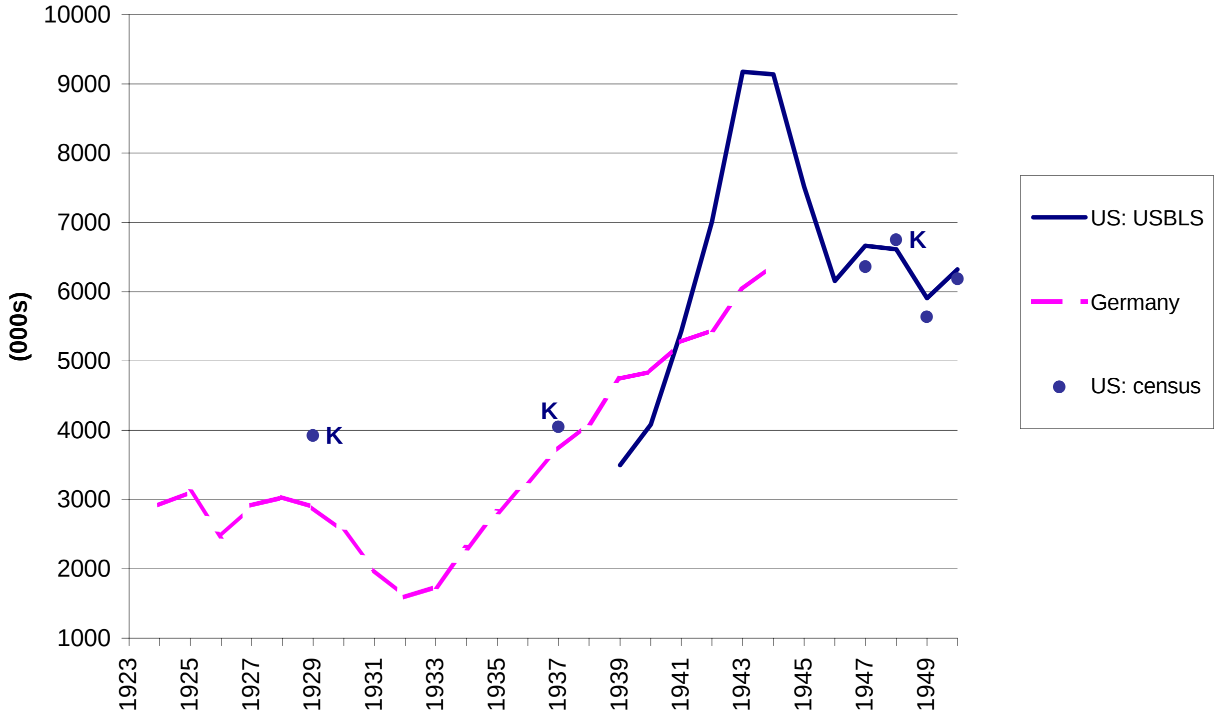
The aim of this article is to reinforce the revisionist thrust in the recent literature by revisiting the terrain covered by the USSBS. Using matching datasets we attempt the first quantified comparison of the size and composition of the machine tool stocks actually installed in Germany and the US between the 1920s and the end of World War II.

Machines and Labour: the aggregate figures

The enormous number of machine tools installed in Germany in 1940, as revealed by the USSBS table, is less surprising if we realize the full extent of the expansion in German metal-working in the 1930s. In 1929, after half a century of rapid development in both countries, employment in German metal-working was approximately three quarters that in the United States. The recession devastated the metal-working industries in both countries. In the 1930s US recovery was halting at best. In Nazi Germany, by contrast, the metal-working sector was one of the chief beneficiaries of rearmament. The result was that by the end of the 1930s German metal-working overtook its American counterpart in terms of total employment. During the war, German metalworking continued to expand. However, in the US, the war brought a complete transformation. The labour that had lain idle since the early 1930s was put back to work at a staggering rate. The American armaments boom was underpinned by capital accumulation. But it was driven above all by a massive mobilization of labour.

[5] Ibid, pp. 341-343.
[6] von Freyberg, *Industrielle Rationalisierung* and T. Siegel und T. von Freyberg, *Industrielle Rationalisierung.*
[7] See also the restatement of the Sabel and Zeitlin position in C.F. Sabel and J. Zeitlin, eds., *World of Possibilities.*

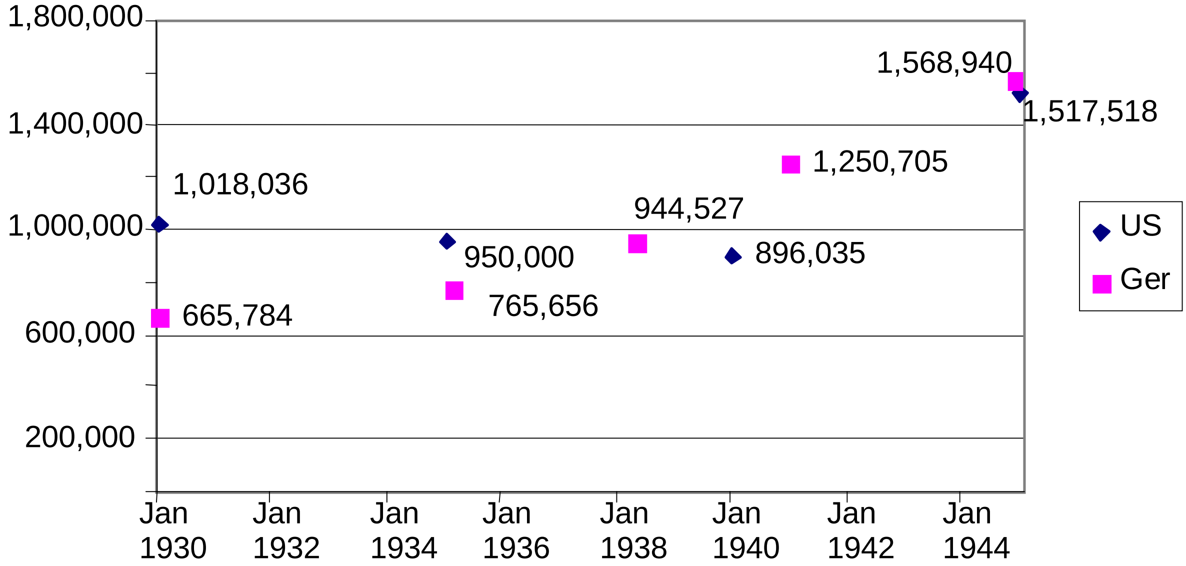
Figure 1: Employment in primary metal and metal-working in Germany and the US (1920-1950)



Sources: Germany – 1924-1939 Hoffmann, *Das Wachstum*, Tabelle 15, pp. 196-198 chained to Wagenfuehr, *Die deutsche Industrie*, Tabelle 3a., p. 140-142; **US - (1)** US, Department of Labor, Bureau of Labor Statistics (1951), Table A3, p. 10; **(2)** Bureau of the Census, Historical Statistics, Part 2, (1975), Table P58-67, pp. 677-681. The K points were computed using the recalculations made by Kendrick on the original censual data (Kendrick 1961, Table D-IV pp. 473-475, and Table D-VII p. 488).

The precise make-up of the machine tool stock in the US and Germany will be discussed below, however, it is useful at this stage to summarize the aggregate movements in the stocks in the period before World War II. As can be seen in Figure 2, if one applies a rigorously consistent definition of the machine tool population across the entire period from 1930 to 1945 to both the American and German data sets, one arrives at conclusions that are broadly similar to those of the USSBS. At the beginning of the war there were definitely more machine tools in Germany. By the end of the war the gap had been closed. Contrary to the USSBS we find that the German population was slightly higher than that of the United States even at the end of the war. This is explained by our slightly different definitions for the machine tool population.

Figure 2: Machine tool Stocks in Germany and the US 1930-1945



Sources: Germany – Bundesarchiv Lichterfelde (BAL) R 31.02 6203, R 31.02 6258 and R31.01 Anh./ alt R7 Anh. MCC 96 fol. 1 and; **US** *American Machinist* (1930 and 1931, 1935, and 1940).
Note: The totals in this figure diverge from those in later tables due to the restricted range of tools for which data is available for the full time period betweeen 1930-1945.

In viewing Figure 2 it should be born in mind the figures for the German stock in 1930 are an absolute minimum estimate.[8] And the figure for the German stock at the beginning of 1945 is an upper bound figure, which does not take account of depreciation or war damage after 1938.[9] The pattern of convergence implied by Figure 2 is therefore exaggerated. However, the margin of error is not such as to call into question our central conclusion. Contrary to the conventional image of US production as far more machine-intensive, the number of machines in the two countries was in fact roughly proportional to the numbers employed, for the entire period from 1930 to 1945. If there was a trend, it would seem that the machine to labour ratio in the US actually fell below that of German metalworking during World War II, as employment surged even more dramatically than the machine tool stock.

[8] The figure for 1930 is the number of tools purchased before 1930 that were still present in 1935. Assuming a modest rate of scrapping, comparable to that in the US, we can infer an actual stock in 1930 of between 730,000 and 770,000. This would imply a ratio of machines to labour in Germany in 1930 almost exactly equal to that in the US and only ten percent less in terms of value.

[9] The USSBS estimated that at most 1.5 percent of German machine tools had been destroyed by bombing by the end of the war, USSBS, *The Effects*, pp. 44-45. Assuming that machines ten years or older were scrapped at the same rate in Germany as in the US, would reduce our estimate at the beginning of 1945 by 14 percent. The combined effect of war losses and depreciation is unlikely therefore to have exceeded 16 percent of the total stock, a margin of error which has no effect on the conclusions to be drawn from Table 3.

Table 2: Estimated Machine to Labour Ratios (1930-1945)[10]

	Ratios for comparable sets of machine tools employed in the metal-working industry	Ratio of the value of installed machine tools using German 1942 prices
Germany1930/US1930	0.89	0.78
Germany1938/US1940	1.02	0.93
Germany1941/US1940	0.99	0.92
Germany1945/US1945	1.48	1.28

Sources (our calculations on data from): Germany – see Figures 1 & 2; **US –** *American Machinist* (1930 and 1931, 1940, and 1945) and United States, Department of Labor, Bureau of Labor Statistics, *Handbook* 1951, p. 10, Table A-3.

Of course, a simple comparison of the total machine tool stock may be misleading because it gives no impression of the relative value of the capital equipment. Between the major categories in our classification the average value of machines varied in some cases by a factor of more than twenty. Stocks of similar size but different composition might therefore embody very different levels of investment. For Germany we have a fairly complete listing of unit values for metal-cutting machinery in 1942 (welding equipment is the major omission from this list).[11] The right-hand column in Table 2 shows the result of applying this set of prices to both the German and American machine tool stocks for 1930-1945. Clearly, applying a fixed set of price weights does not fundamentally alter the story. Using values, rather than quantities, reinforces the impression of convergence between 1930 and 1938-1940. From this we may infer the likelihood that the machine tool stocks were becoming more similar over time, not just in terms of size, but in terms of composition as well.

Ideally, one would wish to repeat this comparison using US prices. However, no comparable dataset is available for the US. Does using German prices introduce a particular bias into our comparison? On balance it would

[10] The ratio is calculated as the number of machine tools per employee in Germany divided by the number of machine tools per employee in the US. Given the lack of suitable employment data for 1930 we have used 1929 employment data to normalise the 1930 machine tool figures (for both Germany and the US). This choice is not likely to affect our figures noticeably, and does not bias our ratio. The employment figure used to adjust the US machine tool figures for 1 January 1940 is an average of the employment figures for 1939 and 1940. This is to do with the fact that there was a substantial increase in the employment figures between the two years. For the 1 January 1945 machine tool figure (both German and US) we used employment in 1944.

[11] BAL R 31.02 6258.

seem that using German prices is unproblematic since it biases against our hypothesis of convergence. If it is indeed true that modern “american style” machine tools were scarcer in Germany than in the US, as the USSBS claimed, one would expect them to command a higher price premium in Germany than in the US. If there were significant differences in the compositions of the stocks, applying German price weights would therefore tend to exaggerate the difference. Using American price weights would tend to underestimate the degree of difference and to introduce a bias in favour of our hypothesis of convergence. Against this train of logic, it might be suspected that the Nazi economic authorities manipulated relative prices to encourage German firms to acquire modern, “american style” machine tools. However, there is no evidence to suggest that any such policy was attempted.

The aggregate findings summarized in Table 2 cast serious doubt on the USSBS’s assertions about differential scrapping rates in US and German industry. Unfortunately, we have no direct evidence for rates of scrapping in Germany. However, to generate a sudden surge in the stock as is visible in Figure 2 would have required two conditions to have been met. The rate of turnover of capital stock before 1930, due to scrapping and new investment, would have had to have been very high. And this pattern of scrapping would then have had to have come to an abrupt halt. There is certainly no evidence to suggest such a bizarre scenario. What explained the sudden surge in the German machine tool stock was not a sudden urge to hoard machines, but a surge in new investment. For the US we can infer the rate of scrapping by comparing the number of machines older than 10 years in 1935 with the number counted in 1925, and so on. Such comparisons hardly support the USSBS claim that US industry was in the habit of writing off its machinery at a very high rate. Of the machines counted in 1925, 1930 and 1935, 75 per cent were still in use ten years later. Though we cannot compare scrapping rates directly, we can compare the age structure of the machine tool populations that resulted from the combined impact of new investment and scrapping. The results in Table 3 cast further doubt on the USSBS interpretation of German and American metal-working.

By any standard, the German machine tool stock was significantly younger at the outbreak of war, which refutes the idea that the size of the stock was inflated by the retention of overage machines. The US machine tool stock was rejuvenated after 1940 and, on the unadjusted figures supplied by the USSBS the average age of machine tools in America in 1945 was lower than in Germany. However, the USSBS made its estimate of the German machine tool stock in 1945 by assuming what it was seeking to prove, namely that there had been no scrapping. If, instead, we standardized the estimates by assuming that the German stock of 1935 was scrapped at the US rate between 1935 and 1945, then the US and German stocks at the end of the war were in fact remarkably similar not only in size, but also in average age.

Table 3: Relative age of US and German Machine Tools 1930-1945

	PERCENTAGE OF MACHINES OLDER THAN:	
	EIGHT YEARS	TEN YEARS
Germany 1930[12]		47%
USA 1930		46%
Germany 1938	66%	
USA 1940		71%
Germany 1945 (raw)		52%
Germany 1945 (standard.)		43%
USA 1945		42%

In conclusion, the USSBS comparison of metal-working for the war period was seriously flawed by its lack of historical context. If one looks at the pattern of movements over the 1930s, the claims made by the USSBS about the rates of accumulation and depreciation in US and German metal-working are implausible. German metal-working was not hoarding an outdated stock of machines. Germany's metal-working capacity in the early stages of the war was the result of new investment carried out after 1935. Even after the outbreak of the war, the degree of US catch-up is exaggerated by the USSBS table. Germany's relative machine-to-labour ratio continued to increase and considering the entire period from 1935 to 1945 the degree of rejuvenation was practically identical. This result is confirmed by the data on the average age of installed machinery in the German and US metal-working industry by machine tool class presented in Appendix 1. The calculations in the appendix are particularly significant as they show that German machinery was no less modern than US machinery even at the level of single types of machinery. This implies that, at least for the metal-working industry, what Abramovitz and David (2000, pp. 28 – 29) describe as the "vintage effect" on the embodiment of technological progress in tangible equipment was not affecting German productivity more adversely than US productivity. It follows that the rate at which technological progress was 'actually incorporated into production', was not necessarily slower in Germany than in the US. Differences in TFP growth in the metal-working sector due to technological change might have arisen only if the rate of growth of practical knowledge was substantially different, or if 'the fraction of new knowledge that require[d] embodiment' (*ibid.*) was dissimilar in the two countries. Both propositions seem, to us, hard to substantiate.

[12] This is a slight underestimate based on the machine tools installed in 1935 that were more than 15 years old as a percentage of the machine tools installed in 1935 that were more than 5 years old.

Classifying machines

To get to grips with the claim that American and German metal-working machinery was fundamentally different in type we need to go deeper into the sources. For Germany we rely on the unpublished results of the so-called *Maschinenbestanderhebungen* for 1935 and 1938, to be found in the German Federal Archive in Lichterfelde, Berlin.[13] The *Maschinenbestandserhebungen* for 1935 and 1938 are truly astonishing statistical artefacts. In 1938 they counted the distribution of 174 different types of tool across 27 sectors of German metal-working and by geographical location. The results appear to cover all plants with more than 5 employees. The machines are distinguished by age and by size. Imported machines are counted separately. The 1938 census also compiled information on whether or not the machines were equipped with direct drive. The result is an astonishing database of which a brief article can give only a rough impression. Unfortunately, the archive offers virtually nothing by way of background information on the design and conduct of the *Maschinenbestandserhebungen*. However, the industrial statisticians who carried out the surveys have been examined by Tooze in *Statistics and the German State, 1900-1945*. After 1933, the Reich's industrial statisticians developed a highly detailed approach to physical planning. The censuses of production for 1933 and 1936 were reworked to form the basis for raw material planning. The literal mapping of German metal-working capacity carried out in the *Maschinenbestandserhebung* is characteristic of this group of statisticians. In practice their success in devising workable tools of planning was limited. So, for the 1930s, there is no reason to worry that their results might have been biased by the effort of firms to manipulate the planning process. The authorship of the *Maschinenbestanderhebung* gives us a strong hint as to their coverage. The Reich's industrial statisticians focussed firmly on the core of German industry. The production censuses of 1933 and 1936 were designed specifically to exclude craft workshops with less than 5 employees and insignificant turnover. The same rules seem to have been applied to the *Maschinenbestanderhebung*. To extend our data series beyond 1938 we can draw on a fully itemized estimate, found in the German federal archive, which was compiled by the Engineering Business Group in 1941 on the basis of detailed sales data.[14] Pencilled into that report are the sales data for 1942. For the last full years of the war we are forced to rely on the less detailed information published in Wagenfuehr's study of German industry at war.

The American data is from five surveys conducted quinquennially from 1925 to 1945 by the engineering magazine *American Machinist*. The *American Machinist Inventories of Metal-Working Equipment* were extensive sample

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[13] Bundesarchiv Lichterfelde (BAL) R 31.02 6203.

[14] BAL R 31.02 6258.

surveys intended to ascertain the type, age, and industrial and geographical distribution, of installed machinery in the US metal-working sector. They typically subdivided metal-working machinery into more than 100 classes of machine tools proper (120 in 1930).[15] Distribution of each class was provided by 20 industries and from 1935 by twelve Federal Reserve Districts (in 1940 and 1945 by nine geographic sections) covering the territory of the United States. The *inventories* also provided the number of machine tools of each class in each industry that were more than ten years old. The inventories refer to the machinery installed on the first of January. Companies were also asked to provide the number of employees on the 15 of December of the year before that of the survey (i.e. 12/15/1934 for the 1935 survey).

The information provided by the *American Machinist* on the ways in which the survey was conducted is far from detailed. In presenting the 1935 inventory for example the journal stated:

> The results here presented are based on the returns from 10,000 questionnaires sent out by this paper. In preparing the mailing list, Mc-Graw-Hill records were supplemented by over 100 code authority lists and trade associations memberships in this field. Every effort was made to compile a list of names truly representative of the metal-working industry. …
>
> The returns were first divided into the twenty industrial groups indicated, and the total of wage earners of reporting firms was obtained for each group. This wage-earner total formed the basis of an extension factor for each industrial classification which, when applied to the machine units as reported, gave an approximate total of machines of each type in each group.
>
> The factors were derived by comparing the wage earners for reporting firms with those given in the latest Census of Manufactures (1933). It will be evident that there was a year's difference in the Census wage-earners figures, which were taken for December 15, 1933, and those reported on the questionnaires. To overcome this discrepancy the Census figures were modified by the ratio between the Department of Labor's index for December 1934 and that for December 1933.[16]

[15] From 1930 the inventories also provided an increasing coverage on auxiliary metal-working plant equipment (heat treating, material handling, foundry equipment, finishing machinery, electroplating, cleaning and polishing equipment etc.). By the 1935 survey, these were classified into ca. 40 additional classes of machinery including such diverse equipment as trucks and tractors, cranes, hoists, fans and blowers (not built into ovens), air compressors, oil extracting machines (from metal chips), parts washing machines, drying machines, pickling machines, tumbling barrels, sand blast equipment, spraying systems, portable welding outfits, portable tools (drills, grinders, power hammers, etc.), finishing equipment (backing and drying ovens), plating equipment, heat-treating and hardening furnaces, polishing and buffing machines. These machines were excluded from our comparison of machine tools.

[16] *American Machinist*, V. 79, April 24, 1935, p. 328.

The same article seems to suggest that the returns covered between 15 and 50 per cent of the wage earners in each industry, a large sample by any standard. Unfortunately, there is no way to ascertain the presence and the likely direction of a no-return bias in the sample used. The compilers clearly assumed that the capital-intensity of the sample was representative. It might be argued that larger, more capital-intensive firms were more likely to make returns than smaller more labour-intensive firms did. However, this would bias our estimates against our hypothesis in the sense of portraying the US metal-working industry as more capital intensive, more mass-production oriented, and ultimately more different from its German counterpart than it actually was. On the other hand, this bias might have been counterbalanced by the fact that little firms had smaller and more manageable capital inventories and thus they were no less able to provide returns on their installed machinery than the larger firms. We are inclined to conclude that either the sample used was indeed representative, or that it was affected by a no-return bias that over-represented modern capital-intensive production methods in the US metal-working industry. In the second case this would not affect our comparative results, since such a hypothetical bias would work against our conclusions.

In taking the *Inventories* at face value we join a host of illustrious predecessors as the US Strategic Bombing Survey, and the US War Production Board that relied extensively on the *American Machinist Inventories'* data.[17] So did Wagoner (1968) in the only serious monograph on the history of the US machine tool industry in the first half of the 20th. The fact that the returns forming the sample covered such a large part of the total employment in each industry offers, *per se*, some comfort on the quality of the estimates provided. Finally, there is no other quantitative source on the subject let alone anything that can boast the same degree of detail and disaggregation.

Our comparison includes all the equipment that can be defined as machine tools or 'power driven machines, not portable, that remove metal in the form of chips'. The only exceptions to this rule are the exclusion of drills that could not be directly compared due to differences of classification,[18] and the residual machine tools classified as 'other machine tools'. To the machine tools proper we have added, wherever possible, a number of significant non-portable power-driven machinery such as welding machines, forging machines, swaging machines, presses, bending machines, shears, and riveting machines.

Perhaps the first really striking thing when comparing the two surveys is the broad agreement in the nature of categorization. A majority of the very large number of sub-classes can be matched directly. Only a relatively small amount

[17] See Stoughton, *History*, p. 7.

[18] The German compilers counted multiple "gang" drills by the number of spindles and not by the number of machines as they and the US compilers did for the rest of the drills. Nor the data for gang drill could be easily expunged from the comparison, as it was impossible to isolate this type of drills from the other multiple spindle drills in the US data.

of rearranging and exclusion is necessary to make the two surveys directly comparable. This similarity of classification hints at one of our most important conclusions. The statisticians in the United States and Germany were dealing with fundamentally similar sets of technology. The language used to describe the machinery of one country required only minimal translation to capture the reality of the other. This is not surprising, perhaps, given the highly internationalized nature of the engineering profession. However, it contradicts the assumption that fundamentally different types of technology, locked in by strategies of local learning, predominated on either side of the Atlantic.

What is, furthermore, striking is that neither the US nor the German statisticians employed the dichotomous distinction that forms the backbone of the literature. The distinction between general-purpose and special-purpose tools is not the main organizing principle of either survey. The main line of division, in both cases, is tool type: shapers are distinguished from planes, from lathes, from grinders, etc.[19] It is only within categories such as lathes that we find sub-categories that can be mapped onto the distinction between general-purpose and special-purpose machinery. Both surveys, for instance, distinguish between general purpose "engine lathes", turret lathes and automatics of various kinds. Of course, custom designed machines, by their very nature, defy standard categorization. Such machines are idiosyncratic, being designed to satisfy the needs of particular products and firms. In some cases a number of tools were merged into entire production units and in some cases built directly into factory buildings. However, in both countries the vast majority of tools could clearly be included in the general classification. In total, the *Maschinenbestandserhebung* of 1938 lumped roughly 10 percent of German machinery into a general category of 'specialized machinery not otherwise classified'. In the *1945 American Machinist Inventory*, allocated only 2.6 per cent of all the machine tools to a category of 'other machine tools'. This hardly suggests that the German compilers were more inclusive in the way they accounted for categorised machine tools. The most likely inference is surely that the vast majority of tools, whether general purpose or specialized, could be classified as one or other of the standard tool types and were thus covered by the surveys.

What is even more surprising is the absence of the category of special-purpose tools, which supposedly occupied such a large place in US manufacturing, in any of the surveys conducted by the *American Machinist*. "Special purpose machines" also went completely unmentioned in the war history of the War Production Board, Tools Division.[20] This was the wartime organization that was charged with managing the tool supply to US industry. Tools were a key bottleneck and at the very centre of US wartime planning.

[19] For a general introduction to machine tool types see Habicht, *Modern Machine Tools* and Rolt, *Tools* and Fermer, *Machine tools.*

[20] Stoughton, *History*.

And yet nowhere in the pages of this account is the category of special purpose tools even mentioned. As far as the War Production Board was concerned, “machine tools” referred to the same standard types, which are categorized and counted in the *American Machinist* surveys and in the *Maschinenbestanderhebungen*. Indeed, the War Production Board cited the *American Machinist Inventories* for 1940 and 1945 to illustrate its remarkable success in retooling American industry. In the *1945 American Machinist Inventory*, allocated only 2.6 per cent of all the machine tools to a category of ‘other machine tools’. The most likely inference is surely that the vast majority of tools, whether general purpose or specialized, could be classified as one or other of the standard tool types and were thus covered by the surveys.

Further confirmation for this interpretation is to be found in the volume of the British official history of the war economy, which deals with *Factory and Plant*. The author, Hornby, explains that the distinction between special purpose and general purpose machine tools needed to be refined to capture the realities of wartime manufacture. In his view one needed to distinguish between special purpose and 'standard' tool types. The vast majority of production tools was of standard types and could be divided into lathes, drills, boring rigs, milling machines, grinders, planers and shapers. All of these machines were produced in different sizes and configurations with widely differing ranges of performance. At one end of the scale was the basic and adaptable engine lathe, the true general purpose tool. By the interwar period, engine lathes were replaced for batch production by turret lathes. In these lathes a number of tools were fixed on a so-called turret, or ‘revolver’, which once set by a skilled worker, could be indexed into position by a semi-skilled hand.[21] For really high volumes, particularly of small parts, automatic lathes were used. For Hornby, automatics were properly classified not as special-purpose tools but as standard tools designed for ‘high volume production’. Turret lathes and automatics were not ‘special purpose’ tools because they retained an important degree of flexibility. They could be set up to turn a variety of work of a certain dimension. However, to operate efficiently, they required a certain minimum volume of work and they could not be adapted to do the full range of tasks, which could be squeezed out of an engine lathe. Automatics were considerably more expensive than standard engine lathes, and in no sense could they be described as ‘general-purpose’ machinery.

True ‘special purpose’ machines were developed out of standard machine designs to accommodate particularly difficult work such as thread milling or in the case of so-called ‘special product machines’ for the efficient mass production of particularly difficult components such as gears, camshafts or

[21] Fermer (1995, p. 54) maintained that ‘[n]o machine tool made a greater contribution to the [British] war effort between 1939 and 1945 than the faithful Herbert and Ward turret lathes which turned out production components by the million.’

crankshafts[22]. Special purpose tools of this type were installed in significant numbers in both Germany and the US and were given special attention by the statisticians by defining them in terms of both machine-type and of product machined (for example crankshaft lathes and gear milling machines). At their most extreme, such machines were designed, like the Ford drilling equipment, for the production of components to one particular design. For such machines Hornby suggests the term "special product machine". The one role in which such machines did figure prominently in war time was in the production of shell cases and gun barrels, which was done on special product lathes and boring and rifling machines. However, the vast majority of war production was not performed on such ultra-specialized machinery. The most demanding work, such as the mass production of aircraft engines, was done on special purpose tools for the manufacture of camshafts, crankshafts etc, high volume tools of standard design such as jig drills and automatic lathes and a large number of turret lathes, which could be adapted to carry out a variety of tasks with far greater efficiency than standard engine lathes.[23]

The distinction between special and general purpose machine tools might have been introduced as an explanatory concept after these documents were compiled. And yet the total absence from these statistical compilations of any similar organising criteria is either testimony to the limited heuristic power of the dichotomy, or of its limited relevance for this particular period.

In the US, Germany and it would seem in Britain as well, efficient production in metal-working depended not on one particular type of tool, but on a complex combination of various types of machine. There is therefore one central question to be answered: in what proportions were the different tools combined? It is here that the statistics provide illumination.

The period up to 1930

The most striking finding for our base year, 1930 is certainly that the US and German machine tool stocks differed far less than one might imagine given the dichotomous stereotypes which pervade the literature. Nevertheless, in 1930, there were large and important differences in the metal-working machinery of the two countries. These are summarized in Table 4, which shows the number of installed machine tools (first two columns), and a measure of the relative machine intensity in the two countries in the third column.

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[22] Scranton 1997, p. 307.

[23] Hornby, *Factories and Plant.*

Table 4: Machine-intensity by class of tool in the German and US metal-working, 1930

TYPE OF MACHINE	US TOTAL UNITS IN PLACE	GERMANY TOTAL UNITS IN PLACE (MINIMUM ESTIMATE)	MACHINE TOOLS PER EMPLOYEE GERMANY/US *
Broaching Machines	4,396	660	0.20
Honing and lapping machines	4,345	661	0.21
Riveting machines (not portable)	22,080	4,316	0.27
Welding and cutting machines	45,201	14,344	0.43
Production Grinders	94,224	33,100	0.48
Keyseaters	4,379	1,764	0.55
Boring machines	28,033	12,940	0.63
Gear-cutting machines	20,006	10,407	0.71
Forging machines	32,598	18,602	0.78
Milling machines	116,978	71,474	0.83
Pipe cutting and threading machines + Thread machines	42,142	27,531	0.89
Lathes	308,170	225,749	1.00
Presses (not forging presses)	174,379	130,303	1.02
Cutting-off machines	39,719	29,931	1.02
Shapers	36,316	28,108	1.05
Planers	19,401	16,385	1.15
Bending machines	23,324	30,944	1.80
Shears	32,106	44,792	1.90
Grand total of classified tools	1,047,797	702,011	0.91
Variance			0.23

* Column 3 is calculated as the number of tools per employee in the German metal-working sector divided by the number of tools per employee in the US metal-working sector. As such it is a normalised measure of machine intensity where the US constitutes the norm.

For three large classes - lathes, milling machines and presses – the numbers are roughly in proportion to the number of workers employed in metal-working. However, in two areas, which were at the cutting-edge of technical development in the 1920s - grinders,[24] and welding and cutting equipment – the numbers installed in Germany in 1930 were half the figure one would expect given the relative size of the workforces. We need to bear in mind that the German figures for 1930 are minimum numbers and that the number of machines actually installed in all categories was almost certainly higher.

[24] Woodbury, *History of the grinding machine*.

However, the deficits in grinders and welding equipment are too large to be significantly affected by this bias. The deficit in welding and cutting equipment would seem to be offset by a significant preponderance of other cutting tools, particularly shears in Germany. Though the numbers are small it is also significant that broaching machines and honing and lapping machines, all of which were widely employed in the mass production of internal combustion engines, are significantly underrepresented in German metal-working. Similarly, the relatively low number of gear-cutters, an automatic machine by definition[25], indicates a lower commitment to high throughput on the part of the German metal-working industry.

This pattern of difference is made even clearer when we analyse the large categories of lathes and production grinders in greater detail (see Table 5). Amongst the categories least well represented in German metal-working were centerless grinders, which were in many ways the emblematic tool of mass production of internal combustion engines.[26]

Within the category of lathes, which were the most numerous machines in metal-working in both countries, there is also a highly significant pattern. The similarity in the machine-to-labour ratio for lathes as a whole hides a sharp difference between three large groups. Turret lathes, the standard batch production tool of the interwar period, were equally represented in the US and Germany. High volume production lathes, which were categorized in 1930 as semi-automatics and automatics, were significantly underrepresented in Germany by comparison with the US. By contrast, the residual category ("all other lathes"), which was dominated above all by 'general purpose' types such as 'engine lathes', was over-represented in Germany by comparison with the US.

[25] Woodbury, *History of the gear-cutting machine*.

[26] Woodbury (1959, p. 11) noted the importance of grinding in the history of automatic machine tools and in particular that of the development in the 1920s of the centerless grinder 'in which the work is supported not on centers, but between two opposed grinding wheels'. The development started in 1921 at the Cincinnati Grinding Machine Company, and soon became the '… basic method of producing many relatively small, very high precision parts, both hardened and otherwise, at very high production rates and at low unit cost' (*ibid.*, p. 11). This was particularly important in mass producing sectors such as the motor industry which increasingly relied on precision worked hardened steels to guarantee the interchangeability of parts (*ibid*., p. 67). Moreover, centerless grinding '… was further extended by the Landis Machine Company into what had been a field of the automatic screw machine, to produce centerless screw-thread grinders, as well as many specialised grinding machines for the automotive industry'. (*ibid.*, p. 11). See also: Scranton 1997, pp. 306-7, and Hounshell 1984, p. 49 and p. 81.

Table 5: Lathes and production grinders in the German and the US metal-working industry in 1930

Type of Machine	US Total units in place	Germany Total units in place (minimum estimate)	Ratio of installed machine tools in Germany to US %	Machine tools per employee Germany/US*
Production Grinders	**94,224**	**33,100**	**35.1**	**0.478**
External cylindrical, plain and universal grinding machines	33,281	16,217	48.7	0.662
Internal cylindrical grinding machines	9,752	3,669	37.6	0.511
Centerless Grinding machines	4,273	1,320	30.9	0.420
Surface, horizontal and vertical + Grinding machines - Disk horizontal and vertical	46,918	11,894	25.4	0.345
Lathes.	**308,170**	**225,749**	**73.3**	**0.996**
Turret lathes	41,894	30,255	72.2	0.982
Semi automatic & automatic lathes	68,158	26,716	39.2	0.533
All other lathes	198,118	168,778	85.2	1.158

* See note to Table 4.

Most of these differences are not as stark as one might perhaps expect. There are no categories which are completely absent in either country. It is particularly worth reminding ourselves quite how much of the installed capacity of metal-working machinery in the US was of a flexible 'general purpose type'. General purpose lathes were the largest group of classified tools in 1930, both in the US and in Germany. Machine tools that could be characterized as typical mass production tool types accounted for no more than a third of the installed capacity in US metalworking in 1930, by value. However, there are undeniable differences in the machine tool equipment of the two countries. In the US, the value of automatic and turret lathes installed almost matched that of general purpose lathes. In Germany, by contrast, the value of automatics and turrets was no more than a third that of engine-lathes. And the US enjoyed a clear advantage in every other type of equipment that was associated with large batch and bulk production.

Depression and recovery: 1930-1939

Over the following decade, the differences that were clearly visible in 1930 were significantly reduced. This striking pattern of convergence was the result of the two processes visible in Figure 2. The American machine tool stock was reduced by a combination of scrapping, losses due to bankruptcy and a very low level of investment. As is clear from the following tables, in certain key categories the reduction was very dramatic. Most of this reduction came between 1930 and 1935, though problems of comparability make the US estimate for 1935 a lower bound. The German machine tool stock may not have fallen as sharply between 1930 and 1935. But, far more important is the fact that it recovered very strongly thereafter. As is clear from Figure 2, we face a dilemma in choosing our point of comparison for the US survey of 1 January 1940. To highlight the scale of the German investment drive, we would compare the US data for January 1940 with German data for January 1941. But this would bias our conclusions in favour of our hypothesis of convergence. Instead, we have chosen to compare the US data for January 1940 with the earlier German data-point for May 1938. As a result in certain categories the convergence appears to be driven more strongly by the decline in the American stock than by German investment, but this is a direct result of our highly conservative choice of dates. As is clear from Figure 2, German investment between 1938 and 1941 was intense and it was heavily concentrated in the types of machines in which Germany had lagged in 1930. A comparison with that later date would only serve to reinforce our convergence hypothesis.

To provide a summary measure of convergence we have used the variance of the normalized machine-to-labour ratios (Table 6, column 3). We interpret the halving of the variance, combined with the increase to close to one in the ratio for the grand total of classified tools, as additional evidence that the machine tool stocks in Germany and the US were becoming more similar, both in terms of absolute size and composition. The variance in this case is not weighted according to the relative size of the different machine tool categories, since we felt that this might downplay the crucial significance of machines, which were installed in relatively small numbers. However, for an indication of convergence that does take account of relative size of stocks, we may return to our earlier tables on machine numbers and machine values. The gap measured in terms of machine values per worker fell more rapidly between 1930 and 1939-1940 than did the gap measured in terms of machine numbers. This would certainly seem to imply a convergence in the quality of the stocks taking into account both the number and the relative value of the different types of machines.

Table 6: Machine-intensity in German metal-working industry in 1938 relative to the US in 1940*

TYPE OF MACHINE	US 1940 TOTAL UNITS IN PLACE	GERMANY 1938 TOTAL UNITS IN PLACE	MACHINE TOOLS PER EMPLOYEE GER1938/US1940 **
Broaching machines	4,731	1,201	0.23 *(0.20)*
Riveting machines (not portable)	21,855	8,616	0.36 *(0.27)*
Welding and cutting machines	75,900	42,140	0.51 *(0.43)*
Boring machines	27,309	20,201	0.68 *(0.63)*
Production grinders	56,823	45,831	0.74 *(0.48)*
Gear-cutting machines	20,753	16,856	0.75 *(0.71)*
Forging machines	27,537	25,521	0.86 *(0.78)*
Presses (not forging presses)	185,633	189,111	0.94 *(1.02)*
Cutting-off machines	43,097	44,068	0.94 *(1.02)*
Honing and lapping machines	2,413	2,514	0.96 *(0.21)*
Milling machines	94,113	104,235	1.02 *(0.83)*
Shears	34,373	42,184	1.13 *(1.90)*
Planers	15,248	18,825	1.14 *(1.15)*
Bending machines	35,938	45,409	1.17 *(1.80)*
Pipe cutting and threading machines + Thread machines	28,503	36,449	1.18 *(0.89)*
Lathes	235,235	303,884	1.19 *(1.00)*
Shapers	27,369	36,310	1.22 *(1.05)*
Keyseaters	3,999	6,497	1.50

			(0.55)
Grand total of classified tools	**940,829**	**989,852**	**0.97** ***(0.91)***
Variance			**0.11** ***(0.23)***

* See note to Table 4.
** In brackets corresponding figure for 1930.

The general pattern of a rise in machine to labour ratios and a convergence towards the American norm is visible for practically every machine type. Presses were now slightly underrepresented, but the number of milling machines per worker, which had previously been below that in the US, was now slightly greater. In production grinders there was clear evidence of convergence. Between 1930 and the end of the decade, the relative gap halved from 50 to 25 percentage points. There was also a significant increase in the welding equipment available to German industry, offset by a fall in the relative 'over-equipment' of German industry in shears. Lathes run against the trend of convergence, but only in the sense that they were now significantly more numerous in the German industry than in the US.

This general pattern is confirmed if we examine lathes and grinders in more detail. Where the gap was biggest in 1930, catch-up is most rapid (Table 7). Internal cylindrical grinders, surface grinders and centerless grinders all show pronounced patterns of convergence over the course of the 1930s. Germany showed the unmistakeable signs of an economy gearing up for the mass production of internal combustion engines. Similarly, there is clear evidence of German 'catch-up' in the category of automatic and semi-automatic lathes. In the categories of single-spindle automatics and semi-automatics, convergence was virtually complete. Contrary to the claims made by the USSBS, German industry clearly used the investment boom of the 1930s to equip itself not only with more machines, but also with increasing numbers of high volume production tools.

By the early 1940s, America's advantage in mass production metal-cutting machinery was restricted to a limited range of types. In multiple-spindle automatics, a truly high volume tool type, the American lead remained unassailable. These were the most expensive of the high volume production tools and this difference is therefore significant even at the aggregate level. By value, multiple-spindle automatics accounted for perhaps as much as nine percent of the US machine tool stock at the end of 1939. Their share in the German stock was no more than three percent. This was one of the few tool types for which Germany relied quite heavily on imports from Switzerland and it would seem likely that this imposed severe constraints on supplies. Broaches, another mass production tool, continued to be far more heavily used in the US than in Germany. And American industry also retained a significant edge in welding equipment and surface grinding machines.

Table 7: Lathes and production grinders installed in Germany 1938 and US 1940*

Type of Machine	US 1940 Total units in place	Germany 1938 Total units in place	Machine tools per employee Germany1938/US1940**
Production grinders	**56,823**	**45,831**	**0.74** ***(0.48)***
Gear tooth	461	1,118	2.24
External cylindrical, plain and universal	17,935	21,747	1.12 *(0.66)*
Thread	767	861	1.04
Internal cylindrical	6,166	6,056	0.91 *(0.51)*
Centerless	3,105	2,593	0.77 *(0.42)*
Surface and disk (horizontal and vertical)	29,617	15,435	0.48 *(0.35)*
Other	17,291	2,088	0.11
Lathes	**235,235**	**303,884**	**1.19** ***(1.00)***
Turret	47,908	44,058	0.93 *(0.98)*
Automatic single-spindle (incl. screw machines)	29,674	28,777	0.98
Semi-automatic	7,093	5,732	0.82
Automatic multiple-spindle (incl. screw machines)	19,099	4,776	0.25
Sub-total automatic & semi-automatic	**55,866**	**39,285**	**0.71** ***(0.53)***
Bench	21,798	43,077	1.82
Engine (incl. toolroom)	95,003	146,639	1.42
Sub-total other lathes	**131,461**	**220,541**	**1.55** ***(1.16)***

* See note to Table 4.
** In brackets corresponding figures for 1930.

Nevertheless, the combined result of German investment and American disinvestment was a striking pattern of convergence. Taken together with the evidence of relative age structure for 1938-1940, this constitutes a complete refutation of the USSBS interpretation. Examined in detail, the evidence does not suggest that German industry at the end of the 1930s was committed to a conservative strategy of hoarding old-fashioned general purpose machinery. On the contrary, German industry was engaged in an aggressive program of expansion that enabled it significantly to reduce the advantage of American industry, both in terms of the numbers and quality of machine tools installed. Differences remained. Convergence was not complete. However, the dichotomous distinction, which formed the starting point for the USSBS interpretation, was increasingly obsolete.

The Arsenals of Fascism and Democracy: 1940-1945

At the aggregate level there can be no doubt that this pattern of convergence was sustained during the war. Once we adjust for the relative level of employment, the enormous expansion in US machine tool investment did not reverse the gains that Germany had made in terms of relative machine-to-labour ratios over the preceding decade. However, once we examine the composition of the machine tool stocks, the simple story of convergence we were able to tell for the 1930s becomes more complicated. Due to the lack of full German data, the comparison for 1945 cannot be as precise as for previous periods. Beyond 1942, the German data are disaggregated only into a limited number of large classes. The comparison in Table 8 is therefore restricted to a limited number of key categories.

The resulting pattern is captured in the two summary variables. The overall ratio of machines to labour in Germany relative to the US continued to increase across the war, whether it is measured in terms of simple numbers or values, though this trend may be somewhat overstated in Table 8. However, as is shown by the dramatic increase in the variance, there are clear differences in the pattern of new investment in the two economies during the war. By the end of the war, we can distinguish four different patterns within the overall population of machine tools. In traditional categories such as shears, shapers and planers, which in the US were replaced by rotary cutting tools and welding equipment, German industry had an enormous advantage. Similarly the German stock of lathes, millers, and presses per worker considerably exceeded that of the US by the end of the war. In boring machines German industry had a more modest advantage. In gear-cutting machinery German industry continued to converge to the US norm. Finally, in categories such as production grinders American investment accelerated to such an extent that the convergence of the 1930s was reversed. Table 8 is inconclusive, and might hide more than it reveals. The patterns of investment clearly differed. Germany became on the whole more machine intensive, but it is hard to come to a firm conclusion as to the relative development of mass production techniques in the two economies. To really clarify the pattern of development during the war, we need to explore the two major categories of metal-cutting tools, production grinders and lathes, in greater detail (table 9).

Table 8: Capital intensity by class of installed machine tool in the German metal-working industry relative to the US in January 1945*

TYPE OF MACHINE	US TOTAL UNITS IN PLACE	GERMANY TOTAL UNITS IN PLACE	MACHINE TOOLS PER EMPLOYEE GER1945/ US1945**
Gear-cutting machines	55,034	28,621	0.74 *(0.70)*
Production grinders	158,706	77,645	0.74 *(0.80)*
Boring machines	50,337	38,074	1.08 *(0.72)*
Presses (not forging presses)	255,030	225,294	1.47 *(0.81)*
Milling machines	171,763	157,372	1.31 *(1.02)*
Lathes	418,501	537,018	1.83 *(1.25)*
Cutting-off machines	62,069	80,193	1.84 *(1.22)*
Pipe cutting and threading machines + Thread machines	45,219	55,324	1.75 *(1.17)*
Bending machines	18,107	24,468	1.93 *(1.00)*
Planers	16,427	23,867	2.07 *(1.04)*
Shapers	36,703	64,114	2.49 *(1.38)*
Shears	34,456	95,114	3.94 *(1.66)*
Grand total of classified tools* **	**1,517,518**	**1,568,940**	**1.48** ***(1.00)***
Variance* **			**0.92** ***(0.15)***

* See note to Table 4.
** In brackets corresponding figures for GER1941/ US1940.
*** Includes classes not shown.

For production grinders the pattern of convergence or indeed German 'over-taking' visible up to the early 1940s was reversed. America made an enormous investment in production grinders during World War II. Between 1940 and 1945 the total stock of production grinders in the American inventory increased almost threefold. By the end of World War II, the general purpose lathe, which in 1930 had still been the most common metal-cutting tool in American industry, had been displaced once and for all by grinders and more specialized lathes. For centerless grinders, internal and external cylindrical grinders we observe an inverse U-shape. The dramatic convergence or even 'over-taking' achieved by Germany in the early 1940s, was substantially reversed thereafter. In every case, however, the German position at the end of World War II was more favourable than it had been in 1930.

Lathes present a complex picture. The most striking difference is the divergence in general-purpose engine lathes. By the end of the war, there were almost three times as many engine lathes per worker in Germany as in the US. This very striking difference may well account for the one-sided assessment of German investment patterns made by the inspection teams of the USSBS. Though this is indeed a striking finding, it should not be allowed to obscure the fact that Germany continued to invest during the war in bulk and mass production lathes. In turret lathes there is no significant difference between US and German equipment, in both countries they continued to play a key role. Over the course of the war, Germany concentrated heavily on single-spindle automatic machines, in which it enjoyed a substantial 'advantage' over the US by 1945. The only group in which the US continued to enjoy a significant advantage were the highly sophisticated multi-spindle automatics. In this category, the US advantage at the end of the war was in the order of four to one. However, this had been true before the war as well. The gap did not widen even in these characteristically high volume tools.

The war thus presents us with a complex picture, which is only inadequately summarized by the USSBS. The idea that Germany remained locked into a traditional pattern of technology best characterized by the general-purpose engine lathe was wrong for the 1930s and is clearly wrong for the war as well. German industry continued to make a heavy investment in the new generation of machines suitable for bulk production. If the standard of comparison had remained the American industrial equipment of the interwar period, then convergence would have been complete in all but a small number of machine types. America, however, began an investment program in 1940 that was to set new standards. This investment drive was not extraordinary in its scale, once we consider the truly astonishing increase in the labour force employed in US metal-working. The machine-intensity in US metal-working declined relative to Germany across the war period. What the US managed to do, by comparison with Germany, was to focus its investment in machine tools in a handful of key categories, above all in production grinders, and multiple spindle lathes. American wartime investment thereby shifted the centre of gravity in its machine tool stock, away from the traditional metal-working technology that was still prevalent in the US in the 1930s, towards the new mass

Table 9: Lathes and production grinders installed in the metal-working industry (January 1945)*

TYPE OF MACHINE	U.S. TOTAL UNITS IN PLACE	GERMANY TOTAL UNITS IN PLACE	MACHINE TOOLS PER EMPLOYEE GERMANY45/US45**
Production grinders	**158,706**	**82,611**	**0.74** ***(0.80)***
Centerless cylindrical grinders	14,769	7,785	0.75 *(1.16)*
Surface, horizontal and vertical grinders	61,583	27,077	0.63 *(0.52)*
External cylindrical grinders	55,277	34,520	0.89 *(1.11)*
Internal cylindrical grinders	27,077	13,229	0.70 *(1.00)*
Lathes	**417,871**	**534,918**	**1.83** ***(1.25)***
Turret	101,912	87,056	1.22 *(0.94)*
Automatic multiple-spindle (incl. screw machines)	45,098	9,247	0.29 *(0.27)*
Automatic single-spindle (incl. screw machines)	30,991	45,232	2.08 *(0.88)*
Semi-automatic	16,605	8,807	0.76 *(0.72)*
Sub-total automatic & semi-automatic	92,694	63,286	0.97 *(0.65)*
Bench	48,926	83,653	2.44 *(2.08)*
Engine (incl. toolroom)	140,214	283,285	2.88 *(1.62)*
Other lathes	34,125	17,638	0.74 *(0.88)*
Sub-total other lathes	223,265	384,576	2.46 *(1.61)*

* See note to Table 4.
** In brackets corresponding figures for GER1941/ US1940.

production technologies that were only beginning to diffuse across American metal-working before the war. By doing so, it reversed the convergence in metal-cutting technology that Germany had achieved during the 1930s.

How successful this new American focus was in dealing with the problems of war production is another matter. Recent literature seems to suggest that, far from being a clear advantage, extreme specialisation might have hindered the US war effort, and that companies that opted for "flexible specialisation" using general-purpose equipment (such as "universal"[27] machinery), and skilled, adaptable workers were better positioned to contribute positively to the production of armaments.[28]

The pattern revealed for Germany during World War II is similarly clear. Faced with a shortage of labour, German metal-working industry was unable to emulate the astonishing expansions of its US counterpart. It tried to compensate this disadvantage by increasing the relatively capital-intensive nature of its production processes. However, despite their ability to produce vast numbers of machine tools, German industry, whether due to fundamental technological constraints or mismanagement, failed to match the new focus of American technology. It could not bridge the existing technological gap in multiple spindle automatic lathes, and found itself unable to keep pace with the American acceleration in the accumulation of production grinders. However, this should not be allowed to obscure the more basic finding that between 1930 and 1945 the gap between the US and Germany closed in virtually every category and widened marginally only in production grinders. On the other hand, it is likely that Germany's strategy to counterbalance labour scarcity with capital abundance ran into diminishing returns. Particularly, as the strategy failed for some of the machine types more likely to yield productivity gains.

Conclusion

In light of the evidence presented in this paper and the work of other scholars in the field, the simple dichotomous view of the difference between American and European metal-working technology must surely be abandoned. We have been able to match our estimates of the machine tool stocks for Germany and the United States at a "two digit" level of magnification. And what we have found is not radical difference but a surprising degree of similarity in the types and numbers of machines employed. Metal-working in the early twentieth century was not like the case of cotton spinning, where different factor endowments and

[27] 'The term "universal" is used somewhat loosely in respect of machine tools but always carries the implication that several different types of operations can be performed. In milling machines the term commonly means that the work table can swivel, that a vertical spindle attachment is provided, and that a dividing head is available so that helices can be cut' (Steeds 1969, p. 165).

[28] See for example: Zeitlin, 1995, p.48, and Sabel and Zeitlin 1985, footnote 89, p. 171. If this interpretation is true, then superiority in grinders or milling machines might have proved more important than superiority in, for example, automatic lathes. Moreover, over-commitment to mass production methods might go some way in explaining the 'large and anomalous slowdowns in output growth' at the macroeconomic level noted by Abramovitz and David (2000, p. 7) for the US during WW2.

market conditions manifested themselves in the choice of completely different technologies on either side of the Atlantic – the mule and the ring spindle respectively. In the interwar period, German and American metalworkers appear to have chosen machinery from a common repertoire. American metalworking was not entirely reliant on special purpose machine tools. On the other hand, high volume tools suitable for mass production could be found in German factories as well. This basic conclusion holds for the entire period between 1930 and 1945, but our data also allow us to describe a complex process of convergence.

If we cast our eye across the entire period of this paper there can be no doubt that German metal-working was playing a game of catch-up. And if we compare key tool categories for 1930 and 1945 there can also be no doubt that it played this game successfully. On the basis of the evidence presented here, it seems likely that in purely technical terms the gulf between German and US industry was at its widest in the 1920s. But even in 1930 the dichotomous model of 'European' and 'American' technology as two radically different paths of development was clearly questionable. Both Germany and the US used a mix of technologies and, even in the US, mass production tools were far from dominant. Over the following 15 years, there is an indisputable pattern of convergence. If we focus on the emblematic tools of mass production such as production grinders or automatic lathes, German equipment was undeniably closer to American standards by the end of World War II than had been the case in 1930. However, one of our key findings is that the state of the art in metal-working was a moving target. After a decade of stagnation, the war dramatically accelerated the pace at which new technologies were introduced into US metal-working. After 1940, convergence slowed and in some cases Germany's gains of the 1930s were reversed. Since this is not explicable in terms of the sheer scale of US investment we do find that there was a significant difference in the pattern of investment during the war. The USSBS was right, therefore, to point to differences. However, its interpretation of these differences was simplistic and completely failed to capture the dynamic of the US-German comparison over time.

What are the implications of these findings for the question of productivity that is at the heart of the economic history literature? There is clearly an urgent need to incorporate the history of both World Wars into the story told about the relative economic development of the major industrial economies. One major priority must be to develop a set of comparable industrial statistics for the combatant countries. On the basis of the data presented here, we would certainly expect to see no widening of the gap in labour productivity between German and US metal-working over the course of the 1930s and early 1940s. But, whatever degree of convergence may be visible in this data, it is more than likely to confirm the persistence of major productivity differentials between the two sectors. So what are the implications of our findings for our understanding of the productivity gap?

It does not seem plausible, given the evidence presented here, to argue that American metal-working was considerably more machine-intensive, whichever measure is used. Nor is it plausible to maintain the idea of a fundamental divergence in technological paths. We have, however, documented persistent and substantial differences in certain key tool types. Germany never made up the gap in welding equipment and in ultra high volume automatic lathes. It is possible that it was not the machine tool stock as a whole, but these critical types of tool that formed the bottleneck. Alternatively, we need to consider the possibility that it was other aspects of production, such as material handling, rather than metal-cutting that formed the key areas of American advantage. In this way, it may be possible to salvage the common sense idea that it is differences in the type of industrial equipment that hold the key to explaining the difference in productivity.

We find it more convincing to explain the persistent productivity differentials between the US and Germany in terms of the more general differences between the American and European economies. In particular, we would invoke the abundance of low cost energy sources and the larger scale of production in US industry. The statistical sources we have begun to explore in this paper are good at describing the numbers and types of tools installed in German and American industry. What they cannot do, is to provide similarly comprehensive information on the capacity of machines, the types of power they were supplied with and the scale of the jobs on which they were employed. Though American and German metal-working firms used similar numbers of essentially similar machines, it is more than possible that the American machines were more productive because they tended to be bigger, because they were more commonly equipped with direct electric drives and because they were employed on larger production runs. There is strong evidence showing a substantial difference both in the installed horsepower in American and German industry and the quantity of electric power actually consumed in manufacturing.[29] These differences are powerfully correlated with productivity differentials. Traditionally, installed horsepower has been seen as closely correlated with the degree of mechanization. In light of our results, it would seem that this is a false equation. German industry was well-equipped both with labour and machines, but both its workers and its machines made do with less power. There is also good evidence to suggest that batch sizes in American production were significantly larger, across all scales of production. A similar number of machines of similar type could thus be employed more productively in the US. This in turn would have warranted the purchase of machines that were larger and more high-powered.

[29] Ristuccia and Solomou (2002, pp. 12-18).

Our ultimate conclusion, therefore, is ironic. The development of machine tools is a fascinating chapter in the history of technology. Without them, the modern world of mass produced, sophisticated consumer products would be inconceivable. As a result, they are best thought of as the common technological heritage of the industrial world, not as the sole property of one particular country, be it Britain, America, Germany, Italy or Japan. Modern machine tools were a technology developed jointly on both sides of the Atlantic. They were a technology proudly displayed and easily transferred from one place to another. Despite their iconic status, they may not, therefore, hold the key to explaining the trans-Atlantic productivity gap.

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Appendix 1. Age of machine tools in the US and German metal-working industry.

Table A1: Age comparison 1930

Type of Machine	U.S. % over 10 years old	German % 10 years old	Age difference	Absolute value >5	Ger/US value Norm.
Bending machines	43.7	46.1	2.4		1.8
Boring machines	56.3	54.6	-1.7		0.6
Broaching Machines	30.3	27.6	-2.7		0.2
Cutting-off machines	50.0	42.0	-8.0	8.0	1.0
Forging machines	52.5	51.7	-0.8		0.8
Gear-cutting machines	38.4	40.8	2.4		0.7
Grinders - Cutter and tool (including abrasive belt and pedestal for cutter and tool)	52.7	50.3	-2.4		0.6
Grinders - External cylindrical, plain and universal	48.1	41.2	-6.9	6.9	0.7
Internal cylindrical grinders	23.4	33.6	10.2	10.2	0.5
Grinders - Surface, and Disk (horizontal and vertical)	40.4	40.6	0.2		0.3
Grinders – centerless	20.0	31.4	11.4	11.4	0.4
Grinders – Other (including twist drill)	31.8	36.3	4.5		0.2
Grinders	42.6	43.9	1.3		0.5
Production grinders (includes twist drill grinders)	38.1	39.3	1.2		0.4
Honing and lapping machines	22.2	23.6	1.4		0.2
Keyseaters	58.2	44.7	-13.5	13.5	0.5
Turret lathes	47.6	47.4	-0.2		1.0
Automatic and semi-automatic lathes	37.7	41.3	3.6		0.5
Other lathes	58.0	52.5	-5.5	5.5	0.0
Lathes	52.1	50.5	-1.6		1.0
Milling machines - Hand (no power feed)	45.0	44.0	-1.0		0.7
Milling machines - bench, knee-type (plain and universal), and bed (Lincoln) type	50.9	52.4	1.4		0.9
Milling machines – vertical	28.6	55.1	26.5	26.5	0.8

Milling machines - Planer type	33.4	57.4	23.9	23.9	0.8
Milling machines – Other	37.9	47.0	9.1	9.1	0.6
Milling machines	45.6	51.3	5.7	5.7	0.8
Planers	70.2	58.2	-12.0	12.0	1.1
Presses (not forging presses)	45.4	45.6	0.2		1.0
Riveting machines (not portable)	21.4	30.2	8.7	8.7	0.3
Shapers	53.5	49.1	-4.4		1.1
Shears	36.2	44.1	7.9	7.9	1.9
Pipe cutting and threading machines + Thread machines (except for pipes)	49.3	43.4	-6.0	6.0	0.9
Welding and cutting machines – electric arc	14.2	14.5	0.3		0.5
Welding and cutting machines – gas	29.3	21.0	-8.3	8.3	0.5
Welding and cutting machines – spot	19.0	24.0	5.0		0.5
Welding and cutting machines – resistance (flash, seam, etc.)	20.5	31.6	11.1	11.1	0.2
Welding and cutting machines	21.5	21.7	0.2		0.4
Grand total of classified tools (not drills)	46.3	47.3	1.0		0.9

As reported in Table 4 at the aggregate level (i. e. considering all the classified machine tools as identical) we observe a strong correspondence between the percentage of US and German machine tools older than 10 year in 1930. They were 46.3 per cent in the US and the corresponding figure for Germany 47.3 per cent (see also last row of Table A1). The very small difference between these figures (less than one per cent) indicates that, at this level of aggregation, there is strong evidence to dismiss the hypothesis that German scrapping practices were inherently different from those prevalent on the other side of the Atlantic. This conclusion seems particularly strong even allowing for the fact that our calculation of the German stock is biased in the direction of underestimating the proportion of older German machine tools. This is particularly so considering that from documentary evidence we know that in Germany machine tool scrapping between 1930 and 1935 was small.[30]

Yet, considering all machine tools as identical is not satisfactory. Table A1 shows that the correspondence in the age structure of the German and US stock in 1930 went well beyond the aggregate level. For all the 18 main classes

[30] We calculated our minimum estimate for Germany in 1930 on the basis of the machine tools predating 1930 still in place in 1935. Therefore, the machine tools older than ten years in 1930 were, in fact, those older than 15 years in 1935. This is likely to underestimate the proportion of older machine tools in 1930 as it is likely that scrapping between 1930 and 1935 affected disproportionately the older machine tools. On the other hand we know that there was very little scrapping in this period, therefore it is unlikely that the underestimate is of any great significance.

of machine tools the share of machines older than 10 years is very similar. For these 18 main machine tool classes on average there were 1.14 per cent fewer older machines in Germany than in the US. The standard deviation around this value was 6.04. In particular there are only seven classes in which the absolute value of the difference in the percentages was more than five per cent. And only in two classes does the absolute value differ more than ten percentage points (keyseaters and planers). In both keyseaters and planers the German stock was younger than its American counterpart. Does this indicate a German predilection for older tool types? Not necessarily. Keyseaters and planers were on the two extremes of a hypothetical continuum of machine tools along the modernity axis. On one hand, planers were certainly an older machine type increasingly supplanted by milling machines and grinders particularly when it came to long production runs. Thus, the relatively young stock of this kind of machinery might indeed indicate a German attachment to surpassed production methods. On the other hand, keyseaters were machine tools strictly associated with the modern mass-producing motor industry. The peculiarly intense German investment effort in this class of machinery in the 1920s indicates an abandonment of idiosyncratic and surpassed production methods in favour of mass production. To summarise at the main class level there is strict correspondence in the age structure of metal-working machinery of the two countries in 1930.

Is this finding of a strict correspondence in the age structure of the German and US machine tool stock in 1930 robust? What happens when we compare the machine tool subclasses? Table A1 provides entries for the constituent subclasses for four groups of strategically important machine tools: grinders, lathes, milling machines, and welding tools. Whithin the large population of lathes the similarity in the age structure by sub-classes is uncanny. This is particularly striking because the similarity extends to automatic and semiautomatic lathes, the paradigmatic example of mass-production tools. The dissimilarities are more marked in two classes of grinders associated with mass production, internal and centerless grinders. Here the U.S. stock is visibly younger, indicating a stronger emphasis on investment in mass-production machinery. Yet the age structure seems remarkably similar when it comes to production grinders as a whole. The U.S. emphasis on modern production methods is again evident for two subclasses of production millers (planer type and vertical), and for resistance welding, where the U.S. stock was markedly younger.

How to make sense of these differences in the age structure? The following tables (Regression 1) show the output of a simple OLS regression intended to assess the determinants of the age structure of the 18 main machine tools classes.

Regression 1.

Correlations

		German 1930 % 10 years older	Machine totals U.S. 1930 - Per c	Ger/US value 1930 Norm.
Pearson Correlation	German 1930 % 10 years older	1.000	.904	.542
	U.S. 1930 % 10 years older.	.904	1.000	.392
	Ger/US value 1930 Norm.	.542	.392	1.000
Sig. (1-tailed)	German 1930 % 10 years older	.	.000	.010
	U.S. 1930 % 10 years older.	.000	.	.054
	Ger/US value 1930 Norm.	.010	.054	.
N	German 1930 % 10 years older	18	18	18
	U.S. 1930 % 10 years older.	18	18	18
	Ger/US value 1930 Norm.	18	18	18

Model Summary [b]

	R	R Square	Adjusted R Square	Std. Error of the Estimate
	.927[a]	.859	.840	4.182

a. Predictors: (Constant), Ger/US value 1930 Norm., U.S. 1930 % 10 years older.

b. Dependent Variable: German 1930 % 10 years older

Coefficients[a]

Model		Unstandard. Coefficients		Standardized Coefficients			95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	11.0	3.471		3.16	.006	3.571	18.369					
	U.S. 1930 % 10 years older.	.632	.082	.817	7.75	.000	.458	.806	.904	.895	.752	.846	1.182
	Ger/US value 1930 Norm.	4.86	2.313	.221	2.10	.053	-.073	9.788	.542	.477	.204	.846	1.182

a. Dependent Variable: German 1930 % 10 years older

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	Variance Proportions U.S. 1930 % 10 years older.	Variance Proportions Ger/US value 1930 Norm.
1	1	2.815	1.000	.01	.01	.02
	2	.144	4.416	.12	.05	.94
	3	4.095E-02	8.290	.87	.94	.04

a. Dependent Variable: German 1930 % 10 years older

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	25.813	60.918	42.716	9.695	18
Std. Predicted Value	-1.743	1.877	.000	1.000	18
Standard Error of Predicted Value	.996	2.948	1.615	.570	18
Adjusted Predicted Value	24.464	61.963	42.824	9.772	18
Residual	-5.746	7.436	3.947E-16	3.928	18
Std. Residual	-1.374	1.778	.000	.939	18
Stud. Residual	-1.528	1.831	-.012	1.014	18
Deleted Residual	-7.108	7.883	-.108	4.603	18
Stud. Deleted Residual	-1.607	2.007	-.009	1.048	18
Mahal. Distance	.019	7.504	1.889	2.046	18
Cook's Distance	.001	.184	.058	.057	18
Centered Leverage Value	.001	.441	.111	.120	18

a. Dependent Variable: German 1930 % 10 years older

We find that by far the most significant predictor for the percentage of older German machine tools is the percentage of older machine tools in the U.S. stock. This indicates that the German scrapping and investment practices conformed to a norm, shared by the U.S., largely determined by the inherent technical characteristics of each machine tool class. The rules adopted by German industrialists to determine the economic life of capital belonging to each of the main tool classes were largely the same as those adopted by their North American counterparts. Moreover, the statistical significance of the ratio between the two capital stocks by employee (Ger/US value norm 1930), and its large positive coefficient, show that deviations from these norms on the economic life of machine tools are largely explained by technical convergence. The age of German machinery is higher in the classes where the German stock per employee is larger than in the US. Conversely, the investment drive had been more intense (the average age of machinery lower) in classes where the German stock per employee was still below that of the US. This indicates that over the 1920s the US and German metal-working industries became more similar in terms of the machine tools they employed. Classes in which in 1930 there were more machine tools per employee in Germany than in the US, were the classes in which German machinery was relatively older. By comparison, classes in which there were more machine tools per employee in the US than in Germany were the ones in which the German machinery was relatively younger.

In other words, both the Germans and the US industry concentrated their renovation effort in classes in which they were at a numerical disadvantage.

Technical convergence can be explained in two ways. Firstly, it might indicate that there was a process of convergence in terms of sectoral distribution of the metal-working sector in the two countries. Alternatively or complementarily, one could see it as evidence that the two industries converged to a more similar distribution in machinery by type because they were converging to an optimal distribution of machinery (which is likely to have coincided to the US best practice). The second is clearly a more intentional explanation and would suggest a clear convergence in the norms of innovation of German and US industrialists.

In conclusion there is no evidence in the data for 1930 in support of the traditional view (implicitly adopted by the USSBS) that the average life of machine tools was only five years in the US as opposed to three times as much on the old continent. On the contrary the age distribution of machinery in Germany and the US shows a striking correspondence even in presence of a wide disparity in the endowment of particular classes of machinery. This would seem to indicate that the economic life of a particular machine tool was dictated by the technical specificities of that particular class of tools and not, as often maintained, by national specific cultural norms.

We repeated this analysis for the comparison between the German stock in 1938 and the US stock at the beginning of 1940. Taken together, the percentage of classified German machine tools older than eight years in 1938 is 5.47 lower than the percentage of the classified American machine tools older than ten years in January 1940. This comparison is strongly biased against Germany for two main reasons. Firstly, there is a purely numerical bias as we are comparing the percentage of machine tools older than *eight* years in the German metal-working industry in 1938, with the percentage of machine tools older than *ten* years in the US metal-working industry in January 1940. Secondly, there is an "historical" bias as the 18 months that separate the German count in 1938 from the U.S. count at the end of 1939 were characterised by massive investments in German metal-working. We conclude that the percentage of the younger classified machinery installed in the German metal-working sector was *at least* 5.47 higher than the percentage of the younger classified machinery installed in the US metal-working industry. This result shows that by the end of the 1930s the German machine tool stock is clearly younger than the US machine tools stock. This, as the results for 1930, sits uneasily with the commonly maintained view that in Germany the installed machine tool stock was far older than in the US due to the practice of maintaining machine tools in service for far longer than on the other side of the Atlantic.

But we are not satisfied with such an aggregate measure of the age structure of the two machine tool stocks. We, therefore, report the results of the comparison at the main machine tool class level of the German and US stock in 1938-1940. Again we report also the result of the sub-class comparison of machine tolls of the following types: grinders, lathes, milling machines, and welding machinery. A summary of the result of this comparison is shown in Table A.2.

Table A.2: Age comparison Germany 1938 – U.S. 1/1940

Type of Machine	Germany % over 8 years old	U.S. % over 10 years old	Age diff.	Ger/US value Norm.
Bending machines.	69.1	62.5	6.62	1.17
Boring machines	69.5	74.4	-4.88	0.68
Broaching Machines.	49.9	60.7	-10.83	0.23
Cutting-off machines	59.2	64.3	-5.14	0.94
Forging machines.	78.1	83.9	-5.77	0.86
Gear-cutting machines.	67.5	50.6	16.83	0.75
Grinding machines – Cutter and tool	61.8	69.1	-7.27	0.79
Grinding machines – Drill	57.8	58.5	-0.70	0.53
Grinding machines – Floor (pedestal type)	60.0	75.7	-15.64	0.87
Grinding machines – External cylindrical	58.3	68.9	-10.56	1.12
Grinding machines – Internal cylindrical	50.5	68.0	-17.44	0.91
Grinding machines – Surface and disk (horizontal and vertical)	57.0	65.0	-7.99	0.48
Grinding machines – thread	21.4	43.7	-22.31	1.04
Grinding machines - Gear tooth	33.0	19.5	13.48	2.24
Grinding machines - Centerless.	38.1	58.6	-20.41	0.77
Grinding machines – Other	64.8	59.0	5.82	0.11
Grinding machines	58.3	68.3	-9.99	0.72
Production grinders	55.0	49.9	5.07	0.61
Honing and lapping machines	31.1	41.9	-10.75	0.96

Keyseaters	70.8	82.7	-11.94	1.50
Bench lathes	64.0	69.9	-5.85	1.82
Lathes – engine (incl. toolroom)	67.6	83.3	-15.73	1.42
Lathes – Automatic multiple-spindle (incl. screw machines)	57.1	75.7	-18.61	0.23
Lathes – Automatic single-spindle (incl. screw machines)	70.7	72.4	-1.67	0.89
Lathes – Semi-automatic	65.2	77.4	-12.18	0.75
Lathes – wheel and axle (railroad)	88.5	85.6	2.87	1.00
Turret lathes	66.8	78.4	-11.60	0.85
Lathes - Other lathes	73.2	80.2	-7.00	2.06
Lathes	67.7	78.7	-11.03	1.19
Automatic and semi-automatic lathes	68.3	74.2	-5.90	0.65
Other lathes (not turret and not automatic or semi-automatic)	67.8	80.8	-13.01	1.55
Milling machines. Hand (no power feed)	68.6	86.1	-17.46	0.86
Milling machines – bench, knee-type (plain and universal), and bed (Lincoln) type	73.9	81.4	-7.55	1.16
Milling machines – vertical	60.3	72.1	-11.87	1.21
Milling machines – Planer type	74.3	78.4	-4.13	0.60
Milling machines – Duplicators and profilers	63.5	79.8	-16.27	0.90
Milling machines – Continuous (inc. rotary)	74.7	57.0	17.73	0.74
Milling machines – Other	54.7	78.3	-23.63	0.43
Milling machines	70.5	80.5	-10.02	1.02
Planers	80.8	90.2	-9.35	1.14
Presses (not forging presses)	70.8	74.8	-3.99	0.94
Riveting machines (not portable)	45.4	62.3	-16.92	0.36
Shapers	69.9	81.5	-11.68	1.22
Shears	68.1	76.0	-7.83	1.13
Pipe cutting and threading machines and thread machines (except for pipes)	62.8	76.1	-13.29	1.18

Welding and cutting machines – electric arc	16.3	27.1	-10.81	0.50
Welding and cutting machines – gas	32.4	28.9	3.49	0.83
Welding and cutting machines – spot	46.4	45.4	1.02	0.39
Welding and cutting machines – resistance (flash, seam, etc.)	45.5	40.7	4.81	0.55
Welding and cutting machines	29.7	34.5	-4.77	0.51
Grand total of classified tools	65.8	71.3	-5.47	0.94

For all but two the 18 main machine tool classes the German stock is younger than the US (see third column, grey rows). The greater average age of bending machines and gear-cutting machines, can be explained in the first case by the greater number of bending machines per worker in Germany than in the U.S. (see last column). As for the gear-cutting machines the difference may be accounted for by the reliance of German metal-working on gear tooth grinders. At this level of disaggregation, the overall result of a younger German stock is entirely confirmed. And the result does not change substantially if one considers the 29 sub-classes presented in table A.2 (white rows). Of these sub-classes, only 7 show a positive sign in the third column denoting an older German stock. Of these, only three are deviations of some significance, namely two sub-classes of grinders (‘Gear tooth’, and ‘Other’), and one class of milling machines: ‘Continuous (including rotary)’. The relative old age of the German stock of ‘Gear tooth’ grinders can be easily explained by the abundance of this class of machine tools in Germany (see last column). The case of the ‘Other’ grinding machines is possibly more important as this sub-class is single-handedly responsible for the slightly higher German percentage of older production grinders. ‘Grinding machines – Other’ is a residual sub-class where the U.S. stock is massively over-represented. In 1940 there were 17,291 of these machines in the U.S. metal-working industry as opposed to the mere 2,088 recorded by the German count in 1938. This macroscopic difference is likely to be the result of inclusion of a large number of German machine tools in two classes not directly comparable with the ones reported in the *American Machinist inventories*. These were ‘General metal-working machines not included in the above classification’ and ‘Special-purpose metal-working machines not included in the above classification’ which in 1938 were 38,947 and 80,021 respectively. We excluded these two German classes from the comparison but this is likely to determine a further bias against the German numeration. This bias will be particularly pronounced when it comes to comparison of German and U.S. machine tools belonging to the various ‘Other’ sub-classes. We can conclude that there is only one sub-class where the German age disadvantage is significative and clear, namely: ‘Milling machines - Continuous (including rotary)’. Continuous millers are undoubtedly modern production tools, and yet it is unlikely that the relative old age of the German machinery in this sub-class can fundamentally alter the result of a comprehensively younger German stock. Particularly when one considers that this class counted for only 1,238 in Germany in 1938 and only 1,539 units in the U.S. in January 1940.

Repeating the procedure employed to analyse the 1930 data, we investigate the determinants of the comparative age structure in by regressing the percentage of German machine tools older than eight years in 1938 against a set of regressors. The first one is the percentage of U.S. machine tools older than ten years on the 1/1/1940. Similarly, we use as a regressor the ratio of German machine tools by U.S. machine tools normalised by the number of employees in the metal-working sector. In this case, though, we can use both the normalised ratio at the beginning of the period (1930), and the normalised ratio at the end of the period (1938/40). The latter appears not to be statistically significant. We interpret this as evidence that by the end of the 1930 the catching up process is almost complete.

The results of the final regression (Regression 2) are reported below. Similarly to our findings for 1930, the age of the German machine tools is largely explained by the age of the American machinery. The rest of the variation in age is explained by convergence. The German metal-working industry in the 1930s invested particularly in those classes of machinery in which there was a wider gap from the U.S. in 1930.

Regression 2

Correlations

		German 1938% Over 8 years	US 1/1940 % Over 10 years	Ger/US 1930 Norm.
Pearson Correlation	German 1938% Over 8 years	1.000	.861	.582
	US 1/1940 % Over 10 years	.861	1.000	.404
	Ger/US 1930 Norm.	.582	.404	1.000
Sig. (1-tailed)	German 1938% Over 8 years	.	.000	.006
	US 1/1940 % Over 10 years	.000	.	.048
	Ger/US 1930 Norm.	.006	.048	.
N	German 1938% Over 8 years	18	18	18
	US 1/1940 % Over 10 years	18	18	18
	Ger/US 1930 Norm.	18	18	18

Model Summary [b]

	R	R Square	Adjusted R Square	Std. Error of the Estimate
	.899[a]	.808	.782	6.749

a. Predictors: (Constant), Ger/US 1930 Norm., US 1/1940 % Over 10 years

b. Dependent Variable: German 1938% Over 8 years

Coefficients[a]

	Unstandardized Coefficients		Stand. Coeff.			95% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
(Constant)	5.463	7.689		.711	.488	-10.924	21.851					
US 1/1940 % Over 10 years	.719	.119	.748	6.045	.000	.466	.973	.861	.842	.685	.837	1.195
Ger/US 1930 Norm.	8.489	3.753	.280	2.262	.039	.489	16.488	.582	.504	.256	.837	1.195

a. Dependent Variable: German 1938% Over 8 years

Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	US 1/1940 % Over 10 years	Ger/US 1930 Norm.
1	1	2.831	1.000	.01	.00	.02
	2	.149	4.364	.06	.03	.91
	3	2.033E-02	11.800	.93	.97	.07

Residuals Statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	33.933	80.058	62.176	12.989	18
Std. Predicted Value	-2.174	1.377	.000	1.000	18
Standard Error of Predicted Value	1.762	4.347	2.632	.837	18
Adjusted Predicted Value	36.376	80.832	62.398	12.915	18
Residual	-8.049	19.597	3.947E-15	6.339	18
Std. Residual	-1.193	2.904	.000	.939	18
Stud. Residual	-1.497	3.147	-.014	1.042	18
Deleted Residual	-12.688	23.010	-.222	7.861	18
Stud. Deleted Residual	-1.569	5.214	.096	1.450	18
Mahal. Distance	.214	6.108	1.889	1.895	18
Cook's Distance	.000	.575	.086	.160	18
Centered Leverage Value	.013	.359	.111	.111	18

For 1938-1940 we are also able to investigate the determinants of the age structure at the sub-class level. We therefore replicated the OLS regression exercise for the 59 sub-classes of our classification. Unfortunately we do not have the 1930 ratio normalised for all these sub-classes. So we opted for an OLS regression including only the U.S. percentage of machine tools older than ten years and the 1938/40 German/US stock ratio normalised by the number of employee in the metal-working sector. The results confirm those of the Regression 2. The main determinant of the age of German machine tools is the age of US machine tools. Showing that there is a strict correspondence between the two. The German/US stock normalised ratio for 1938/40 is again statistically not-significant.[31]

[31] The regression output can be obtained by contacting one of the authors.