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Machine tools and mass production in the armaments boom: Germany and the United States, 1929–44[1]

By CRISTIANO ANDREA RISTUCCIA and ADAM TOOZE*

This article anatomizes the 'productivity race' between Nazi Germany and the US over the period from the Great Depression to the Second World War in the metal-working industry. We present novel data that allow us to account for both the quantity of installed machine tools and their technological type. Hitherto, comparison of productive technologies has been limited to case studies and well-worn narratives about US mass production and European-style flexible specialization. Our data show that the two countries in fact employed similar types of machines combined in different ratios. Furthermore, neither country was locked in a rigid technological paradigm. By 1945 Germany had converged on the US both in terms of capital-intensity and the specific technologies employed. Capital investment made a greater contribution to output growth in Germany, whereas US growth was capital-saving. Total factor productivity growth made a substantial contribution to the armaments boom in both countries. But it was US industry, spared the war's most disruptive effects, that was in a position to take fullest advantage of the opportunities for wartime productivity growth. This adds a new element to familiar explanations for Germany's rapid catch-up after 1945.

Rearmament in the 1930s followed by the industrial effort for the Second World War unleashed an unprecedented boom in worldwide metalworking production. Over the entire period from the early 1930s to the end of the Second World War, the combatants between them produced in excess of 600,000 military aircraft and many times that number of highly sophisticated aero-engines. They launched in excess of 12,000 major naval vessels. They produced more than 300,000 tanks and countless other motor vehicles. The arsenals of the major industrial countries were stocked with more than fifty million rifles and hundreds of thousands of new-fangled automatic weapons, which fired tens of billions of rounds of ammunition.[2] This enormous armaments production

*Author Affiliations: Cristiano Andrea Ristuccia: Faculty of Economics and Trinity Hall, University of Cambridge; Adam Tooze: Department of History, Yale University.

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[2] Data in Harrison, *Economics*, pp. 15–16. Harrison's useful compilation is marred by the absence of ammunition, which made up a large share of total armaments output.

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Table 1. *Output, labour, labour productivity*

	German metalworking output 1929 = 100	*US metalworking output 1929 = 100*	*German employment index 1929 = 100*	*US employment index 1929 = 100*	*German labour productivity*	*US labour productivity*
1929	100	100	100	100	100	100
1930		81				
1931		49				
1932		23				
1933		30	60			
1934		45				
1935		62		89		
1936	103	82	113		91	
1937		93				
1938		61				
1939	160	83	164		97	93
1940		115		104		
1941		190	183			
1942		264				
1943		374				
1944	325	382	222	233	147	164

Sources:
Germany: To match our comprehensive figures for machine tool stock we calculated a broad measure of output for the 'metalworking and metal producing' industries. The German estimates are conservative. They are based on the production figures for 1933, 1936, and 1939 estimated by Gleitze, *Ostdeutsche wirtschaft*, pp. 169–72, from the 1936 production census. His figures anticipate the adjustments recently proposed by Fremdling, 'German industrial employment', and adopted by Ritschl, 'Anglo-German industrial productivity puzzle' (see Fremdling and Stäglin, 'Input-output table', pp. 2–13). We chain these forward to 1944 with production indices taken from US Strategic Bombing Survey, *Report 55* (for a full discussion of the data sources, see also Tooze, 'No room for miracles'), and backward using a combination of output indices from Hoffmann, *Das Wachstum*, and the revised machine-building and metal-working data from Ritschl, 'Anglo-German industrial productivity puzzle', tab. 5, p. 545. For labour, the series for 1929–39 is from Hoffmann, *Das Wachstum*, tab. 15, pp. 196–8, chained to Wagenführ, *Die deutsche Industrie*, tab. 3a, pp. 140–2, for the war years. On the recent debate on the comparative productivity of the German manufacturing sector before the Second World War, see also Broadberry and Burhop, 'Comparative'; Broadberry and Burhop, 'Resolving'; Fremdling, de Jong, and Timmer, 'British and German'; Ritschl, 'Anglo-German'.
US: From data from US Bureau of the Census, *Statistical Abstract*, p. 277, we calculated an index of production at constant prices. For labour, we used US Department of Labor, Bureau of Labor Statistics, *Handbook of Labor Statistics*, tab. A3, p. 10; US Bureau of the Census, *Historical Statistics, part 2*, tab. P58–67, pp. 677–81, and Kendrick, *Productivity trends*, tab. D-IV, pp. 473–5, and tab. D-VII, p. 488.

required further gigantic investments in industrial plant and infrastructure, which stretched the capacity of the world's engineering industry to the limit.

The development of metalworking output from peak to peak, 1929–44, is spectacular in both Germany and the US (see table 1), and it follows a strikingly similar trajectory.[3] German labour productivity grew less rapidly than in the US during the war. But given the widespread use of forced labour, particularly in armaments production, these figures for per capita labour productivity growth are a lower bound estimate.[4] The amount of output squeezed out of the half-starved and brutalized labour force would make the Nazi war economy appear even more

[3] We attribute the contrast between our results and those proposed by Field, 'Impact', and idem, 'Technological change', to the breadth of his macroeconomic approach, as opposed to our focus on metalworking and more importantly to his decision to evaluate growth over the sub-periods 1929–41 and 1941–8. This periodization has the effect both of minimizing the impact of the double-dip recession in the 1930s and of treating the peak of the war effort as an anomaly that is excluded from analysis. Between 1944 and 1945 alone, output in US metal-working plunged by 25%. On the problems of measuring state-sponsored capital accumulation in the US during the war, see Higgs, 'Wartime socialization of investment'.

[4] This may be compounded by our reliance on Hoffmann's employment figures which overstate employment growth between the 1920s and the 1930s; Hoffman, *Das Wachstum*. See Fremdling, 'German industrial employment'.

'efficient' if an adjustment was made for 'human capital' input, or simply for the nutritional status of the average worker.

This story of parallel development is consistent with the analysis of long-run labour productivity differences offered, for instance, by Broadberry.[5] Large transatlantic differences in absolute productivity persisted across the twentieth century as a result of broadly parallel productivity growth. Many factors clearly contributed to this persistent differential in labour productivity. Insofar as capital is invoked as an explanatory factor, it tends to be in two distinct, sometimes overlapping arguments. One is the standard neoclassical account of factor proportions in which the relative scarcity of suitably skilled labour in the US led to a higher capital intensity and higher labour productivity. This argument of capital intensity can then be supplemented or married to an argument about technological styles. Metalworking is one of the crucial sites for the development of these narratives. As early as the late nineteenth century, the US was credited with having pioneered a new type of mass production 'American' tools, whereas engineering in Germany and Britain remained wedded to general-purpose machine tools and customized production making use of a relatively abundant labour force with craft skills.[6]

However, this begs three questions. First, how do we account for parallel dynamic development in labour productivity, in radically distinct technological paradigms? Second, what do we actually know about the technologies employed in metalworking in the US and in the countries that were the leading European producers, notably Germany? Third, how did common shocks such as the demands of wartime production impact the different productive systems?

To date, the literature discussing questions of capital and technology has suffered from two limitations. It has tended to focus on case studies of particular industries and particular plants, and has been largely devoid of a systematic comparative dimension.[7] This article aims to give more quantitative precision to this debate by introducing a novel set of sources. These allow the construction of a closely matched comparison of the entire stock of machine tools installed in Germany and the US in the 1930s and 1940s. This is significant, because machine tools are quite commonly treated as the emblematic locus of the two production paradigms—widespread use of specialized tools in the US as opposed to flexible general-purpose tools in Europe. In his highly influential comparison of the major war economies, Milward adapted this narrative to the Second World War. There was, he argued, particularly in the German case, relatively little technological innovation during the war.[8] Milward in turn borrowed this thesis from the US Strategic Bombing Survey (USSBS), which attempted the first comparative analysis of German metalworking industries in the immediate aftermath of the conflict. The USSBS discovered that Germany had by 1944 accumulated a gigantic stock of machinery. By the end of the war they estimated that there were more machines

[5] Broadberry, 'Manufacturing', pp. 776–7; idem, *Productivity race*, tab. A3.1(c), p. 49; tab. 8. 1, p. 106; tab. 8.2, p. 107.

[6] For the first in-depth, comparative, and critical investigation of the emergence of these stereotypes, see Richter, 'Der Amerikanische und Deutsche Werkzeugmaschinenbau'. See also Piore and Sabel, *Second industrial divide*, pp. 19–48.

[7] For the case of Germany, see Abelshauser, 'Rüstungsschmiede der Nation?', and for Japan, Sasaki, 'Rationalization'.

[8] Milward, *War*, pp. 189–91. For a traditional characterization of the US and German war economies, see also Overy, *Why the Allies won*, pp. 190–207.

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per worker in Germany than in the US. To reconcile these remarkable figures with familiar assumptions about capital intensity and the large gap in labour productivity, the USSBS radicalized the familiar story about technological difference. They argued that the German machine tool stock was large but unproductive. During the war manufacturers had horded large quantities of tools as a hedge against inflation. To US eyes this might appear wasteful. But there was little cost to this strategy because the abiding European commitment to flexible general-purpose machinery meant that the large German stocks of machine tools were not subject to rapid obsolescence. They were not so much productive capital as a savings bank.[9]

There are two problematic aspects of this characterization. The first is the presumption that, whereas US machine tools embodied a dynamic and constantly improving technology, German machine tools embodied an unchanging, traditional, technological style. This is hard to reconcile with the stylized facts of productivity development. There may have been a large productivity gap, but it did not widen.[10] Whatever technology the Europeans were using, whether or not it was radically different from that employed in the US, it was clearly not 'static'. Second, it must be asked how useful it is to apply simple labels such as 'mass production' or 'flexible specialization' to entire industries. For the US, Scranton has shown, through a combination of case studies with analysis of the census results, that in 1923 only 12.2 per cent of the value added generated by US metalworking firms was attributable to out-and-out mass production. Of the rest 47.1 per cent was accounted for by 'specialty' producers and 33.7 per cent by industries involved in a mixture of flexible 'specialty production' and 'bulk production'.[11] The importance of flexible, 'European-style' machine tools in the US has also been driven home forcefully in Hounshell's excellent study of the rise and fall of the 'American system'.[12] In a similar spirit, Zeitlin has argued that US aircraft production during the Second World War was largely organized around flexible production principles.[13] On the other hand, von Freyberg and Siegel were the first to cast doubt on the characterization of German metalworking technology offered by Milward and the USSBS.[14] They show how German metalworkers creatively adapted 'American' technologies, combining 'American' design elements with the flexibility necessary to respond to smaller and more diverse markets.[15] Between the extremes of the special-purpose machine and the general-purpose machine tool von Freyberg and Siegel describe a new category of machines known as 'multi-purpose' tools, which could be set up to perform a sequence of operations at high speed with

[9] US Strategic Bombing Survey, *Effects*, pp. 8, 21, 43–51; idem, *Report 55*. The US Strategic Bombing Survey was established on 3 Nov. 1944 to provide a comprehensive and authoritative study of the effects of the 1943–5 Allied bombing campaign over Germany.

[10] Broadberry, *Productivity race*.

[11] Ibid., pp. 341–3; Scranton, *Endless novelty*, pp. 341–3. Sabel and Zeitlin, 'Historical alternatives', p. 137, show that even in the 1970s less than a third of US metalworking output was mass-produced.

[12] Hounshell, *American system*, pp. 9, 85–96, 162–4, 169, 174, 178, 182–7, 194, 198, 202–4, 231–3. See also Lewchuk, *American*, pp. 33–5.

[13] Zeitlin, 'Flexibility', p. 48.

[14] von Freyberg, *Industrielle Rationalisierung*; Siegel and von Freyberg, *Industrielle Rationalisierung*. See also Benad-Wagenhoff, *Industrieller Maschinenbau*; Ruby, *Entwicklungsgeschichte*; Haak, *Die Entwicklung*.

[15] See also the restatement of Sabel and Zeitlin's position in Sabel and Zeitlin, 'Stories'. On the successful process of technological imitation and counterfeit of American machine tool designs by German machine tool makers from the late nineteenth century to the 1920s, see Richter and Streb, 'Catching-up and falling behind'.

minimal operator intervention, but which also retained a high degree of flexibility. This meshes with recent work which sees the Second World War as a training ground in which German manufacturers learned to combine their techniques of 'flexible specialization' with methods of mass production.[16] These revisionist works are compelling, but they do not address themselves explicitly to the transatlantic comparison and, with the exception of Scranton's work, they are not quantified.

I

To build the basis for a comparison of metalworking technologies we start with German data drawn from the unpublished results of the so-called *Maschinenbestandserhebungen* for 1935 and 1938.[17] In these remarkable official surveys the Statistical Office counted the distribution of 174 different types of tools across 27 sectors of German metalworking and by geographical location. The results appear to cover all plants with more than five 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 as opposed to old-fashioned belt and pulley drive trains. The result is an astonishing database of which a single article can give only a rough impression.[18] Unfortunately, the archive offers virtually nothing by way of background information on the design and conduct of the *Maschinenbestandserhebungen*.[19] However, there is no evidence to suggest that these surveys were ever used as a planning tool. There is, therefore, no reason to worry that their results might have been biased by the effort of firms to manipulate the planning process. The survey was compiled with the active collaboration of the Engineering Business Group, which for 1941 compiled an extension of the results on the basis of detailed sales data.[20] This report also includes sales data for 1942. With a little manipulation these can also be used to produce a set of prices for the most important classes and many sub-classes of tools. For 1942–4, we rely on the less detailed information published in Wagenfuehr's well-known study of German industry during the war.[21]

The American data are from five surveys conducted quinquennially from 1925 to 1945 by the engineering magazine *American Machinist*. The *American Machinist* 'Inventories of metal-working equipment' were sample surveys. They typically subdivided metalworking machinery into more than 100 classes of machine tools (120 in 1930). Distribution of each class was provided by 20 industries and from 1935 by 12 Federal Reserve Districts (in 1940 and 1945 by nine geographic sections) covering the territory of the US. The inventories also counted the number of tools that were more than 10 years old. The inventories refer to the machinery installed on 1 January. Companies were also asked to provide the number of employees on 15 December of the year before that of the survey (that is, on 15 December 1934 for the 1935 survey).[22]

[16] For the aircraft industry, see Budrass, *Flugzeugindustrie*.
[17] Bundesarchiv Lichterfelde, Lichterfelde, Berlin (hereafter BAL), R 31.02 6203.
[18] See Tooze, ' "Punktuelle" '.
[19] For the general development of the Reich's Statistical Office in this period, see Tooze, *Statistics*.
[20] BAL, R 31.02 6258.
[21] Wagenführ, *Die deutsche Industrie*, pp. 162–3.
[22] *American Machinist.*

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The methodology of the *American Machinist* in compiling the 1935 survey was described as follows:

> 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.[23]

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. In relying on the statistical methodology adopted by the *American Machinist* we join a host of predecessors, including the USSBS, the US War Production Board, which relied extensively on the *American Machinist* inventories' data, and Wagoner, the author of the only in-depth technical history of the US machine tool industry in the first half of the twentieth century.[24]

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'.[25] The only exceptions to this rule are the exclusion of drills that could not be directly compared due to differences of classification,[26] 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.

When comparing the two surveys, one is immediately struck by the broad agreement in the nature of categorization. Dozens of sub-classes can be matched directly. This similarity of classification strongly hints at our most basic conclusion: the statisticians in the US and Germany were dealing with similar families of technology. This is not surprising, perhaps, given the highly internationalized nature of the engineering profession. However, it is at odds with the claim that fundamentally different types of technology, locked in by strategies of local learning, predominated on either side of the Atlantic. Furthermore, neither of the two surveys employs the dichotomous distinction between general-purpose and

[23] 'How the figures were compiled', *American Machinist*, 79 (24 April 1935), p. 328.
[24] See Stoughton, *History*, p. 7; Wagoner, *US machine tool industry*, p. 60.
[25] This definition was taken from: *American Machinist*, V. 89, 5 July 1945, p. 98.
[26] The German compilers counted multiple 'gang' drills by the number of spindles and it was not possible in the US data to isolate 'gang' drills from the other machines.

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special-purpose tools that is the staple of general historical accounts. The main line of division, in both cases, is by tool type.[27] 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 distinguish between general-purpose 'engine lathes', turret lathes, and automatic lathes of various kinds. Of course, custom-designed machines, by their very nature, defy standard categorization. However, in both countries the vast majority of tools could clearly be included in the general classification of tool types. In total, the *Maschinenbestandserhebung* of 1938 lumped roughly 10 per cent of German machinery into a general category of 'specialized machinery not otherwise classified'.[28] What is 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 *American Machinist*. In 1945 the *American Machinist* inventory allocated only 2.6 per cent of all the machine tools to a category of 'other machine tools'.[29] In the war history of the War Production Board Tools Division, 'special-purpose machines' went unmentioned.[30]

II

In both countries, the installed metalworking capacity in the late 1920s was a result of investment during the preceding upswing, as well as the metalworking boom of the First World War. The figures in table 2 capture US metalworking in the first flush of 'Fordism'. If there was ever a moment at which one would expect to see a difference in the types of machinery installed in America and Europe, this was surely it. Our basic results are summarized in this table which shows for each class of machine tools the number of machine tools per worker in Germany divided by the number of machine tools per worker in the US. Though there is no major class of tools that was wholly absent from either country, this table does reveal very striking differences in the proportions of tools employed. For three large classes—lathes, milling machines, and presses—the numbers are roughly in proportion to the number of workers employed in metalworking. However, in two areas, which were at the cutting edge of technical development in the 1920s—production grinders,[31] and welding and cutting equipment—the numbers installed in Germany in 1930 were half the figure in the US, allowing for the relative size of the workforces. 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 were small, it is also significant that broaching machines and honing and lapping machines were significantly under-represented in German metalworking. All were particularly important in the mass

[27] The US and German machine tool classification are almost identical to that described by Hornby, *Factories and plants*, p. 301, in relation to wartime British machine tool demand. For a general introduction to machine tool types, see Habicht, *Modern machine tools*; Rolt, *Tools for the job*; Fermer, *Machine tools*.
[28] BAL, R 31.02 6203.
[29] Our calculation based on data from: 'American Machinist 1945 inventory of metal-working equipment by twenty industrial divisions', *Supplement to American Machinist*, 5 July 1945.
[30] Stoughton, *History*.
[31] Woodbury, *History of the grinding machine*, pp. 151–61.

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Table 2. *Similarity and difference in machine-intensity in German and US metalworking, 1930*

Type of machine	*Machine tools per employee, Germany/US*[a]	*US, total units in place*	*Germany, total units in place (minimum estimate)*
Broaching machines	0.20	4,396	660
Honing and lapping machines	0.21	4,345	661
Riveting machines (not portable)	0.27	22,080	4,316
Welding and cutting machines	0.43	45,201	14,344
Production grinders	0.48	94,224	33,100
Keyseaters	0.55	4,379	1,764
Boring machines	0.63	28,033	12,940
Gear-cutting machines	0.71	20,006	10,407
Forging machines	0.78	32,598	18,602
Milling machines	0.83	116,978	71,474
Pipe-cutting and -threading machines + thread machines	0.89	42,142	27,531
Lathes	1.00	308,170	225,749
Presses (excluding forging presses)	1.02	174,379	130,303
Cutting-off machines	1.02	39,719	29,931
Shapers	1.05	36,316	28,108
Planers	1.15	19,401	16,385
Bending machines	1.80	23,324	30,944
Shears	1.90	32,106	44,792
Grand total of classified tools	**0.91**	**1,047,797**	**702,011**
Variance	**0.23**		

Notes: a Col. 1 is calculated as the number of tools per employee in the German metalworking sector divided by the number of tools per employee in the US metalworking sector. As such it is a normalized measure of machine intensity where the US constitutes the norm. The figure of 0.2 implies that there were five times more broaching machines per worker in the US than in Germany.
Sources: No. of machine tools: see section II above. Labour: see tab. 1.

production of internal combustion engines. Similarly, Germany's relatively small number of gear-cutters, an automatic machine by definition, is telling.[32]

This pattern of difference comes more clearly into view if we break down the large categories of lathes and production grinders (table 3). It is within these broad classes that we find the truly emblematic tools of mass production. One group of machines worthy of particular attention are centreless grinders. These tools were in many ways the iconic equipment of Detroit's engine production lines.[33] In a centreless grinder the piece to be worked is not fixed between 'centres' as in a classic lathe, but is forced against the grinding wheel by the opposite rotation of a second wheel. The workpiece can simply be dropped between the wheels and falls down when it has been ground to the predetermined dimensions. Centreless grinders were among the categories of tool least represented in German metalworking in 1930.

Lathes were the most numerous machines in metalworking in both countries. But within this enormous class of machines, we see a significant pattern of differences. Turret lathes were the standard batch production tool of the interwar period. These were not automatic machines, but 'multi-purpose'. They could be preset by a skilled operator, so as to enable unskilled hands to move the tools into position in a predetermined sequence, simply by operating a set of levers and

[32] Woodbury, *History of the gear-cutting machine*, pp. 120–6.
[33] See Woodbury, *History of the grinding machine*, p. 11; Scranton, *Endless novelty*, pp. 306–7; Hounshell, *American system*, pp. 49, 81.

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Table 3. *Lathes and production grinders in the German and US metalworking industries, 1930*

Type of machine	*Machine tools per employee, Germany/US*[a]	*US, total units in place*	*Germany, total units in place (minimum estimate)*
Production grinders	**0.48**	**94,224**	**33,100**
External cylindrical, plain and universal	0.66	33,281	16,217
Internal cylindrical	0.51	9,752	3,669
Centreless	0.42	4,273	1,320
Surface, horizontal and vertical + disk, horizontal and vertical	0.35	46,918	11,894
Lathes	**1.00**	**308,170**	**225,749**
Turret	0.98	41,894	30,255
Automatic and semi-automatic	0.53	68,158	26,716
All others	1.16	198,118	168,778

Note: a As for tab. 2.
Sources: See tab. 2.

switches. They offered a compromise between the advantages of mass production tools and flexibility. It is interesting, therefore, to find them equally well represented in the US and Germany. By contrast, high volume production lathes—semi-automatics and automatics—were significantly underrepresented in Germany by comparison with the US. At the other end of the scale, the residual category ('all other lathes'), dominated by general-purpose types such as 'engine lathes', was overrepresented in Germany.

To find these differences so clearly marked in the data is confidence-inspiring, in that it confirms the ability of our sources to describe what, by all accounts, were very dissimilar industries, with a productivity differential of at least 2 to 1 in favour of the US. At the same time our results also strongly confirm the basic claim of the revisionist literature, which insists that mass production technologies were only ever one element in a portfolio of technologies employed across US industry.

III

The crisis of 1929–33 devastated the metalworking industries in Germany and the US alike. Across the decade of the 1930s, however, the fortunes of the two industries diverged drastically. The US industry continued in the doldrums during the second half of the 1930s. Owing to scrapping and limited investments, the machine tool capacity recorded for 1940 was substantially lower than in 1930. This confirms Field's contention that the 1930s were a decade of 'modest investments in instrumentation' in US manufacturing.[34] By contrast, German metalworking was one of the chief beneficiaries of the Nazi rearmament boom.[35] By 1938 both employment and the machine tool stock in Germany exceeded that in the US. According to our data, the German metalworking industry used 989,852 machine tools in 1938 while the comparable number for the US metalworking industry in

[34] Field, 'Technological change', p. 216. See also idem, 'Equipment hypothesis', tab. 2, p. 52.
[35] On the previously underestimated surge of investments in war-related industries from 1934 to 1944, see Scherner, 'Nazi Germany'.

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Table 4. *The new pattern of convergence: machine intensity in German metalworking industry in 1938 relative to the US in 1940*[a]

Type of machine	*Machine tools per employee, Germany, 1938/US, 1940*[b]	*US, 1940, total units in place*	*Germany, 1938, total units in place*
Broaching machines	0.23 *(0.20)*	4,731	1,201
Riveting machines (not portable)	0.36 *(0.27)*	21,855	8,616
Welding and cutting machines	0.51 *(0.43)*	75,900	42,140
Boring machines	0.68 *(0.63)*	27,309	20,201
Production grinders	0.74 *(0.48)*	56,823	45,831
Gear-cutting machines	0.75 *(0.71)*	20,753	16,856
Forging machines	0.86 *(0.78)*	27,537	25,521
Presses (excluding forging presses)	0.94 *(1.02)*	185,633	189,111
Cutting-off machines	0.94 *(1.02)*	43,097	44,068
Honing and lapping machines	0.96 *(0.21)*	2,413	2,514
Milling machines	1.02 *(0.83)*	94,113	104,235
Shears	1.13 *(1.90)*	34,373	42,184
Planers	1.14 *(1.15)*	15,248	18,825
Bending machines	1.17 *(1.80)*	35,938	45,409
Pipe-cutting and -threading machines + thread machines	1.18 *(0.89)*	28,503	36,449
Lathes	1.19 *(1.00)*	235,235	303,884
Shapers	1.22 *(1.05)*	27,369	36,310
Keyseaters	1.50 *(0.55)*	3,999	6,497
Grand total of classified tools	**0.97** ***(0.91)***	**940,829**	**989,852**
Variance	**0.11** ***(0.23)***		

Notes: *a* As for tab. 2.
b Corresponding figure for 1930 in parentheses.
Sources: See tab. 2.

January 1940 was only 940,829. In addition, contrary to the USSBS's claims, Germany's large stock of machine tools was not the result of long-term hoarding. The German tools were on average more up-to-date than those installed in the US. In May 1938, one-third of the machine tools installed in Germany were less than *eight* years old. By comparison, at the end of 1939 only 29 per cent of the machine tools in the US had been purchased since 1929.

Table 4 confirms that there was catch-up in technological terms as well. As a summary measure of convergence, table 4 compares the variance of the normalized machine-to-labour ratios in 1938/40 with that in 1929/30 (table 4—first

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Table 5. *Lathes and production grinders installed in Germany, 1938, and the US, 1940*[a]

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

Notes: a As for tab. 2.
b Corresponding figures for 1930 in parentheses (when available).
Sources: See tab. 2.

column, 1929/30 figure in parentheses). 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 strong evidence for convergence. In all the machine tool classes in which Germany was lagging in 1930 the disadvantage was either reduced or turned into a German advantage. Similarly the classes of machine tools in which the Germans were 'overstocked' in 1929/30 saw this excess reduced by the end of the 1930s.

Among specialized modern production tools the pattern was the same (table 5). For production grinders, 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 German industry than in the US.

Where the gap was biggest in 1930, catch-up was most rapid. Internal cylindrical grinders, surface grinders, and centreless grinders all show pronounced patterns of convergence. Germany by the late 1930s showed all the signs of an economy tooling up for the mass production of internal combustion engines on the lines pioneered by

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the US in the 1920s. Interestingly, whereas German industry used the investment boom of the 1930s to 'Americanize', there is evidence in the US data of a shift away from more typical mass production equipment. The number of grinders installed in US industry fell more sharply than the number of lathes between 1930 and 1940, and within the class of lathes there was a highly characteristic pattern: whereas the number of automatics and semi-automatics fell by almost 20 per cent, the number of turret lathes, a compromise tool combining bulk production capacity with a degree of flexibility, actually increased between 1930 and 1940.

IV

This analysis of the 1930s sets the stage for a proper appreciation of relative trends during the Second World War. The expansion of US metalworking between 1940 and 1945 is the stuff of legend. Machine tool shipments, which had run at $100 million per year between 1929 and 1938, increased to an average of $100 million per month between April 1942 and June 1943. The number of machine tools installed in the metalworking industry, which had been 896,000 at the beginning of 1940, had reached 1,518,000 by the end of 1944. But the drama of this expansion was, of course, in large part an effect of the extraordinarily prolonged depression in the US in the 1930s. As we have seen with regard to output and labour inputs, compared peak to peak, the expansion of German and US metalworking was, in fact strikingly similar. Moreover, the evidence for machine tool investment suggests what is at first a surprising conclusion: German expansion from the late 1930s onwards was in fact relatively more capital-intensive than that in the US (table 6). It is quite possible that by 1944, the number of machine tools in Germany had doubled relative to the level in 1929, while those in the US had only increased by 50 per cent. Germany ended the war with more machine tools per worker than the US in 10 of the 12 main classes for which the comparison is possible. In the remaining two classes (gear-cutting machines and production grinders) the differential was only 25 per cent. In only one sub-class, production grinders, Germany lost ground to the US, but then only by 5 per cent. In particular, even classes like centreless and external cylindrical grinders, that saw a substantial US investment effort during the war, show only the transformation of a slight German advantage in 1940/1 into a slight US advantage by 1944 (table 7).

In only one class of modern machine tools was the process of convergence relatively limited in its impact. During the war, in the US resources were poured into the expensive and highly sophisticated multiple-spindle automatics, doubling the total stock. Clearly, multiple-spindle automatics were a priority for German industry as well. German holdings also doubled. However, one must suspect that supply constraints were binding in this case, since German industry remained severely underequipped relative to the US. By contrast, German holdings of single-spindle automatics, which were widely available from German manufacturers, were almost twice those of US industry by the end of the war.

The main difference between German and US wartime investment was that US investment was more targeted. By contrast, German firms continued to accumulate traditional tools: engine lathes and bench lathes. By the end of the war, there were almost three times the number of engine lathes per worker in Germany than

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Table 6. *Capital intensity by class of installed machine tool in the German metalworking industry relative to the US, January 1945*[a]

Type of machine	*Machine tools per employee, Germany, 1945/ US, 1945*[b]	*US, total units in place*	*Germany, total units in place*
Gear-cutting machines	0.74 *(0.70)*	55,034	28,621
Production grinders	0.75 *(0.80)*	158,706	82,869
Boring machines	1.10 *(0.72)*	50,337	38,924
Presses (excluding forging presses)	1.47 *(0.81)*	255,030	225,294
Milling machines	1.31 *(1.02)*	171,763	157,874
Lathes	1.84 *(1.25)*	418,501	538,271
Cutting-off machines	1.86 *(1.22)*	62,069	80,819
Pipe-cutting and -threading machines + thread machines	1.75 *(1.17)*	45,219	55,472
Bending machines	1.93 *(1.00)*	18,107	24,468
Planers	2.10 *(1.04)*	16,427	24,166
Shapers	2.52 *(1.38)*	36,703	64,783
Shears	3.94 *(1.66)*	34,456	95,114
Grand total of classified tools[c]	**1.47** ***(1.00)***	**1,517,518**	**1,565,394**
Variance[c]	**0.92** ***(0.15)***		

Notes: a As for tab. 2.
b Corresponding figures for Germany, 1941/US, 1940 in parentheses.
c Includes classes not shown.
Sources: See tab. 2.

there were in the US. One may conjecture that it was the ubiquity of these most characteristic general-purpose machine tools that confirmed the USSBS in its misplaced stereotypes.

The USSBS was right to believe that the German accumulation of machine tools was remarkable. And there may well have been a hoarding impulse on the part of German firms. They were heavily incentivized to invest internally and were on the look-out for inflation-proof assets. But the further claim that this strategy was linked to a static European production paradigm with low rates of depreciation is rejected by the evidence. The huge accumulation of tools was not due to the disproportionate retention of old machines, but to new acquisitions. Many of these acquisitions were of high volume production equipment. When we compare Germany's position in 1944/5 with its position in 1929/30, it is clear that German metalworking not only modernized its machinery, but even managed a substantial degree of convergence with the US. Despite spectacular and highly focused US investment during the Second World War, there is no category of 'mass production tool' in which Germany's relative position in 1944/5 had not improved when compared to 1929/30.

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Table 7. *Lathes and production grinders installed in the metalworking industry, January 1945*[a]

Type of machine	*Machine tools per employee, Germany, 1945/US, 1945*[b]	*US, total units in place*	*Germany, total units in place*
Production grinders	**0.75** **(*0.80*)**	**158,706**	**82,869**
Centreless cylindrical	0.75 (*1.16*)	14,769	7,785
Surface, horizontal and vertical	0.63 (*0.52*)	61,583	27,238
External cylindrical	0.89 (*1.11*)	55,277	34,577
Internal cylindrical	0.70 (*1.00*)	27,077	13,269
Lathes	**1.83** **(*1.25*)**	**417,871**	**535,951**
Turret	1.22 (*0.94*)	101,912	87,056
Automatic and semi-automatic	0.98 (*0.65*)	92,694	63,531
Automatic multiple-spindle (incl. screw machines)	0.30 (*0.27*)	45,098	9,492
Automatic single-spindle (incl. screw machines)	2.08 (*0.88*)	30,991	45,232
Semi-automatic	0.76 (*0.72*)	16,605	8,807
Bench, engine, and other lathes	2.46 (*1.61*)	223,265	385,364
Bench	2.44 (*2.08*)	48,926	83,653
Engine (incl. toolroom)	2.89 (*1.62*)	140,214	283,786
Other lathes	0.75 (*0.88*)	34,125	17,924

Notes: a As for tab. 2.
b Corresponding figures for Germany, 1941/US, 1940 in parentheses.
Sources: See tab. 2.

V

If output expanded only slightly faster in the US than in Germany between 1929 and 1944, and if US labour input was only slightly larger whereas Germany's investment in machine tools was considerably heavier, then it follows that German labour productivity was able to keep pace with that of its fabled US counterpart only at the price of disproportionately heavy investment, that is, at a considerable opportunity cost. For every machine tool it installed, Nazi Germany could have had an additional artillery piece for the Wehrmacht, or a tractor to release scarce labour either for the front line or the engineering factories. It also follows that if US labour productivity in metalworking did not pull decisively ahead between 1929 and 1944, growth in capital productivity outstripped that of Germany.

Table 8 shows averages across all machines installed. An even more dramatic picture emerges if we perform a rough calculation of the incremental productivity of capital. If we assume that the stock installed in 1929 was still surviving in 1944 and

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Table 8. *Capital productivity and capital productivity growth in the German and US metalworking sectors (output per machine tool)*

	Capital productivity	*Capital productivity growth*	
	US/Germany	*US*	*Germany*
1929/30	1.81		
1929–44		119%	50%
1929–39		0%	19%
1939–44		131%	28%

Sources: For output, see tab. 1. For capital, see tab. 2. The capital figures for the US include all main machine tool classes except presses, forging machines, and drills. The capital figures for Germany included the same machine tool classes as for the US with the exception of welding and cutting machines. Note that the figure for German capital in 1939 is in fact for 1938. For the US/G comparison we use RM/$=4.2.

operating at the same intensity that it had in 1929, every new tool added to the German stock was contributing in 1944 twice as much as the average tool of 1929 vintage.[36] In the US, on the same somewhat artificial assumption, the new machines added since 1929 were more than six times as productive. The armaments boom and the new technologies associated with it were dramatically capital-saving.

Of course, all things were not equal. In both cases the labour force had doubled. Furthermore, there is good reason to assume that there were productivity enhancements across the board affecting old capacity and new alike. To gain at least an approximate sense of the relative size of these different factors, we can use a simple growth accounting framework.

$$\frac{\Delta Y}{Y} = \alpha \frac{\Delta K}{K} + \beta \frac{\Delta L}{L} + TFP$$

where $\frac{\Delta Y}{Y}$ is the growth in output over time; $\frac{\Delta K}{K}$ is the growth of the capital input over time, $\frac{\Delta L}{L}$ is the growth in labour over time; and α and β are non-negative constants with $\alpha + \beta = 1$. In line with conventional assumptions we set $\alpha = 0.3$ and $\beta = 0.7$.[37] There are obvious caveats to apply to any standard Cobb–Douglas-type growth accounting exercise and these are particularly severe with regard to wartime economies, but the framework can nevertheless be helpful in allowing us to summarize the implications of the data.

The unusual richness of our data allows us to elaborate this simple growth accounting exercise by exploring several different measures of 'machine tool capital' and its composition. The machine tool censuses of course allow a crude count of the number of machines installed, but as we have begun to set out above,

[36] The current authors have dispelled the myth that US industry tended to replace machinery more often than its German counterpart and that, by default, US metalworkers were endowed with more modern and productive machinery. See Ristuccia and Tooze, 'Cutting edge', pp. 10–12, 37–48.

[37] These values for α and β are in line with those calculated for individual German aircraft companies by Budrass, Scherner, and Streb, 'Fixed-price contracts', p. 122, n. 69.

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we can also compare the stocks in terms of vintage and in terms of the actual types of tools installed. Furthermore, to enable valuation of the stocks we have compiled one extremely detailed set of prices for German machine tools purchased in 1942 and a coarser set of data for prices paid in the US in 1942.

Table 9 shows total factor productivity (TFP) estimates where capital inputs are measured in terms of the number of machine tools installed, at German 1942 prices, and with the coarser set of US data for the same year.[38] The estimates are broadly unresponsive to changes in the methodology adopted to calculate the growth of capital. This suggests that they are reasonably robust.

The results are dramatic. The peak-to-peak calculations for the period 1929/30–1944/5 show a very large 'residual' for both the US and Germany. TFP accounts for almost half of output growth in the German case, while capital and labour inputs grow in line with each other. Due to the modest rate at which capital input increased, the 'residual' is even larger in the US case. Depending on the estimate of capital used, TFP contributed just under two-thirds of the entire output growth, whereas capital investment accounts for between 3 and 6 per cent. The size of the TFP terms is certainly striking, but given the obvious scale economies to be reaped in wartime mass production it is not surprising. Nor it is surprising that the US was more able to take advantage of these opportunities. Whereas the US Home Front was barely affected by the depredations of the war, German industry had to struggle with difficulties, many of which, including the large-scale deployment of slave labour, were alien to modern factory managers in the US.

Comparing machine tool capital valued at German and US prices results in an interesting pattern of differences. One striking fact about the data in table 9 is that whether weighted by German or US prices the German capital stock grows in value terms less than in terms of numbers. The reasons for this become clear when we consider that according to German prices a bench lathe cost as little as 1,500 RM, an all-purpose engine lathe was priced at 6,000 RM, whereas a multiple-spindle automatic cost on average 27,900 RM. As we have shown, Germany was buying a large number of very modern machine tools, but at the same time it was also acquiring large stocks of cheaper tools that had no equivalent in the US and that tended to depress the average price of Germany's new acquisitions. The effect of this diversified investment was compounded by differences in the structure of prices. When valued at US prices, both stocks grew faster. But in the US case this effect was dramatic. Valued at US prices, the US stock grew twice as fast compared to valuation at German prices. Unfortunately the US data are too coarse to allow a really detailed comparison of prices, but table 10 shows a comparison of average prices for broad categories of tool on the basis of an exchange rate of $1:3.80 RM, a rate used by German experts in 1941–2 to compare war expenditures.[39] This confirms the hunch that the structure of US prices tended to give particularly heavy weight to rapidly growing categories such as gear-cutting machines.

Given what we know about the composition of new purchases in categories such as lathes, it is not surprising to find that the average lathe purchased in the US was

[38] For aggregate TFP growth in the US during the Second World War, see Rockoff, 'United States', p. 106.

[39] See, BAL R2501 7009, fo. 2, 'Internationaler Vergleich der Wehrmachtsausgaben' (Aug. 1942). These figures diverge dramatically from the $2.5:1 parity used by Goldsmith, 'Power of victory'.

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Table 9. *TFP in the German and US metalworking sectors*

		$\frac{\Delta Y}{Y}$	$\frac{\Delta K}{K}$	$\frac{\Delta L}{L}$	*TFP*
Germany, 1929–44					
	No.	2.25 (8.2)	1.25 (5.6) *17*	1.22 (5.5) *38*	1.02 (4.8) *45*
	German 1942 prices	2.25	1.11 (5.1) *15*	1.22 *38*	1.06 (4.9) *47*
	US 1942 prices	2.25	1.15 (5.2) *15*	1.22 *38*	1.05 (4.9) *47*
US, 1929–44					
	No.	2.82 (9.4)	0.36 (2.1) *4*	1.33 (5.8) *33*	1.78 (7.1) *63*
	German 1942 prices	2.82	0.27 (1.6) *3*	1.33 *33*	1.81 (7.1) *64*
	US 1942 prices	2.82	0.57 (3.1) *6*	1.33 *33*	1.72 (6.9) *61*
Germany, 1929–39[a]					
	No.	0.60 (4.8)	0.43 (3.6) *22*	0.64 (5.1) *75*	0.02 (0.2) *4*
	German 1942 prices	0.60	0.38 (3.3) *19*	0.64 *75*	0.04 (0.4) *6*
	US 1942 prices	0.60	0.4 (3.4) *20*	0.64 *75*	0.03 (0.3) *5*
US, 1929–39					
	No.	–0.17 (–1.9)	–0.16 (–1.7) *28*	–0.11 (–1.2) *45*	–0.05 (–0.5) *26*
	German 1942 prices	–0.17	–0.24 (–2.7) *42*	–0.11 *45*	–0.02 (–0.2) *12*
	US 1942 prices	–0.17	–0.16 (–1.7) *28*	–0.11 *45*	–0.05 (–0.5) *26*
Germany, 1939–44[b]					
	No.	1.03 (15.2)	0.57 (9.4) *17*	0.35 (6.2) *24*	0.61 (10.0) *60*
	German 1942 prices	1.03	0.53 (8.9) *15*	0.35 *24*	0.63 (10.3) *61*
	US 1942 prices	1.03	0.54 (9.0) *16*	0.35 *24*	0.62 (10.1) *60*
US, 1939–44					
	No.	2.82 (30.7)	0.61 (10.0) *6*	1.61 (21.2) *40*	1.51 (20.2) *54*
	German 1942 prices	2.82	0.67 (10.8) *7*	1.61 *40*	1.49 (20.0) *53*
	US 1942 prices	2.82	0.86 (13.2) *9*	1.61 *40*	1.44 (19.5) *51*

Notes: % contributions to output growth in italics. Annual compound growth rates in parentheses.
a Capital growth refers to the period 1929–38.
b Capital growth refers to the period 1938–44.
Sources: As for tab. 1. We calculate the growth capital input over a subset of machine tool classes for which we have consistent figures in both the US and German datasets for 1929/30, 1938/9, and 1944 and for which we also have 1942 German price data. For the US price comparisons we have used a different selection of classes (those for which US data exist). Note that US prices cover more classes than German prices (they include all main classes except presses, forging machines, and drills). Moreover, the no. of classes of machine tools included for the US calculations with US 1942 prices is larger than that used for the German calculation (which excludes welding and cutting machines).

Table 10. *Price comparison in RM ($1 = 3.8RM)*

	German unit prices	*US unit prices*	*Ratio US/Germany*
Grinders	6,605	14,729	2.3
Lathes	7,456	19,464	2.6
Millers	6,821	19,670	2.9
Boring	18,351	53,872	2.9
Broaching	9,023	34,045	3.8
Gear-cutting	8,116	30,626	3.8
Planers	27,836	115,941	4.1

Sources:
US: US National Archive and Records Administration (National Archives at College Park, College Park, Maryland), War Production Board 179-1-403, Tools Division, Equipment Bureau, Office of the Operations Vice Chairman—War Production Board, 'History of the tool division of the War Production Board and its predecessor agencies' (draft version Sept. 1945), pp. 31–2.
Germany: BAL, R3101 Anh./ alt R7 Anh. MCC 96 fo. 1; BAL, R3101 Anh./alt R7 Anh MCC 162.

more expensive. For the entire population of tools we know that the average machine tool purchased in Germany between 1938 and 1945 cost 7,355 RM, while those added in the US between 1940 and 1945 valued at US prices cost an average of 20,958 RM (at 3.8 RM to the dollar). If we break down the US aggregate and apply the German prices for 1942 to each sub-class, the US machines purchased during the war would have cost on average 9,811 RM at German prices. Of the total difference of 13,602 RM in the price of the average German and US tools, a difference of 2,456 RM, less than 20 per cent, can be explained by the US tendency to concentrate their investment on more expensive tool types. The rest is attributable to the higher price paid in the US across the board.

The US price premium may be an artefact of accounting rules. The US prices are for machine tools complete with attachments, tools, and engines. It is possible that these were excluded from the German data. There were severe supply bottlenecks that inflated US prices. Given the extraordinary urgency of its armaments drive, the US certainly had good reason to incentivize the production of those tool types most in demand.[40] Moreover, given the extraordinary TFP opportunities to be exploited in the US, it is not surprising that US manufacturers were willing to pay a premium to start up production. All of these contextual factors may explain some of the difference. But it is also likely that given the truly remarkable increment to output attributable to each newly installed machine in the US, some element of the price premium is due to 'within-class differences' in the technology and productive potential embodied in the US tools. From a basic engineering standpoint a turret lathe in 1940s Germany and the US may have been the same, but the US version is likely on average to have been larger, faster, more highly powered, and thus both more productive and more valuable to its purchasers. This would confirm simple intuitions about the proper relationship between the prices of factor inputs and their productivity. But even if we take the US machine tool prices at face value, the basic conclusions of the growth accounting exercise stand. It was Germany, rather than the US, where capital intensity was increasing more rapidly.

[40] On the severity of US supply shortages in machine tools, see Smith, *Army*, pp. 564–6.

VI

In 1929 the essential elements of the familiar story of transatlantic productivity difference all lined up. US labour productivity in metalworking was much higher. US workers were equipped with more machines per head. Even though the difference in capital intensity was rather less than a standard neoclassical narrative might suggest, the mix of technologies employed on either side of the Atlantic was markedly different. As this article has shown, over the course of the armament boom the story becomes much more complicated. Output expanded to a comparable degree. Labour productivity increased rapidly, but in parallel, leaving the labour productivity gap little changed. At the same time a striking difference opened up with regard to capital inputs. In terms of basic metalworking techniques Germany converged on the US. But the investment patterns were strikingly different. Germans bought mass production tools, but they also accumulated a large general-purpose capacity. US investment was remarkably concentrated. The familiar story in which US-style mass production technology is associated with higher levels of overall capital intensity no longer holds good. But does this mean that capital, technology, and machine tools did not matter? Do we conclude that because the capital input term is surprisingly small, TFP did 'all the work'?

Deriving such interpretations and causal evaluations from growth accounting exercises is a notoriously tricky and paradoxical business. After all, if we have a small capital input term, does this mean that growth was 'driven' by disembodied TFP, or does it mean that since capital productivity increased, thanks to embodied technical change, every machine tool 'contributed' more? If US metalworking output was able to expand to 380 per cent of its 1929 level with only a 40 per cent increase in the number of machines installed, this certainly implies remarkable ratios for machine tool productivity taken as a whole. But the aggregates hide all-important differences. There were a series of important tool types for which the rate of expansion between 1929 and 1944 came close to matching or exceeded that of output as a whole. We see clusters of technology—precision drilling, gear shaping, thread grinding, honing and lapping, and finally the new electric and gas welding technologies—in which investment substantially outstripped output growth (table 11). Nor were these small groups of tools. On extremely restrictive criteria there were one-third of a million tools that fell into

Table 11. *Bottleneck tools in the US, 1940–5*

	Factor of increase, 1940–5	*No. of machines, 1945*
Precision boring machines	6.34	15,636
Gear-cutting machines—generators—shaper type	6.65	12,367
Gear-cutting machines—generators—bevel, spiral bevel, and hypoid	3.55	7,193
Internal cylindrical grinders	4.39	27,077
Thread grinders	7.75	5,941
Centreless grinders	4.76	14,769
Honing and lapping machines	6.69	16,134
Milling machines—duplicators and profilers	4.05	13,562
Welding and cutting machines—electric arc	4.23	146,808
Welding and cutting machines—gas	5.57	58,549

Sources: See tab. 2.

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these high growth areas in US industry in 1944. Their 'productivity' did not soar. If we think instead of these as bottleneck tools, essential preconditions for output growth, we get a clearer idea of the way in which embodied technology and armaments output may have been positively related. Behind the overall patterns charted in this article lies a hugely complex story of technological adjustment, through which selective investment and redesign of particular elements of the productive processes allowed an unprecedented rate of output growth at relatively lower overall capital intensity.

Returning, to conclude, to the big picture and shifting focus from the US to Germany, the story we are telling for metalworking over the growth cycle from 1929 to 1944 points forward to the postwar industrial boom. Our data provide strong support to the familiar argument that West Germany's economic miracle was prepared by large-scale investment in Hitler's rearmament boom. We add three points to that story. The expansion under Hitler was not merely quantitative. Not only was the capital stock younger by 1945, but in metalworking there had been considerable qualitative modernization as well. Second, during the war Germany, like other combatants, benefited from economies of scale and other efficiency-enhancing effects. It learned new skills of mass production. However, as measured by TFP growth, it did so to a significantly lesser extent than the US. Once the stresses of the war economy were removed, this points to a significant source of catch-up potential. But what the US experience also taught was that building state-of-the-art mass manufacturing capacity did not, as is sometimes imagined, depend simply on piling up 'modern mass production machinery'. The US armaments boom, coming in the wake of the convulsive shock of the great depression, pointed the way towards a far more selective and complex model of production, which was capital- as much as labour-saving. There is every reason to think that West Germany exemplified precisely such a complex strategy. But we are once again reminded of how much more we have to learn about the history of modern mass production after Fordism.

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Footnote references

Abelshauser, W., 'Rüstungsschmiede der Nation? Der Kruppkonzern im Dritten Reich und in der Nachkriegszeit 1933–1951', in L. Gall, ed., *Krupp im 20. Jahrhundert: Die Geschichte des Unternehmens vom Ersten Weltkrieg bis zur Gründung der Stiftung* (Berlin, 2002), pp. 267–472.

Benad-Wagenhoff, V., *Industrieller Maschinenbau im 19. Jahrhundert: Werkstattpraxis und Entwicklung spanabhebender Werkzeugmaschinen im deutschen Maschinenbau 1870–1914* (Stuttgart, 1993).

Broadberry, S. N., 'Manufacturing and the convergence hypothesis: what the long-run data show', *Journal of Economic History*, 53 (1993), pp. 772–95.

Broadberry, S. N., *The productivity race: British manufacturing in international perspective, 1850–1990* (Cambridge, 1997).

Broadberry, S. N. and Burhop, C., 'Comparative productivity in British and German manufacturing before World War II: reconciling direct benchmark estimates and time series projections', *Journal of Economic History*, 67 (2007), pp. 315–49.

Broadberry, S. N. and Burhop, C., 'Resolving the Anglo-German industrial productivity puzzle, 1895–1935: a response to Professor Ritschl', *Journal of Economic History*, 68 (2008), pp. 930–4.

Budrass, L., *Flugzeugindustrie und Luftrüstung in Deutschland 1918–1945* (Düsseldorf, 1998).
Budrass, L., Scherner, J., and Streb, J., 'Fixed-price contracts, learning, and outsourcing: explaining the continuous growth of output and labour productivity in the German aircraft industry during the Second World War', *Economic History Review*, 63 (2010), pp. 107–36.
Fermer, H., *Machine tools: a history 1540–1986* (Amberley, 1995).
Field, A. J., 'Technological change and U.S. productivity growth in the interwar years', *Journal of Economic History*, 66 (2006), pp. 203–36.
Field, A. J., 'The equipment hypothesis and US economic growth', *Explorations in Economic History*, 44 (2007), pp. 43–58.
Field, A. J., 'The impact of the Second World War on US productivity growth', *Economic History Review*, 61 (2008), pp. 672–94.
Fremdling, R., 'German industrial employment 1925, 1933, 1936 and 1939: a new benchmark for 1936 and a note on Hoffmann's Tales', *Jahrbuch für Wirtschaftsgeschichte—Economic History Yearbook* (2007), pp. 171–95.
Fremdling, R., de Jong, H. and Timmer, M. P., 'British and German manufacturing productivity compared: a new benchmark for 1935/1936 based on double deflated value added', *Journal of Economic History*, 67 (2007), pp. 340–78.
Fremdling, R. and Stäglin, R., 'An input-output table for Germany and a new benchmark for German gross national product in 1936', Univ. of Groningen, Growth and Development Centre research memorandum, GD-106 (2009).
von Freyberg, T., *Industrielle Rationalisierung in der Weimarer Republik: untersucht an Beispielen aus dem Maschinenbau und der Elektroindustrie* (Frankfurt, 1989).
Gleitze, B., *Ostdeutsche wirtschaft: industrielle Standorte und volkswirtschaftliche Kapazitäten des ungeteilten Deutschland* (Berlin, 1956).
Goldsmith, R. W., 'The power of victory: munitions output in World War II', *Military Affairs*, 10 (1946), pp. 69–80.
Haak, R., *Die Entwicklung des deutschen Werkzeugmaschinenbaus in der Zeit von 1930 bis 1960* (Berlin, 1997).
Habicht, F. H., *Modern machine tools* (Princeton, N.J., 1963).
Harrison, M., ed., *The Economics of World War II: six great powers in international comparison* (Cambridge, 1998).
Higgs, R., 'Wartime socialization of investment: a reassessment of U.S. capital formation in the 1940s', *Journal of Economic History*, 64 (2004), pp. 500–20.
Hoffmann, W. G., *Das Wachstum der deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts* (Berlin, 1965).
Hornby, W., *Factories and plant. The history of the Second World War* (1958).
Hounshell, D. A., *From the American system to mass production 1800–1932: the development of manufacturing technology in the United States* (Baltimore and London, 1984).
Kendrick, J. W., *Productivity trends in the United States* (Princeton, N.J., 1961).
Lewchuk, W., *American technology and the British vehicle industry: a century of vehicle production in Britain* (Cambridge, 1987).
Milward, A. S., *War, economy and society 1939–1945* (Harmondsworth, 1977).
Overy, R., *Why the Allies won* (1995).
Piore, M. J. and Sabel, C. F., *The second industrial divide: possibilities for prosperity* (New York, 1984).
Richter, R., 'Der Amerikanische und Deutsche Werkzeugmaschinenbau zwischen Konvergenz und Divergenz, 1870–1933' (unpub. Ph.D. thesis, Univ. of Bielefeld, 2009).
Richter, R. and Streb, J., 'Catching-up and falling behind. Knowledge spillover from American to German machine tool makers', Forschungszentrum Innovation und Dienstleistung (FZID), discussion papers, Univ. Hohenheim, no. 09-2009 (2009) http://ssrn.com/abstract=1516327 (accessed on 14 Aug. 2012).
Ristuccia, C. A. and Tooze, J. A., 'The cutting edge of modernity: machine tools in the United States and Germany 1930–1945', Cambridge Working Papers in Economics, no. 0342 (2003).
Ritschl, A., 'The Anglo-German industrial productivity puzzle, 1895–1935: a restatement and a possible resolution', *Journal of Economic History*, 68 (2008), pp. 535–65.
Rockoff, H., 'The United States: from ploughshares to swords', in M. Harrison, ed., *The economics of World War II: six great powers in international comparison* (Cambridge, 1998), pp. 81–121.
Rolt, L. T. C., *Tools for the job: a history of machine tools to 1950* (rev. edn. 1986).
Ruby, J., *Zur Entwicklungsgeschichte der Werkzeugmaschine* (Magdeburg, 1997).
Sabel, C. F. and Zeitlin, J., 'Historical alternatives to mass production: politics, markets and technology in nineteenth-century industrialization', *Past and Present*, 108 (1985), pp. 133–76.
Sabel, C. F. and Zeitlin, J., 'Stories, strategies, structures: rethinking historical alternatives to mass production', in C. F. Sabel and J. Zeitlin, eds., *World of possibilities: flexibility and mass production in western industrialization* (Cambridge, 1997), pp. 1–33.
Sasaki, S., 'The rationalization of production management systems in Japan during World War II', in J. Sakudō and T. Shiba, eds., *World War II and the transformation of business systems: the International Conference on Business History 20: proceedings of the Fuji Conference* (Tokyo, 1994), pp. 30–54.
Scherner, J., 'Nazi Germany's preparation for war: evidence from revised industrial investment series', *European Review of Economic History*, 14 (2010), pp. 433–68.
Scranton, P., *Endless novelty: specialty production and American industrialization, 1865–1925* (Princeton, N.J., 1997).

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Siegel, T. and von Freyberg, T., *Industrielle Rationalisierung unter dem Nationalsozialismus* (Frankfurt, 1991).
Smith, R. E., *The army and economic mobilization* (Washington, D.C., 1959).
Stoughton, B., *History of the Tools Division, War Production Board* (New York, 1949).
Tooze, J. A., *Statistics and the German state, 1900–1945: the making of modern economic knowledge* (Cambridge, 2001).
Tooze, J. A., ' "Punktuelle Modernisierung": Die Akkumulation von Werkzeugmaschinen im "Dritten Reich" ', *Jahrbuch fuer Wirtschaftsgeschichte*, 1 (2003), pp. 79–98.
Tooze, J. A., 'No room for miracles: German industrial output in World War II reassessed', *Geschichte und Gesellschaft*, 31 (2005), pp. 439–64.
Wagenführ, R., *Die deutsche Industrie im Kriege 1939–1945* (Berlin, 2nd edn. 1963).
Wagoner, H. D., *The US machine tool industry from 1900 to 1950* (Cambridge, Mass., and London, 1968).
Woodbury, R. S., *History of the gear-cutting machine: a historical study in geometry and machines* (Cambridge, Mass., 1958).
Woodbury, R. S., *History of the grinding machine: a historical study in tools and precision production* (Cambridge, Mass., 1959).
Zeitlin, J., 'Flexibility and mass production at war: aircraft manufacture in Britain, the United States, and Germany, 1939–1945', *Technology and Culture*, 36 (1995), pp. 46–79.

Official publications

US Bureau of the Census, *Statistical Abstract of the United States 1948* (Washington, D.C., 69th edn. 1948).
US Bureau of the Census, *Historical Statistics of the United States. Colonial Times to 1970, Bicentennial Edition, Part 2* (Washington, D.C., 1975).
US Department of Labor, Bureau of Labor Statistics, *Handbook of Labor Statistics* (Washington, D.C., 1951).
US Strategic Bombing Survey, *The Effects of Strategic Bombing on the German War Economy* (Washington, D.C., 1945).
US Strategic Bombing Survey, *Report 55: the Machine Tool Industry in Germany* (Washington, D.C., 1947).

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