**A Hard Sell: Factors Influencing the Inter-war Adoption of Tungsten Carbide Cutting Tools in Germany, the United States and Britain**

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Cemented tungsten carbide cutting tools came on the market in Germany, Britain and the United States in the late 1920s. The tools are known for their ability to enhance labor productivity, yet although American productivity led German and British, American machine shops were the slowest to adopt the tools in the interwar period. Examination of the details of the introduction and adoption of the new type of cutting tool in comparative perspective suggests that the tools were initially adopted (or not adopted) for a range of reasons besides higher cutting speeds. Crucial among these was the cutters’ ability to save material resources. The case raises important questions about the relationship of technological innovation to measures of productivity as well as about the role of patent monopolies and national networks in introducing innovations in production technology.

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Tungsten carbide cutting tools, although little known to historians, were credited by contemporaries with playing a critical role in rearmament during the interwar period. Evidence submitted to the United States Senate in 1942 attested to the fact that in the interwar period, German firms consumed about 22 times as much hard metal as their American counterparts per unit of produced steel.[[1]](#footnote-1) In 1943, a senator argued that‘without cemented tungsten carbide the German military machine could not have been built in the time that it was built and in the efficient fashion that it was built’.[[2]](#footnote-2) Germans agreed after the war that without the tools, they would not have been able to ‘launch a major war in 1939.’[[3]](#footnote-3) In 1947, the British Hard Metal Association (founded in 1939) argued that defeated Germany should not be allowed to rebuild its carbide production because new entrants could quickly build up commercially threatening businesses.[[4]](#footnote-4)

A typical explanation for the importance of the tools is that given by H. Eckersley in an article in *The Times Survey of the British Machine Tool Industry* of 1949 that ‘output… would be halved if tungsten carbide tools were not available, using the same number of men and machines a present.’ Indeed, the American senator who was so concerned in 1943 about American tungsten carbide use argued similarly that, ‘technology is our key to productivity, productivity is the key to victory.’[[5]](#footnote-5)Yet these assertions that increased cutting speeds and thus enhanced labor productivity was the key attribute of tungsten carbide cutting tools came years after cemented tungsten carbide cutting tools were first put on the market in the late 1920s. Indeed, an emphasis on increased labor productivity as the crucial driving factor for the adoption of tungsten carbide cutting tools shapes our historical accounts of this innovation. By examining the adoption of tungsten carbide cutting tools in the years after their introduction in the interwar period, this paper argues that these tools were initially adopted for reasons other than gains in labor productivity, which were only realised years after the tools were introduced. Chief among these was the tools’ potential to conserve raw materials.

There are few direct records of the adoption of this low profile technology. The lack of quantitative data about tungsten carbide cutting tools in their earliest years means that this paper is necessarily speculative. It begins by situating the question of carbide cutting tools in the current understanding of the trans-Atlantic productivity gap, before turning to a discussion of the many factors that influenced adoption, including industry structure. By comparing the production and use of tungsten carbide cutters in the three leading industrialised economies of the world in the interwar period - Germany, Britain and the United States, the paper will highlight the uneven impacts of the range of considerations that influenced adoption, many of which contradict our understanding of what drove production innovation in the interwar period.[[6]](#footnote-6)

Early levels of adoption in the three countries were widely different. Contemporary statistics gathered by a leading producer of the metal, Friedrich Krupp AG of Essen, Germany, suggest that adoption of tungsten carbide cutting tools in the interwar period was much faster in Germany than in the United States or Britain. According to Krupp, between 1928 and 1938 the annual production of carbide tools in Germany ranged between eight and twenty times that in the United States and three and eight times that in Britain, when turnover is normalized by national steel production.[[7]](#footnote-7) A post-war British intelligence report agreed that ‘the German output of hard metal has always been many times that of this country even allowing for the difference in population,’ although the American industry was less fully developed than Britain’s in 1939.[[8]](#footnote-8)

The comparative story told here, centred on an innovation in production technology that was first marketed by a German firm and adopted more quickly in Europe than in the United States,challenges the assumption of an American-centric literature that all of the important manufacturing innovations in the twentieth-century originated in the United States. David Hounshell has proscribed comparative studies as a good way to combat the often implicit chauvinism of the American history of technology as well as to better understand the technological connections between America and European countries. Differences between adoption in Germany and Britain also suggest caution in using the traditional characterization of a single ‘European’ as opposed to ‘American’ production practice.[[9]](#footnote-9) Through comparison, the paper’s discussion of the first firms to make and sell carbide will add empirical flesh to Christopher Freeman’s notion of ‘national innovation systems’, or the ‘networks of relationships… necessary for any firm to innovate’.[[10]](#footnote-10)

Comparative discussions of manufacturing often begin with consideration of the by now well-established, persistent ‘productivity gap’ in manufacturing between the United States and Europe that favoured the United States in the first half of the twentieth-century.[[11]](#footnote-11) Productivity is generally given as an aggregate figure for an entire economy, often measured in GDP per hour worked.[[12]](#footnote-12) The so-called productivity gap has long been explained with reference to national differences in installed machine tool types that embodied two radically different technological paths. Yet recent work suggests that different machine tool stocks do not explain the gap, alternate paths are not a satisfactory explanation. Richter has argued for the existence of a ‘highly interdependent international market’ in machine tools in the early twentieth-century, which spread production innovations between Germany and the United States.[[13]](#footnote-13) Indeed, the types of machine tools in use in Germany and America actually became more similar over the 1930s.[[14]](#footnote-14)Notwithstanding the detailed information available on interwar machine tools,we lack information about how those machines tools were used[[15]](#footnote-15) - including about the types of cutting tools that were attached to them. Tungsten carbide cutting tools seem to be a production innovation that does not obviously fit into the discourse on labor productivity, as contemporaries suggested.

There seems to be a contradiction between the fact that American firms were slower than their European counterparts to adopt tungsten carbide tooling and that American industry is considered in the 1930s to have been both more technically advanced and more productive than its international peers. Historians must be careful not to assume, as Broadberry has cautioned, that leadership in technological innovation and productivity necessarily entail each other in every case. Citing Habakkuk’s 1962 study of British and American manufacturing in the nineteenth-century, Broadberry demonstrated that the two measures can run counter to each other: if a given system of production ‘is technologically more dynamic… then it is possible to have technological leadership by a country such as Britain with lower labour productivity than America.’[[16]](#footnote-16) Productivity is not necessarily a reliable proxy for comparing technological choices.

The history of technology offers relatively few studies of production technology in the twentieth-century. Its study of production has been focused overwhelmingly on two peculiar, headlining production systems, which have been credited with increasing American productivity: the American system of manufactures and mass production. David Hounshell acknowledged in 1989 that the amount of literature on the American system and mass production (including his own) has obscured ‘even larger patterns of technological development in the United States.’[[17]](#footnote-17) Indeed, Philip Scranton’s detailed study of American production between 1865 and 1925 powerfully demonstrated that mass production was never overwhelmingly central to the American economy, although it benefitted at the cost of other production systems from the widespread assumption that it was.[[18]](#footnote-18) The only serious study of mid-twentieth-century production technology is David Noble’s research on computer-controlled machine tools, which focused on the social consequences and interests that accompanied different production choices.[[19]](#footnote-19) This study seeks similarly to use the case of carbide cutting tools to reveal new facets of the process of innovation in production technology.

The discussion of cutting tools is distinct from that of machine tools, yet cutting tools have rarely attracted the attention of historians. The most frequently mentioned twentieth-century innovation in cutting tools is the arrival of high speed steel tools in machine shops after the turn of the century, an honour it owes, however, primarily to its connection to Frederick Winslow Taylor, the leading, American advocate of scientific management.[[20]](#footnote-20) The literature emphasizes the ability of high speed steel cutting tools to increase machining speeds and hence labor productivity. Tungsten carbide cutting tools, in the rare cases in which they are explicitly dealt with, figure as little more than a postscript to the earlier, high speed steel tools. They tend to be analysed in the same terms. Thus like high speed steel tools, the chief benefit of cemented carbide cutting tools is seen as making it possible to machine faster. Scholars who have commented on the introduction of tungsten carbide tools in interwar Germany, America and Britain have generally concluded that the tools were quickly adopted in each case, but have based this conclusion on changes in the design of machine tools rather than on empirical study of the cutting tools.[[21]](#footnote-21)

One feature of the introduction of tungsten carbide tools that has drawn some attention is the fact that General Electric held a patent monopoly covering the production of the metal for cutting tools in the United States. In 1942, the United States Senate Committee on Patents, as part of its investigation of the effects of international cartels on the American war effort – or in the more inflammatory terms of the populist Senator Robert M. La Follette, ‘the economic penetration of America from Nazi firms’,[[22]](#footnote-22) concluded that General Electric’s carbide monopoly had weakened America’s war-production capacity.[[23]](#footnote-23) Authors then and since have argued that the firm – and through it, its German partner Krupp - stifled American usage by keeping prices excessively high.[[24]](#footnote-24) Yet high prices alone do not explain a low rate of adoption: although the products sold by Singer and McCormick were more expensive than competitors’, the two American firms became the dominant firms in their respective industries.[[25]](#footnote-25) Other American tools gained a reputation for being technically advanced despite the fact that ‘in many cases they cost twice as much as corresponding British or German machines.’[[26]](#footnote-26)Furthermore, patent monopoly and cartel agreements do not explain the levels of adoption because tungsten carbide production was controlled by virtually identical monopolies in Germany and Britain. The variable impact of patent monopolies seen in this case supports literature in economics and economic history that has argued that patent monopolies do not necessarily inhibit innovation and may even encourage it.[[27]](#footnote-27) The heavily monopolistic economy of interwar Germany was undoubtedly innovative.[[28]](#footnote-28) This paper seeks to overcome one limitation of the economic literature by drawing attention not only to the actions of the producers of innovation, but crucially also to the many different barriers encountered by users in adopting new technologies.

A New Cutting Tool

Tungsten carbide is second only to diamond in its hardness. It is also extremely brittle and therefore unsuited to cutting tools, which must be shock-resistant, in its pure form. Cemented carbide, or hard metal, combats the brittleness of pure tungsten (or other metallic) carbide by mixing grains of carbide with a binder metal of a lower melting temperature, most often cobalt or nickel. The metal powder is then put under pressure and heated (subsequently or at the same time) so as to fuse the carbide and melt the binder metal in a process known as sintering. Sintering made it much easier to create alloys from metals, like tungsten carbide, with extremely high melting points. This gave rise to a new field of metalworking in the late 1920s known as powder metallurgy, which did not favour existing toolmakers over other types of firms.[[29]](#footnote-29)

In the interwar period, for use as a cutting tool, a piece of hard metal was sintered in the shape of a blank or a tool tip and then ground into the appropriate cutting edge shape. Importantly, the angles at which carbide cutters were cut differed from those used for the existing alternative: high speed steel tools. In the case of tipped tools, in which the hard metal was used for little more than the tool’s cutting edge, the sintered tips were affixed to a shank of cheaper metal, often of low quality steel. This process could be carried out by a toolmaker or the end user.

Different grades or compositions of cemented carbide were developed for specific applications by changing the proportion of the different component metals or by adding carbides of other refractory metals to the mixture. The addition of more cobalt to a composition, for example, increased toughness, while a greater proportion of tungsten carbide increased a tool’s hardness. The introduction of mixed carbides overcame the limitations of earlier tools, such as the problems encountered by pure cemented tungsten carbide when cutting steel. In the latter case, the addition or use of titanium carbide was crucial to overcome undesirable chemical reactions. Krupp’s steel cutting composition, Widia grade X, which appeared in 1931, contained about 10 percent titanium carbide, 84 percent tungsten carbide and 6 percent cobalt.[[30]](#footnote-30) The mechanical properties and machinability of a given carbide composition could be changed by altering the size of the carbide grains and by treating the powders and making the alloy. Carboloy, the leading American manufacture of the tool metal, doubled its offering to twelve different grades in 1934.[[31]](#footnote-31) In 1935, one worker reflected that the number of possible combinations of carbides was ‘virtually unlimited’, an early multiplicity reflected in the number of hard metal patents taken out in the 1930s.[[32]](#footnote-32) Compositions proliferated in the interwar period, improving performance and enabling the accurate machining of cast iron, aluminum alloys and steel.

Although some early advertisements focused on the ability of tungsten carbide cutting tools to cut at high speeds - estimates suggested that they could be used 5 to 13 times as fast as steel tools - they had many other advantages. By remaining sharp longer, the tools enabled longer runs and reduced the required frequency of re-setting, thus lessening the number of skilled tool setter hours required for a given machining operation. Their use eliminated additional steps in production such as drying (the tools could be used at high temperatures without lubrication), polishing, and fitting, which also saved production time and ultimately destroyed Sheffield’s lucrative file trade. Thus the tools did offer gains in labour productivity, albeit not necessarily through faster machining. Crucially for manufacturing, the tools enabled the machining of new materials for the first time, including tough aluminium and steel alloys and many insulating materials. They performed better than steel tools on non-ferrous metals and highly abrasive materials including Bakelite, ebonite, hard rubber, electrode-carbon, porcelain and slate.[[33]](#footnote-33) Virtually continuous development during the interwar period improved the quality and durability of hard metal cutting tools hugely, and its use was extended to increasingly more complicated cutters. By 1933, hard metal was not only used to make simple lathe tools, but also milling cutters, saws, reamers, counterbores and twist drills. It was also used in mining.[[34]](#footnote-34)

Like other long-lived, widespread technologies, the history of innovation and use in cemented tungsten carbide tools are almost entirely concomitant. When they were first introduced, cemented tungsten carbide cutting tools were far less durable than alternative cutting metals at the time. Yet by the end of the war, their quality had improved dramatically. A standard rough machining operation on a bomb forging of hard nickel chrome steel carried out in Britain using tungsten carbide tools in 1945 would have quickly destroyed the tungsten carbide tools of the early 1930s.[[35]](#footnote-35) From the time that the tools were introduced, extensive cooperation occurred between producers and users aimed at determining the best composition and ideal cutting conditions for each particular operation. In all three countries, information regarding the use and maintenance of hard metal tools was made available to users of the tools by the technical press and by tool suppliers, much of it won through extensive testing.[[36]](#footnote-36) The American National Bureau of Standards reported receiving a ‘large number’ of inquiries regarding testing tungsten carbide tools in the first years after their introduction in the United States, and the Bureau therefore developed a method for testing tungsten carbide lathe tools and determining the best cutting conditions for the tools (speed, feed, depth).[[37]](#footnote-37) In 1930, the American Society of Mechanical Engineers reported that at least 50 of 75 responding manufacturers in the United States were using tungsten carbide tools in an experimental capacity – a precondition for potential adoption.[[38]](#footnote-38) The importance of experiment to innovation adds weight to Parkinson’s argument, in a study of the machine tool industry, that ‘effective user-supplier relationships’ were crucial to ‘successful new product development’ because ‘close interaction’ around a given application often resolved the problems associated with introducing a new product.[[39]](#footnote-39)

A good relationship between users and sellers promoted and enabled innovation. As Parkinson commented in the case of earth-moving machinery, ‘the credibility of the source of supply proved to be a very important variable in influencing the buyer’s willingness to adopt quickly… the early adopters were companies that saw the relative advantages of the new machine and were confident that if anything went wrong, the supplier would look after them.’[[40]](#footnote-40) Existing producers of steel tools had few advantages in powder metallurgy except their established links of trust with user firms, or in the United States, with individual foremen, who were in charge of distributing cutting tools and determining their grade and form.[[41]](#footnote-41) New firms that began selling cutting tools for the first time with the advent of carbide, including the Fansteel Metallurgical Corporation in the United States and the British Thomson Houston Company in Britain, collaborated with firms already in the industry in order to overcome their lack of familiarity with the cutting tool market.[[42]](#footnote-42) Other firms, like Krupp in Germany, sold carbide tools primarily through agents. If, as Rosenberg suggests, the machine tool industry was a point of diffusion for machining innovation because of its role as a node in the manufacture of many different objects,[[43]](#footnote-43) then the relatively lesser involvement of machine tool makers in the cemented carbide tool industry in the United States versus Britain might help to explain the difference in the speed of adoption between machine shops in those countries.

Vendors of the new cutting tools and tool material devoted time and effort to training users because it was crucial for their sales that early adopters saw the innovation under advantageous conditions. To achieve this, it was necessary to train users because the maintenance of the tools was different from the then standard high speed steel tools, and failure for whatever reason could lead a firm to abandon the new material.[[44]](#footnote-44) The common tendency to use cemented carbide tools on existing machine tools that had not been designed with tungsten carbide in mind increased the chance of premature breakage or a performance that was worse than existing cutters.[[45]](#footnote-45) Indeed, the earliest adoption of tungsten carbide tools consisted in the substitution of the new technology into an infrastructure built up around an older one.[[46]](#footnote-46) Old machine tools were more likely to produce excessive vibration and be too weak to power carbide cutting tools at the highest speeds that could attain. Using the new cutting tools on existing machine tools was particularly widespread in the United States, where the average age of machine tools rose dramatically over the interwar period, suggesting that there was a greater chance of unimpressive performances of the new tools in American shops that might have dissuaded users.[[47]](#footnote-47)

In 1927, Krupp commissioned a new high-speed lathe in order to show its new-cemented carbide cutting tools to best effect at the raw materials exhibition in Berlin in October 1927. The German firm particularly emphasized the ability of its tools to cut at increased speed. The exhibition lathe, a show piece, was noted for its 35 horse-power electric motor, the fact that its spindles were all mounted in ball bearings, and for its centralized control – features necessitated by the machine’s high cutting speed. Yet this machine tool by no means represented typical machine shop practice. Indeed, *The Engineer* reported that the lathe ‘is the only machine in existence on which the new cutting metal can be used to its full capacity.’[[48]](#footnote-48) That machine tools intended for use with cemented carbide tools were quickly introduced to the market (as many studies relate[[49]](#footnote-49)) does not tell us about their uptake in machine shops. Buying a new machine tool was a large capital investment, unlike experimentation with a new cutting tool. Sellers redesigned machine tools for use with tungsten carbide cutting tools, reducing vibration and increasing cutting power. Because tungsten carbide tools were less shock resistant than high speed steel tools but could run at very high speeds, some (but not all) of the changes adopted after the arrival of high speed steel tools, like the abandonment of the belt drive, had to be rethought. Some new developments, like efforts to develop a hydraulic drive, gained new impetus.[[50]](#footnote-50)

Despite enthusiastic contemporaries like Alfred Herbert who claimed in 1931 that ‘though not yet in universal use, [cemented tungsten carbide’s] value is being appreciated and firms are rapidly adopting it’,[[51]](#footnote-51) cemented tungsten carbide cutting tools were used in only a small percentage of cuts in Britain and the United States before 1937. In 1934, about 2 percent of machine cuts in the United States were made using tungsten carbide cutting tools.[[52]](#footnote-52) The new tools by no means entirely replaced high speed steel cutting tools, which remained in wide use even after the second world war. Revolutionary claims notwithstanding, an estimate suggests that in Germany (an early adopter of carbide cutting tools) the use of carbide tools was almost equal to that of high speed steel in 1951 - more than two decades after their introduction.[[53]](#footnote-53)

Monopolizing the German Market

The first firm to sell cemented tungsten carbide for use in cutting tools was the Friedrich Krupp AG in Germany. In 1925, Krupp purchased the rights to the patents for tungsten carbide belonging to the Osram Studiengesellschaft, the joint research departments of three leading German electric lamp manufactures, the Deutsche Gasglühlight Aktiengesellschaft, Siemens and Halske and the Allgemeine Elektrizitäts Gesellschaft. The name ‘Osram’ reflected the companies’ work with OSmium and tungsten (wolfRAM).[[54]](#footnote-54) Osram originally developed the metal for use in drawing dies for tungsten light bulb filaments, and Krupp engaged the company to carry out research on both production processes and (patentable) hard metal compositions suitable for cutting tools. At the same time, in the mid-1920s, the rights to Osram’s patents for cemented tungsten carbide, albeit limited to light bulb manufacture, were spread internationally through existing patent pooling agreements. Firms with access to the patents – notably General Electric in the United States and the British Thomson Houston Company in Britain – decided subsequently to develop tungsten carbide further for their own use in cutting tools, and this brought them into conflict with Krupp when they later considered selling the tools to others.[[55]](#footnote-55)

Krupp produced and sold the cemented carbide developed by Osram under the trade name Widia (“wie diamant”, like diamond). Krupp held a monopoly over the manufacture of the metal,but not tools, and the Essen-based company continually expanded its production capacity throughout the 1930s to meet growing demand. In June 1937, Dr Ernst Ammann, the head of the Widia factory, explained that ‘[b]ecause we are obliged as monopoly holders to quickly and regularly make deliveries to our customers and license holders, an expansion of the hard metal works are unavoidable.’[[56]](#footnote-56) Production at Krupp grew from 2.05 tons in 1928 to 7.22 in 1933 to 67.2 tons in 1938. Its turnover in Reichsmarks grew from 3.65 Million in 1928/29 to 16.85 Million in 1937/38 (omitting profits from manufacturing ammunition with tungsten carbide cores, which began 1935/1936).[[57]](#footnote-57) Although Krupp left the fabrication of cutting tools to other firms, some of whom sold tools and some of whom made them for use in their own factories (including the Allgemeine Elektrizitäts Gesellschaft, Siemens and indeed Krupp), the firm boasted that itsmonopoly over tungsten carbide production led it to pay for tool shops’ conversion to the new tool type, including the costs of changing over production methods, re-educating machinists, resetting machine tools, installing new grinding and welding machines for producing hard metal tools, and training workers to make tools from the new material.[[58]](#footnote-58)

Throughout the interwar period, Krupp also sold Widia abroad. In the business year 1929/1930, Krupp reported that its sales by weight were 57 percent within Germany and 43 percent outside it. In the business year 1931/32, during the low-point of Weimar Germany’s credit crisis, when German exports more generally declined by about 30 percent, some 46 percent of Krupp’s turnover in hard metal was in foreign countries. This figure dropped below 40 percent in the year 1933/1934, but this was a result of increasing domestic consumption; the volume of trade abroad continued to increase. By 1935, Krupp had sold Widia in Germany, England, Spain, Poland, Rumania, Czechoslovakia, Japan, China, Russia, the United States, South Africa and Australia.[[59]](#footnote-59) The German firm did not produce Widia outside of Germany, but where local demand justified it, Krupp often helped foreign firms to begin producing cemented carbide or carbide tools, often using metallic powders imported from Krupp. Production of hard metal commenced in the United States, Britain and France before 1931, in Italy in 1936, and in Poland, Hungary, Czechoslovakia and Spain in 1938-1939.[[60]](#footnote-60)

Only two other firms in Germany produced hard metal before 1939: the Deutsche Edelstahlwerke AG (Krefeld) and the Gebrüder Böhler Corporation (Düsseldorf). Both were steel firms that also produced high-quality steel for cutting tools, and both produced cemented titanium carbide, thus avoiding Krupp’s monopoly over cemented tungsten carbide.[[61]](#footnote-61) Deutsche Edelstahlwerke sold mixed carbides under the trade name Titanit. Böhler sold its titanium carbide under the trade name Böhlerit. Krupp produced much more cemented carbide than either the Deutsche Edelstahlwerke or Böhler, however, a dominance that continued through the Second World War. In May 1942, before the serious impact of Allied bombing, Deutsche Edelstahlwerke produced some 19 percent of Krupp’s output; Böhler produced 5 percent.**[[62]](#footnote-62)** Other significantly smaller producers did appear in Germany, although their output was often meant only for their own use.[[63]](#footnote-63)

The Deutsche Edelstahlwerke was an important part of a small network of firms producing mixed carbide-cutting tools that used carbides other than of tungsten (particularly those of molybdenum and titanium) grew up in Austria, Germany, Britain and the United States in the interwar period. The firms made tools based on the work of Dr-Ing Paul Schwartzkopf, a veteran of patent warfare in the international light bulb business. These tools were sold under the trade name Titanit, anglicised as Cutanit. From 1931, Titanit and Cutanit contained 42.5 percent Mo2C, 42.5 percent TiC, 14 percent Ni and about 1 percent Cr.[[64]](#footnote-64)

The powder for making Schwartzkopf’s mixed carbides was first produced in Reutte, Tyrol at the Metallwerke Plansee Corporation, which produced and worked molybdenum and tungsten. The firm was established by Schwartzkopf and his business partner, Richard Kurtz, in 1921. A decade later, in 1931, Titanit GmbH was founded, likewise in Reutte. Schwartzkopf owned approximately half of the firm through a Dutch holding company. The Deutsche Edelstahlwerke also held a stake in the company.[[65]](#footnote-65) It was the Deutsche Edelstahlwerke that took over Schwartzkopf’s Austrian firms when he was forced to give them up after the Anschluß with National Socialist Germany. In late 1938, the Deutsche Edelstahlwerke founded the Titanit Hartmetall GmbH in Krefeld, which took over Titanit GmbH in Reutte. During the war, Reutte produced the majority of the metal powder for the Deutsche Edelstahlwerke.

Although Schwarzkopf was not paid for his expropriated Austrian companies, the Deutsche Edelstahlwerke transferred its interest in the British Cutanit Ltd to Schwarzkopf. The latter company, established in London by 1933, sold the products of Schwarzkopf’s British manufacturer of mixed carbides, Metropolitan Vickers.[[66]](#footnote-66) Metropolitan Vickers, which Schwarzkopf had approached in the late 1920s, began producing molybdenum-titanium-carbide in 1932 using metal powders imported most likely from Metalwerk Plansee.[[67]](#footnote-67) Cutanit was partially owned by Metropolitan Vickers and included members of that firm’s business leadership.[[68]](#footnote-68)

Schwartzkopf extended his reach also to the United States. In 1929, he established the American Electro Metal Corporation in Lewiston, Maine to import and press mixed carbide powders from Metallwerke Plansee. American Cutting Alloys Inc., an affiliated company established by Deutsche Edelstahwerke, manufactured titanium carbide tips and tools from the metal. Schwartzkopf eventually sold his American tool businesses to Firth Stirling in 1939 (after Union Carbide rejected the offer of his patents).[[69]](#footnote-69) None of Schwartzkopf’s firms ever came close to the output of Krupp or its allied firms; although backed by its own patents, Schwartzkopf’s network remained much smaller and less powerful than Krupp’s.[[70]](#footnote-70)

The Tools in Britain

Already in 1927 or 1928, Krupp was approached by Axel C. Wickman, who expressed his interest in obtaining exclusive selling rights for Widia in Britain. The son of German immigrants, Wickman already sold German machine tools through his eponymous firm in Coventry, which he had established in 1925. Through collaboration with Krupp, Wickmans moved progressively from selling imported tools, to mounting imported Widia tips onto steel shanks, to using British-made tungsten carbide tips to make tools.[[71]](#footnote-71) Despite being reliant on Krupp for metal powders and expertise, Wickmans promoted the tools in Britain by developing machine tools and auxiliary tools suited to the new cutting tools, including a range of grinding machines that sported ‘Speedia’ grinding wheels made from diamond and Bakelite. Wickmans dominated the British market for tungsten carbide tools long after the interwar period.[[72]](#footnote-72)

Through its connection with Wickmans, Krupp remained influential in the British market. In December 1930, the German firm jointly founded a new company with Wickman to exercise Krupp’s British patent rights: theTool Metal Manufacturing Company of Coventry. On 14 January 1931, Krupp signed over ten vital British patents covering the production of tungsten carbide tools to thenew firm. On 12 January 1931, Wickman bought stock in the Tool Metal Manufacturing Company, but Krupp retained control over it, nominating two Germans to the company’s four-man board of directors. At least one of them – M.J. Louis - became a business manager of the Widia factory in Essen in late 1939.[[73]](#footnote-73)By 1932, theTool Metal Manufacturing Company had begun producing tungsten carbide in Britain. Wickmans sold tools made from the locally produced British hard metal under the trade name Wimet (‘Wickman metal’). Exploitation by a British company was likely crucial to keeping Krupp’s British patents valid. Relocating production to Britain might also have allowed both firms to avoid or minimize tariffs introduced on German goods when the value of the German mark dropped in 1931.[[74]](#footnote-74)

Krupp reserved the right to import and sell products protected by the transferred patents and agreed to share technical information with theTool Metal Manufacturing Company, although Wickman reported that Krupp did not share information about powder production with the firm; Wickmans was forced to reconstruct the process after the war broke out.[[75]](#footnote-75) Because not only the chemical composition but also the sizes of the particles and the homogeneity of the powder was of critical importance to the final, sintered product’s characteristics, material supply was an effective means for Krupp to control diffusion of their trade secrets.

TheTool Metal Manufacturing Company, and through it Krupp, controlled the market for tungsten carbide in Britain by establishing production quotas for British firms and setting monetary penalties for excess production. After the war, Britain’s government reported that (counter to scare mongering in the United States[[76]](#footnote-76)) ‘[t]here is no evidence in the T/E [Treasury] Department of any restrictive or price controlling agreements’ of tungsten carbide cutting tools in Britain.[[77]](#footnote-77) Nevertheless, Krupp clearly benefitted from the British market through the royalties paid by British firms that used its patents. The British Tungsten Electric Company, for example, representing about 10 percent of the British market in 1946, paid almost £20,000 on production between 1935 and the outbreak of war (when the at that point British-owned TMMC agreed to forgo its royalties).[[78]](#footnote-78) This was ample incentive for TMMC to vigorously defend its patent monopoly in Britain. Krupp played an active role in the Tool Metal Manufacturing Company’s legal actions, carrying out extensive experiments in Essen from 1933 to 1936 for its case against the British Thomson-Houston Company. The case was ultimately settled out of court.

The British Thomson Houston Company was an early producer of the tools in Britain.Although the electrical firm had not sold cutting tools before, it had both the knowledge and the facilities needed for the production of tungsten carbide tools. It was approached by Alfred Herbert, an established British machine tool maker, who suggested that the two firms collaborate. Herbert’s company was an enthusiastic promoter of carbide tools and had unveiled an auto lathe that used all Widia cutters already in 1930. Herbert was particularly concerned to secure Britain’s supply of tungsten carbide tools in the case of war with Germany – a fear not however shared by the government.[[79]](#footnote-79) In 1932 it was agreed that Herbert’s eponymous machine tool company would help the electrical company to develop carbide cutting tools and sell them under the trade name ‘Ardoloy’.[[80]](#footnote-80)

Despite initial hopes that the British Thomson-Houston company did not need a licence, the firm was forced by the Tool Metal Manufacturing Company to take out a production licence in late 1936.[[81]](#footnote-81) Following the preferences of the British Thomson-Houston company, however, the final agreement did not bind any of the electrical firm’s affiliated companies. Chief among these was Metropolitan Vickers, which had begun producing titanium-carbide tools in connection with Schwartzkopf in 1932. Cutanit Ltd, which sold Metropolitan Vickers’ tools also indemnified the firm against violations of TMMC’s patents. In 1937, Metropolitan Vickers produced about 2 percent of the number of tool tips as Wickmans had in 1935.[[82]](#footnote-82)

The first British firms to take out production licences from the Tool Metal Manufacturing Company were two innovative Sheffield cutting tool makers: Firth-Brown Tools (created by Firth-Brown Steels Company in 1935) and Edgar Allen. The mid-1930s thus marked the first time that any Sheffield firm had taken a licence for a foreign technique since Taylor and White’s patents on high speed steel had been ruled invalid decades before.[[83]](#footnote-83) Although they failed to develop an alternative to Krupp’s patented process for making tungsten carbide, researchers in Sheffield actively developed the new material and took out patents of their own. Firth-Brown, an important defense contractor, became the largest producer of carbide tools in Sheffield, which it sold under the name “Mitia”.[[84]](#footnote-84) Smaller producers of tungsten carbide also appeared in Britain. The two most successful, based on wartime production figures, were Murex, a British leader in the magnetic separation of metallic ores that was owned by ICI, and the Tungsten Electric Company, which was founded in London in around 1935 to enable a switch to local production of cemented carbide using powders (rather than metal) imported from Carboloy.[[85]](#footnote-85) In April 1938, the British firm closed a license agreement with the Tool Metal Manufacturing Company to ‘import, make, use and sell’ carbide in Britain.[[86]](#footnote-86) Regardless of the firms that took up the new tools, Wickman remembered having a ‘virtual monopoly’ of British production before 1939 – an advantage that remained reflected in Wickman’s share of the market.[[87]](#footnote-87)

Wickman’s relationship with Krupp ended in the summer of 1939. The German-owned shares of the Tool Metal Manufacturing Company passed through the British custodian of enemy property to Axel Wickman, who after gaining full control over the Tool Metal Manufacturing Company, renamed it Hardmetal Tools. At first, the firm remained reliant on imported metal powders; its ties with Krupp severed, it imported metal powder from early 1940 powder from the American Carboloy. Over the following years, Hardmetal Tools worked successfully to become independent of foreign supply. Wickman also used Carboloy powders in his factory in Canada, which began operations in 1940. The establishment of production in Canada, was allowed by the British Treasury in order to supply both Canadian and British industry in the expectation that domestic war demand would keep the United States from exporting the metal. [[88]](#footnote-88)

Although far behind Germany’s manufacturers, the adoption of tungsten carbide tools by British firms was ahead of that in the United States.[[89]](#footnote-89) This contradicts the consensus that the British machine tool industry lagged far behind the United States and Germany during the twentieth-century.[[90]](#footnote-90) The early presence of these tools in British firms instead supports arguments that Britain’s leading machine tool firms continued to be innovative in the twentieth-century, often by adopting but also by improving on innovations from abroad.[[91]](#footnote-91) It cannot be argued that a reluctance to innovate in the machine tool industry was a symptom of broader British economic malaise– an idea that has anyways already been discredited by revisionist literature.[[92]](#footnote-92)

The American Jungle

The introduction of American-made tungsten carbide to the American market began in November 1928, when Krupp reached an agreement with the American General Electric. The German company assigned its American patents to the American-based international behemoth, which had in fact already developed tools of its own based on the Osram patents and was interested in selling them. Both firms agreed to admit the validity of each other’s patents and to pool hard metal patents – including new ones - for fifteen years. Crucially, the agreement gave General Electric the right to fix the price of sale of tungsten carbide metal in the United States without consulting Krupp (a point which Krupp was loath to concede); royalties on Krupp’s patents were to be split, two-thirds going to Krupp and the remainder to General Electric. The two firms divided the global market: General Electric agreed not to sell its tools outside of North America, and Krupp agreed not to manufacture tungsten carbide in the United States. The German firm did, however, reserve the right to import Widia for sale in the United States, albeit at the price set by General Electric. The American firm agreed to honor the manufacturing licenses that Krupp had previously granted to the Firth Sterling Steel Company and Ludlum Steel Company as well as to grant non-exclusive licences to Krupp’s established American agents, the Union Wire Die Corporation and Thomas Prosser and Son. [[93]](#footnote-93)

General Electric founded Carboloy, a subsidiary, to carry out its agreement with Krupp. On 6 December 1928, General Electric and Carboloy signed an agreement that gave Carboloy exclusive rights to manufacture and sell tungsten carbide in the United States. The latter firm undertook not only to refrain from exporting hard metal but also to restrain others from doing so. Carboloy was to be responsible for issuing production licenses to American companies and General Electric would receive royalties from Carboloy based on its sales. The subsidiary decided to sell not only hard metal but also what it referred to as a complete ‘tool service’ – a decision that was the opposite of Krupp’s practice in Germany, and which Krupp later insisted was a fundamental mistake.[[94]](#footnote-94)

Heir to General Electric’s legal privileges with respect to tungsten carbide cutting tools, Carboloy set a price on tungsten carbide of $459 per pound, which was about 9.5 times higher than Krupp’s had been previously in the United States and some 500 to 900 times as much as equivalent high speed steel tools (in Germany carbide tools cost two to fifteen times as much as **tungsten carbide** tools). This price is frequently quoted as emblematic of Carboloy’s abuse of the market. Yet the firm’s pricing system was highly complex. It dictated different prices for different products, different grades of carbide and different sizes of order. The firm lowered prices on different items more than six times before 1942. Its last price reduction before October 1935 was on the price of ‘large pieces,’ which dropped from 70 cents to 40 cents. Despite Krupp’s constant advice that the firm lower its prices in order to increase turnover, the change resulted in no increase in sales. Jeffries, the chairman of Carboloy’s board, stated that the firm was ready at any time to lower its prices if this would result in increased revenue.[[95]](#footnote-95)

Throughout the 1930s, Carboloy fought against both competition from other producers and low demand from American firms. Both Krupp and Schwartzkopf pulled out of the American market entirely in the 1930s. In April 1936, Krupp stopped selling Widia in the United States in exchange for higher royalty payments, possibly most directly because of a German ban on the export of strategic metals. Just the previous year, in October-November 1935, the manager of Krupp’s Widia factory, Ammann had toured the United States to see how Krupp could establish a going concern in the country. He confessed himself baffled by the fact that the American market differed so much from the German. Schwartzkopf, who left the American market in 1939, blamed the prohibitively high cost of educating users in the United States.[[96]](#footnote-96)

One unique challenge for the new tools in the United States was the fact that American firms used far more of a different cutting alloy known as stellite than their European counterparts. Stellite, nickel-chrome and cobalt-chrome alloys, had been available since about 1910 and performed significantly better than high speed steel, if not better than hard metal, although it was maintained in the same way.[[97]](#footnote-97) The price of stellite cutters was considerably lower than that of cemented tungsten carbide, at about $2-5 per pound. The material was particularly common in the automotive industry, which made up about half of the American market for hard metal.[[98]](#footnote-98)

In addition to fixing the price of tungsten carbide metal and tools,[[99]](#footnote-99) Carboloy took over responsibility for enforcing General Electric’s patent monopoly, which it did by establishing and financially underwriting the ‘Cemented Carbide Supervision Bureau’. The Bureau imposed penalties on other companies for non-observance of licence agreements with Carboloy and threatened firms that it judged to be in violation of the firm’s licences, patents or price structure. Although it avoided taking patent infringers to court, the enforcement Bureau nevertheless told its targets that the corporation’s size would guarantee its victory in court over all comers.[[100]](#footnote-100)

Carboloy set out to enforce its rights over the small but splintered American market. Through significant discounts on large orders (for example offering 20 percent off orders of more than $20,000), the firm convinced big corporate users like Ford, General Motors, Warner & Swasey, Cincinnati Milling Machine, and International Harvester to give up producing tools themselves and buy from Carboloy or firms working under its price structure.[[101]](#footnote-101) At the same time, the firm tried to buy back the manufacturing and sales licenses originally granted by Krupp. In 1934 it succeeded in buying back Ludlum’s license, and in 1936 that of Prosser and Union Die; the latter firms sold their licenses for around $240,000 and $1 million respectively. Firth Stirling - later a vocal critic of Carboloy’s policies, refused to give up its production rights, even for a much larger sum. At the time, Prosser and Union Die represented together about 16 percent of domestic sales; Firth represented about 15 percent.[[102]](#footnote-102)

Central to Carboloy’s attempt to secure control of the market and enforce its price structure were license and production agreements with other American companies. The firm aggressively pursued firms that violated its patents but preferred to reach settlements out of court, exchanging a production license for a firm’s agreement to make royalty payments, follow Carboloy’s price structure, observe production limits, and join the firm’s hard metal patent pool, which meant agreeing not to challenge the validity of Carboloy’s patents. By 1935, Carboloy had issued five production and sales licenses: in January 1929 to Firth-Sterling and Lundlum Steel Companies (originally given by Krupp), in April 1933 to Schwartzkopf’s American Electro Metals and its associated American Cutting Alloys, in August 1933 to the Fansteel Products Company (and the associated companies, Ramet Corporation of America and the Vanadium Alloys Steel Company – where Paul McKenna worked as research director from 1928 until 1938, when he left and ultimately founded Kennametal[[103]](#footnote-103) - and later the joint Vascaloy-Ramet Corporation), and in October 1934 to the Eisler Electric Company. Fansteel was restricted to producing tantalum-carbide, which it had made before being sued by General Electric for patent infringement. Schwartzkopf’s American Cutting Alloys put its patents for titanium-carbide into Carboloy’s pool, yet was limited to making titanium-carbide and mixed carbide hard metals. The fact that other American producers chose to conform with Carboloy’s price structure rather than fight the company in court made them complicit in holding up Carboloy’s patent monopoly in the United States, although it was General Electric and Krupp who were ultimately tried in American court for restricting trade.[[104]](#footnote-104)

Carboloy’s share of the market continued to increase. By April 1936, the firm’s hard metal patent pool had expanded from 13 to 50 patents.[[105]](#footnote-105) Between 1936 and 1937 alone, the firm’s market share in the United States increased from about 47 percent to 63 percent. During the 1930s, Carboloy avoided testing its patents in court. It paid close attention to the Tool Metal Manufacturing Company’s case against the British Thomson-Houston Company because any weakening of the British Krupp patents would likely be detrimental to its patents in the United States. As it turned out, the British Thomson-Houston Companydid not want to see Krupp’s patents ruled invalid; the two companies resolved their dispute out of court.[[106]](#footnote-106)

It was only in 1940, that General Electric’s patents were challenged in court for the first time. In that year, General Electric took the Willey Carbide Tool Company, a maker of carbide tools, to court alleging patent violations.[[107]](#footnote-107) (This incorporated a suit from 1934 that had not been tried before.[[108]](#footnote-108)) The case had two important results. The presiding Michigan district court judge ruled in 1940 that six of Carboloy’s foundational patents were invalid because they did not go beyond common practice. Willey’s was thereby exonerated from charges of patent infringement. The judge’s supplementary decision was also crucial, however, because the judge ruled that Carboloy’s price fixing was not illegal. He argued that the firm ‘in its license agreements, agency agreements and price schedules has done no more than was reasonably and properly necessary to enable it to protect its efforts to make a profit from the manufacture and sale of the patented material’.[[109]](#footnote-109) The ruling thus challenged the basis of Carboloy’s monopoly, but upheld the firm’s general business strategy.

Nevertheless, General Electric’s business strategy was condemned by the American courts in 1948, when General Electric was found guilty of conspiring to constrain trade between 1927 and September 1940. (The original case was brought in 1941, just before the United States entered the Second World War. It was tried from January 1947 to November 1948.) The government argued that the firm’s patent pool and fixed prices were illegal actions whether or not the firm’s patents were valid – thus the reverse of the Willey decision. The case is best known because General Electric was found guilty, yet the defeat cannot be interpreted as proof that Carboloy’s actions had restricted the market for tungsten carbide cutting tools in the United States. The assumption that the firm’s prices restricted trade – for which the firm was demonized - depended on the comparison of the use of hard metal in the United States to that in Germany. Yet the explanation of such a comparison through a single factor – price - is confounded by the distinctive aspects of adoption in Germany and the United States.

Indeed, despite accusing Carboloy of hurting the American economy, the prosecution never demonstrated that the firm’s monopoly had impacted the amount of hard metal traded in the United States. Instead, it attempted to prove that Carboloy’s prices had been aimed at making a profit for the firm and were thus unreasonably high. Carboloy contended that its pursuit of a monopoly over tungsten carbide cutting tools had been appropriate given that the firm was bringing an entirely new product to the market.

Carboloy’s prices reflected the high cost of introducing the new tools, including the cost of educating users, often individually.[[110]](#footnote-110) In the words of a Carboloy engineer: ‘apprentice training was necessary’, but ‘it was also costly.’[[111]](#footnote-111) A negatively self-reinforcing spiral militated against lower prices: as long as firms avoided using the tools, Carboloy’s costs of education remained high, the price of the tools remained high, and so firms continued to use the tools as little as possible.[[112]](#footnote-112)

During its first years of existence, Carboloy became indebted to General Electric for about $1.5 million.[[113]](#footnote-113) It was only in 1936 that the firm made a profit, which it returned to its investors as a princely dividend that year of $46 for every $30 share.[[114]](#footnote-114) Thus the trial counterposed the pro-monopoly position of patent law, meant to enable innovation, and the anti-monopoly position of the Sherman Anti-Trust Act.[[115]](#footnote-115) From the late 1930s, the American justice system prosecuted trusts with renewed vigour, after more than a decade of relative disregard. In a case in 1940, for example, the Supreme Court had underlined that it viewed all horizontal price fixing agreements as criminal, no matter their effect on the market.[[116]](#footnote-116)

The State and Tungsten Carbide Cutting Tools

A key difference between the German, American and British markets for hard metal in the 1930s was that only the National Socialist government chose to intervene in the adoption of hard metal tools during the interwar period. This meddling seems to have been initially motivated not by the need to increase of labour productivity, but by the need to save metal. Self-sufficiency became a crucial goal of the National Socialist state, not least for reasons of foreign exchange.[[117]](#footnote-117)

A post-war British intelligence report noted that ‘from 1933 onwards considerable Government pressure was placed on [German] industry to make the fullest possible use of the material [hard metal].’[[118]](#footnote-118) In 1934, the government exhibition in Berlin, ‘Deutsches Volk – Deutsche Arbeit’ (‘German Folk – German Work’), featured Widia cutting tools. The next year, the very same hard metal tool exhibit appeared again in an exhibit at the Deutsches Museum entitled ‘Neue Werkstoffe – Neue Wege’ (‘New materials – New paths’). The latter show promoted new German-made materials as the country’s primary route to autarky and Widia appeared beside other German products like I.G. Farben’s synthetic gasoline.[[119]](#footnote-119) In 1936, the tools were explicitly part of the four-year plan launched by the National Socialist government. [[120]](#footnote-120) Krupp moved to meet a predicted increased demand: in June 1937, Amman defended his suggestion that Krupp expand its Widia factory by noting that the firm could expect a ‘considerable’ increase in demand for Widia because ‘the use of hard metal is already stipulated in some instances by the authorities.’[[121]](#footnote-121) In 1939, the German Hard Metal Tool Company (Deutschen Hartmetall Werkzeug GbmH), founded in 1936, promoted the new tools in National Socialist language, writing that ‘the hard metal tool… represents one of the most effective tools in the war of production of German industry.’[[122]](#footnote-122)

Tungsten carbide tools were embraced by the National Socialists despite the fact that they cost more than alternative cutting tools.[[123]](#footnote-123) It seems therefore likely that the tools’ contribution to autarky through saving metal was judged to be of more crucial importance. Firms could save tungsten by replacing high speed steel tools with tungsten carbide tools. Because of their durability, 33 kg of Widia hard metal tools in 1937 could machine as much material as 1000 kgof high speed steel tools.[[124]](#footnote-124) High speed steel (which retained roughly the same composition after 1910) contained approximately 18 percent tungsten, so a ton of high speed tool steel contained 180 kg of tungsten and 750 kg of iron. Against this, 33 kg of cemented tungsten carbide tools, despite being roughly 90 percent tungsten, required only 29.7 kg of tungsten and no iron at all. Thus substitution meant that less iron and less tungsten - both crucial elements in the alloy steels used in armaments - were needed for cutting tools.

Using tungsten carbide tools allowed Germany’s firms to retain their machining capacity while decreasing the required amount of costly metal imports. According to Amman in 1937, they used only about one eighth to one tenth of the foreign raw materials required for the equivalent in high speed steel tools. He connected the political support behind the new cutting tools to the government’s policy of autarky and the ‘crucial foreign exchange situation’.[[125]](#footnote-125) Thus the increased use of tungsten carbide cutting tools can be understood as a significant move towards autarkic machining capability in the Third Reich – another example of the National Socialist government embracing and promoting an immature technical innovation because of its desire to continue war production despite its limited financial and material situation. In her internationally comparative study of the shoe industry, Sudrow has argued similarly that the German government’s policy of autarky, which demanded that German firms develop substitutes for leather, not only did not lead to a technological lag in shoe production but in fact let German firms catch up with the technical lead of American and British shoe producers. She shows that state intervention helped to overcome the unattractive high cost and low quality typical of new products in the case of early ersatz materials for shoe production.[[126]](#footnote-126) The tendency of German firms to use hard metal tools even in operations where high speed tools were preferable – a feature of production in Germany that both Krupp and the British Hard Metal Association commented on after the war – could have been an indication of adoption resulting from a high-level determination to embrace the new tools.[[127]](#footnote-127)

Despite having the tools brought to their attention already in 1931, the British government chose not to intervene in British hard metal production.[[128]](#footnote-128) It could not say whether or not Widia was likely to ‘displace the older materials,’ but it was confident that ‘in time of war’ hard metal ‘could be produced in any required quantities at short notice’.[[129]](#footnote-129) At a subsequent meeting in 1938, the Supply Board, similarly concluded that there would be no need to control tungsten carbide cutting tools at the outbreak of war. (Alfred Herbert, minister of munitions during the First World War, helped the situation by working with the British Thomson-Houston company to produce tungsten carbide using materials available in the Empire and arranged to hold large reserves.)[[130]](#footnote-130) No crisis in the supply of tungsten carbide cutting tools to British industry came. Instead, after importing tungsten carbide tools from the United States under Lend/Lease (the American industry had expanded rapidly), Britain ended up with an excess of tools.[[131]](#footnote-131)

Although they did not intervene before the war, during the war, both Britain and the United States, like National Socialist Germany, also actively encouraged the use of the tools as ways to save metal.[[132]](#footnote-132) Because of the extremely fast expansion of hard metal production in the United States and England early in the war (due both to the ease of expansion and commercial diligence), interwar differences in adoption quickly disappeared into quantitative oblivion. Carboloy expanded production by 2.25 times between 1940 and 1941. In 1942, the president of the company reported that the production by weight of tungsten carbide in the United States had surpassed Germany, and that American consumption was then over three times the rate in Germany in early 1939.[[133]](#footnote-133) Yet despite widespread adoption, sellers of cemented carbide tool sellers in all three countries continued after the war to complain that machine shops (including government arsenals[[134]](#footnote-134)) were using the tools incorrectly. Although the vendors can hardly be considered non-partisan judges, their common refrain suggests that high speed cutting was not the primary reason that the tools were adopted, since firms did not use them so as to maximize performance in this respect. Although war hastened adoption and development, it seems also to have hindered the spread of (empirically-based) information about how to use the tools most productively. After the war, makers identified room for growth and continued to promote their cutters. In 1945, Wickmans founded the ‘Wimet School’ to increase technicians’ familiarity with the metal and to provide first-hand information on its use and maintenance, thereby helping firms to achieve ‘potential production increases and cost reductions’.[[135]](#footnote-135) American tool manufacturers estimated in 1949 that 50 to 80 percent of carbide tool failures were attributable to incorrect grinding, using the tools ‘correctly’ was expected to provide benefits that the manufacturing industry ‘cannot afford to forego’.[[136]](#footnote-136) The story of adoption ran on for many decades.

Conclusion

The story of the adoption of tungsten carbide cutting tools does not solve the puzzle of productivity gap in the interwar period, but it shows that the relationship between technological innovation and productivity is a complex one. Feinstein, Temin and Toniolo have argued that in the interwar period, ‘the growth of labor productivity is evidence not only that capital continued to be accumulated throughout this period (albeit with interruptions) but also that there was no interruption in the incorporation of new knowledge into production techniques and in the formation of new human capital through better education.’[[137]](#footnote-137) Yet the differences in international adoption of carbide tools suggest that there were in fact serious barriers to technological innovation in the interwar period. Among these were the performance of the cutting tools (which changed dramatically over time), the performance of alternatives, the necessity for innovation in complementary technologies and the high costs of innovation.

The costs of innovation included not only the cost of the new cutting tools, but also the cost of new machine tools, of re-training machinists, and of establishing the facilities needed for production and maintenance. Adoption relied also on social relations: the dominant supplier of the tools in Britain was a machine tool seller, in Germany, a steel company, and in the United States an electrical firm. Patent monopolies and patent pools played a key part in linking supply and demand in each national market, but patent monopolies proved to be a remarkably flexible business form that could hinder or encourage innovation depending on local legal, economic, political and production realities.

The apparently dramatic difference in the level of use of tungsten carbide cutting tools in Germany, the United States and Britain in the interwar period does not seem to have translated into any significant differences in labour productivity. Thus despite the fact that the tools are known today overwhelmingly for high speed cutting, this paper has suggested that in the first decade during which these tools were available, reasons other than enhancing labor productivity were more important in driving their adoption, particularly the tools’ ability to save strategic metals. Adoption seems to have proceeded fastest where strategic materials were in shortest supply.

The difficulties of recovering the story of the adoption of tungsten carbide cutting tools mean that this paper has been speculative and wide-ranging. Yet this case suggests that there are thought-provoking reasons to study low-profile technologies despite the challenges. The complicated dynamics that surrounded the adoption of tungsten carbide cutters call out the need to understand such changes more deeply. This is crucial if we want to avoid letting an emphasis on ever-increasing machine cutting speeds continue to distort studies of production innovation.

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53. Trapp, “The German Hard Metal Industry”; Otto Patterman, *Werkzeugstähle,* 367; Mont and Schmidt, *Werkzeugstähle,* 6; Holzberger, “Wirtschaftlicher Auswirkung von Hartmetallegierungen.” [↑](#footnote-ref-53)
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60. KRUPP WA 146/665, *25 Jahre Widia-Hartmetall* [↑](#footnote-ref-60)
61. Gebr. Böhler & Co., “Durch Sintern oder Sintern und Eintränken der Hilfsmetalle erzeugte harte Metallegierungen”; Deutsche Edelstahlwerke, “A Hard Metal and Method of Producing the Same.” [↑](#footnote-ref-61)
62. KRUPP WA 146/733, Kapazitäts-, Leistungs- und Gefolgschafts-Übersicht der deutschen Hartmetallindustrie [Capacity, Performance and Employment Overview of the German Hard Metal Inudstry] ; WA W7f/1158, 3 August 1938, Aufsatz von Oehmke, Die Lage im deutschen Hartmetallgeschäft 1938 [The Condition of the German Hard Metal Industry 1938]; Gebr. Böhler, *25 Jahre Böhler, Düsseldorf*; KRUPP WA W7f/1163, 1 March 1942, Techinsche Rationalisierung der Hartmetal Industrie [Technical Rationalization of the Hard Metal Industry] [↑](#footnote-ref-62)
63. Firms listed by the government during the war as producing metal powders included: Röchling, Poldihütte, and Watt. Producers of hard metal included: Rheinmetall, Schoeller-Bleckmann, Röchling, Poldihütte, Stahlwerk Braunschweig, Diener, Watt, Wallram, and Haniel & Lueg. (KRUPP WA 146/733) [↑](#footnote-ref-63)
64. Schwarzkopf and Kieffer, *Cemented Carbides*, 7 [↑](#footnote-ref-64)
65. Plansee, “About us”; Spuhler et al., *“Arisierungen” in Österreich*, 136-9. [↑](#footnote-ref-65)
66. Spuhler et al., *“Arisierungen” in Österreich”*, 137-8; BNA BT 64/2767, Tungsten Carbide: Summary of Information from 1946 Onwards [↑](#footnote-ref-66)
67. Dummelow, *Metropolitan-Vickers*, 140; CA PA 1318/55/1, Cutanit Carbides Trade Literature [↑](#footnote-ref-67)
68. Spuhler et al., *“Arisierungen” in Österreich*, 137; Schwarzkopf, *Geschichten aus Molybdänmark*, 95. [↑](#footnote-ref-68)
69. Testimony of Ollier and Fischer, United States v. General Electric Co. et al.; Avinger, “The Economics of Durability,” 244-5; Spuhler et al., *“Arisierungen” in Österreich*, 137-8; KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry] [↑](#footnote-ref-69)
70. Schwartzkopf, *Geschichten aus Molybdänemark*, 37-9. [↑](#footnote-ref-70)
71. CA PA 2050/10/2, 1985, Research notes of Lexa Dudley about her father Axel Wickman; BNA SUPP 3/41, P.S.O.(B.T.)150, Widia and Similar Cutting Tool Alloys [↑](#footnote-ref-71)
72. CA PA 2050/10/3, Testimony of Reginald J. Dixon (Wickman employee); CA PA 2050/3/20, April 1949, “Grinding and Lapping Carbide Tools”, reprint from *Machinery;* BNA AVIA 22/2363, 4 September 1946, List of principal producers [↑](#footnote-ref-72)
73. CA PA2050/10/2, 12 January 1931, Letter from Wickman; BNA SUPP 3/41, 16 July 1931, Note on the Tool Metal Manufacturing Company; CA PA 2050/10/5; KRUPP WA 4/2757, 27 November 1939, Betr. Vorschlag zur Neuorganisation des Widia-Geschäfts [Regarding suggestion about new organization of the Widia business] [↑](#footnote-ref-73)
74. CA PA2050/10/3, 2 September 1982, Letter from Donovan G. Franklin to Reginald J. Dixon; Sandford, “Hardmetal: the History to 1950,” 86. [↑](#footnote-ref-74)
75. BNA SUPP 3/41, 16 July 1931, Note on Tool Metal Manufacturing Company; CA PA 2158/4/1, A.C. Wickman Ltd. War Record 1939-1945 [↑](#footnote-ref-75)
76. Borkin and Welsh, *Germany’s Master Plan*. [↑](#footnote-ref-76)
77. BNA BT 64/2767, Tungsten Carbide: Summary of Information from 1946 Onwards [↑](#footnote-ref-77)
78. BNA AVIA 22/2363, 4 September 1946; Tool Metal Manufacturing Co., Ltd. v. Tungsten Electric Co. Ltd.. [↑](#footnote-ref-78)
79. BNA SUPP 3/41, P.S.O. 303 (B.T. 135), Fourth Annual Report of the Supply Board; BNA SUPP 3/41, 6 July 1931, Minutes of Board of Trade Supply Organisation [↑](#footnote-ref-79)
80. BNA SUPP 3/9, 5 October 1938, Minutes of Supply Board Meeting [↑](#footnote-ref-80)
81. BNA SUPP 3/41, June 1932, P.S. O. (B.T.) 150, Committee of Imperial Defense Principal Supply Officers Committee; “Wimet/Ardoloy Patent Litigation”, *The Engineer*, 19 February 1937. [↑](#footnote-ref-81)
82. Allibone, “Charles Sykes”, 563; The firm’s early tools were sold in Britain by Quality Steels. Cutanit was later also distributed by George Richards & Co of Manchester and the Jessop Saville & Company of Sheffield. BNA SUPP 3/41, P.S.O. (B.T.) 150, Widia and Similar Cutting Tool Alloys; BNA BT 64/2767, Tungsten Carbide: Summary of Information from 1946 Onwards; CA PA 1318/55/1, Cutanit Carbides Trade Literature; BNA SUPP 3/9, April 1933, List No C1. (Trade Lit) [↑](#footnote-ref-82)
83. Tweedale, *Steel City*, 223-33; Sandford, “Hardmetal: The History to 1950”; Tweedale, “Metallurgy and Technological Change,” 213. [↑](#footnote-ref-83)
84. Fodor, “Improvements in and relating to the Manufacture of Bodies containing Metallic Carbide”; Hatfield and Burden, “Improvements in the manufacture of sintered hard metallic alloys”; Tweedale, *Steel City,* 223-33 and 301; *Flight*, 14 January 1937; BNA SUPP 3/41, P.S.O.(B.T.)150, Widia and Similar Cutting Tool Alloys; Firth, *“Mitia” carbide tools and tips: instruction book.* [↑](#footnote-ref-84)
85. BNA AVIA 22/2363, 4 September 1946; BNA SUPP 3/73, 9 December 1930, Extract from Letter from Sir A. Balfour to Mr. Ashley (Board of Trade) about tungsten, molybdenum and vanadium ores; Bird, *Murex,* 34-51. [↑](#footnote-ref-85)
86. KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry]; Tool Metal Manufacturing Co., Ltd. v. Tungsten Electric Co. Ltd; Tweedale, *Steel City,* 235; BNA SUPP 3/31, 31 January 1936, Letter from Lord Riverdale (Balfour) [↑](#footnote-ref-86)
87. CA PA 2050/10/2-1, 1985, Research notes of Lexa Dudley about her father Axel Wickman; BNA AVIA 22/2363, 4 September 1946, Letter from G.J. Trapp Deputy Director Ferro-Alloys, Ministry of Supply Iron and Steel Control, “Featherstone – Development” [↑](#footnote-ref-87)
88. Wake, *Kleinwort Benson*, 255; CA PA 2050/10/5, War notes; BNA BT 64/2767, Tungsten Carbide: Summary of Information from 1946 Onwards; CA PA2158/4/1, Wickman War Record; BNA T 161/1123, 25 April 1941, Letter to Lee from HP Trouncer; BNA T 161/1123, 13 July 1943, notes for Mr Blackshaw; cf. the expropriation of German chemical firms to create an American chemical industry in WWI. (Steen, “Confiscated Commerce,” 261-84.) [↑](#footnote-ref-88)
89. BNA BT 64/2767, Tungsten Carbide: Summary of Information from 1946 Onwards [↑](#footnote-ref-89)
90. For a discussion of the debate: Tooze and Ristuccia, “The Cutting Edge of Modernity,” 4. [↑](#footnote-ref-90)
91. Arnold, “Innovation, Deskilling and Profitability”; Aldcroft, “The Performance of the British Machine-Tool Industry”; Sayers, “The Springs of Technical Progress in Britain”. [↑](#footnote-ref-91)
92. S. Pollard, *Britain’s Prime and Britain’s Decline* quoted in Arnold, “Innovation, Deskilling and Profitability”, 51; Edgerton, *Warfare State.* [↑](#footnote-ref-92)
93. Hoyt, *Men of Metals,* 100-2; *Popular Science Monthly,* January 1929; BNA SUPP 3/31, 31 July 1936; KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry]; Avinger, “The Economics of Durability”, 232; United States v. General Electric Co. et al. [↑](#footnote-ref-93)
94. United States v. General Electric Co. et al.; KRUPP WA 146/1, Statement of Dr. Zay Jeffries, Chairman of the Board of the Carboloy Company, Inc. at the Senate Patent Committee Meeting, April 16, 1942; KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry] [↑](#footnote-ref-94)
95. United States v. General Electric Co. et al.; KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry] [↑](#footnote-ref-95)
96. Hoyt, *Men of Metals*, 103; Testimony of Ollier and Fischer, United States v. General Electric Co. et al.; Avinger, “The Economics of Durability,” 244-5; Spuhler et al., *“Arisierungen” in Österreich*, 137-8; KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry] [↑](#footnote-ref-96)
97. Smithells, *Tungsten: A Treatise on Its Metallurgy, Properties and Applications*, 142; Wittmann, *The Development of the Lathe*, 128;*The Engineer*, 10 Feb 1928. [↑](#footnote-ref-97)
98. KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry]; Rolt, *Short History of Machine Tools,* 226 (about Speedia); United States vs. General Electric [↑](#footnote-ref-98)
99. See special defense in General Electric Co. et al. v. Willey’s Carbide Tool Company et al. [↑](#footnote-ref-99)
100. United States v. General Electric Co. et al.; KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry]; Avinger, “The Economics of Durability”, 239 and 245-6; BNA BT 64/2767, Tungsten Carbide: Summary of Information from 1946 Onwards [↑](#footnote-ref-100)
101. KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry]; Testimony of Adam MacKenzie, United States v. General Electric Co. et al. [↑](#footnote-ref-101)
102. Avinger, “The Economics of Durability,” 242-4. [↑](#footnote-ref-102)
103. “History of Kennametal Inc.” [↑](#footnote-ref-103)
104. KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry]; United States v. General Electric Co. et al.; “Company History”; Avinger, “The Economics of Durability,” 244. [↑](#footnote-ref-104)
105. United States v. General Electric Co. et al.; Avinger, “The Economics of Durability,” 244. [↑](#footnote-ref-105)
106. BNA BT 64/2767, Tungsten Carbide: Summary of Information from 1946 Onwards [↑](#footnote-ref-106)
107. General Electric Co. et al. v. Willey’s Carbide Tool Company et al. [↑](#footnote-ref-107)
108. Willey’s testimony, United States v. General Electric Co. et al. [↑](#footnote-ref-108)
109. General Electric Co. et al. v. Willey’s Carbide Tool Company et al. [↑](#footnote-ref-109)
110. United States v. General Electric Co. et al. [↑](#footnote-ref-110)
111. Hoyt, *Men of Metals*, 102. [↑](#footnote-ref-111)
112. On adoption at Ford: KRUPP WA 146/734, 4 November 1935, Ammann, Reisebericht über die Reise vom 19.9 bis 24.10.1935 zur Information über das amerikanische Hartmetallgeschäft [Travel report on the trip from 19 September to 24 October 1935 for information over the American hard metal industry]; KRUPP WA 146/735, 1930, American Society of Mechanical Engineers, “Report of Sub-Committee on Tungsten Carbide Cutting Materials” [↑](#footnote-ref-112)
113. Hoyt, *Men of Metals*, 103; United States v. General Electric Co. et al. [↑](#footnote-ref-113)
114. Avinger, “The Economics of Durability”, 236 and 241-2 esp. fn 38. [↑](#footnote-ref-114)
115. United States v. General Electric Co. et al. [↑](#footnote-ref-115)
116. Kovacic and Shapiro, “Antitrust Policy,” 49-50. [↑](#footnote-ref-116)
117. Mazower, *Hitler’s Empire*, 274; Tooze, *Wages of Destruction*, 116-28 and 234-5. [↑](#footnote-ref-117)
118. Trapp, “The German Hard Metal Industry”, 201. [↑](#footnote-ref-118)
119. Vaupel, “Schrittweise Anpassung an den Zeitgeist,” 535-82. [↑](#footnote-ref-119)
120. Agte, et al., *Technisch-wissenschaftliche Abhandlungen*. [↑](#footnote-ref-120)
121. KRUPP WA 146/732, 9 June 1937, Ammann, Antrag auf Bewilligung von M. 500,000 für Verlegung des Werkzeugbetriebs der Hartmetallbetriebe [Application for approval of M. 500,000 for the expansion of the facilities of the hard metal factory] [↑](#footnote-ref-121)
122. Agte et al., *Technisch-wissenschaftliche Abhandlungen*, Introduction. [↑](#footnote-ref-122)
123. Trapp, “The German Hard Metal Industry”, 201; Agte, et al., *Technisch-wissenschaftliche Abhandlungen*. [↑](#footnote-ref-123)
124. KRUPP WA 146/732, 9 June 1937, Ammann, Antrag auf Bewilligung von M. 500,000 für Verlegung des Werkzeugbetriebs der Hartmetallbetriebe [Application for approval of M. 500,000 for the expansion of the facilities of the hard metal factory] [↑](#footnote-ref-124)
125. KRUPP WA 146/732, 9 June 1937, Ammann, Antrag auf Bewilligung von M. 500,000 für Verlegung des Werkzeugbetriebs der Hartmetallbetriebe [Application for approval of M. 500,000 for the expansion of the facilities of the hard metal factory] [↑](#footnote-ref-125)
126. Sudrow, *Der Schuh im Nationalsozialismus,* 760-4. [↑](#footnote-ref-126)
127. BNA FO 943/221, 20 May 1947; KRUPP WA 146/665, *25 Jahre Widia-Hartmetall* [↑](#footnote-ref-127)
128. BNA SUPP 3/41, 6 July 1931, Minutes of Board of Trade Supply Organisation; BNA SUPP 3/41, 26.5.31, Letter from R. Fennelly to Major N.G.) [↑](#footnote-ref-128)
129. BNA SUPP 3/41, Fourth Annual Report of the Supply Board, P.S.O. 303 (B.T. 135); BNA SUPP 3/41, 6 July 1931, Minutes of Board of Trade Supply Organisation; BNA SUPP 3/41, 26.5.31, Letter from R. Fennelly to Major N.G. Hind; BNA SUPP 3/41, 26 February 1931, Letter from G.S. Whitham to Major N.G. Hind; BNA SUPP 3/41, P.S.O.(B.T.)150, Widia and Similar Cutting Tool Alloys; A similar government concern about German influence over Britain’s non-ferrous metal supply had resulted in the establishment of the British Metal Corporation in 1918. (Ball, “The German Octopus.”) The empire was a crucial source of material strength for Britain’s war effort. (David Edgerton, *Britain’s War Machine*.) [↑](#footnote-ref-129)
130. BNA SUPP 3/9, 5 October 1938, Minutes [↑](#footnote-ref-130)
131. BNA BT 11/2299, 28 June 1944, Telegram No 269 Askew, Board of Trade to Washington [↑](#footnote-ref-131)
132. BNA AVIA 46/196; BNA AVIA 12/73, 1943, Report by the Joint Metallurgical Committee; BNA AVIA 22/2628, 25.3.41, Small Tools Advisory Panel Minutes; “1939: Metallurgy.” [↑](#footnote-ref-132)
133. United States v. General Electric Co. et al.; KRUPP 146/1, 15.4.42, “Statement Issued by Dr. Zay Jeffries, Chairman of the Board, Carboloy Company, Inc., and W.G. Robbins, President, at Washington D.C.” [↑](#footnote-ref-133)
134. Testimony of Lewis Gerald Firth, United States v. General Electric Co. et al. [↑](#footnote-ref-134)
135. Wickman, *Wimet Standard Tools Manual*, 4. [↑](#footnote-ref-135)
136. CA PA 2050/3/20, April 1949, “Grinding and Lapping Carbide Tools”, reprint from *Machinery* [↑](#footnote-ref-136)
137. Feinstein, Temin and Toniolo, *The World Economy Between the World Wars*, 72. [↑](#footnote-ref-137)