Catching-up and Falling Behind. Knowledge Spillover from American to German Machine Tool Makers[♣]

Ralf Richter, Hans Böckler Foundation
Jochen Streb, University of Hohenheim

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Abstract

In our days, German machine tool makers accuse their Chinese competitors of violating patent rights and illegally imitating German technology. A century ago, however, German machine tool makers used exactly the same methods to imitate American technology. To understand the dynamics of this catching-up process we use patent statistics to analyze firms' activities between 1877 and 1932. We show that German machine tool makers successfully deployed imitating and counterfeiting activities in the late 19th century and the 1920s to catch-up to their American competitors. The German administration supported this strategy by stipulating a patent law that discriminated against foreign patent holders and by delaying the granting of patents to foreign applicants. Parallel to the growing international competitiveness of German firms, however, the willingness to guarantee intellectual property rights of foreigners was also increasing because German firms had now to fear retaliatory measures in their own export markets when violating foreign property rights within Germany.

Corresponding author:

Prof. Dr. Jochen Streb
University of Hohenheim (570a)
70593 Stuttgart
Germany
Email: j-streb@uni-hohenheim.de

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1 Introduction

In March 2008, the Association of German Machine Builders (*Verband Deutscher Maschinen- und Anlagenbauer*) complained of the notorious Chinese product piracy: *"More than half of the German machine builders discover illegal replicas at exhibitions. Three quarters of these replicas come from China. Unfortunately, China's entry into the WTO in 2001 has not improved the legal protection of intellectual property rights of foreign firms.*[1] *The resulting loss of German mechanical engineering is about seven billions Euros per year* (or about 4 percent of total sales)."[2] The Association of German Machine Builders did not mention that, a century ago, many of its then already existing member firms used the same counterfeiting strategies to catch up to their British and American competitors. Already in 1897, the periodical American Machinist observed: "*In going through the shops of a prominent German machine-tool builder who has been in the United States and got a good many ideas there from, as well bought a good line of the best standard machines from which to copy or vary, in the production of its own line, I notice that every solitary American machine, whether from Providence, New Haven, or Cincinnati, had had the name chipped off and the place painted over.*"[3] Thirty years later, in 1927, the French periodical La Machine Moderne reported: "*Information coming from Germany indicates that a number of American machine-tools are now being copied by German constructors, some of which are made without the slightest alteration. Most of these machines are actually sold as originals, the name of the American constructor of the original machine being mentioned in the advertising notices, and often even appearing stamped on the machine, with the indication 'type' or 'model". We can cite a case where a German firm copied a machine designed and constructed by a well-known American manufacturer, and sold in the United States.*"[4]

We claim in this article that imitating and even counterfeiting advanced foreign technology and products are typical strategies of firms located in an economically backward country. These activities are formally legal when the imitating firms use their new knowledge only in those markets where the intellectual property rights of the original inventor are not protected – like in Germany before 1877. These activities are clearly illegal when the imitating firms sell

[1] „Argumentationshilfe aus dem VDMA zum Stichwort Produktpiraterie", March 2008.
[2] Press release „Produkt- und Markenpiraterie in der Investitionsgüterindustrie 2008" of the VDMA, April 2008.
[3] German Machine Copying, American Machinist, February 1897, p. 116. According to Kiesewetter, the lawyers of McCormick, an American manufacturer of agricultural machinery, accused the German imitators of being the most infamous pirates in 19th century-Europe. See Kiesewetter, H. (1992). Beasts or Beagles? Amerikanische Unternehmen in Deutschland. In Pohl, H. (ed.). *Der Einfluß ausländischer Unternehmen auf die deutsche Wirtschaft vom Spätmittelalter bis zur Gegenwart*. Stuttgart: Franz Steiner, p. 170.
[4] Cited after W.H. Rastall, 2. May 1927, NARA, RG 151, 413 (Box 1806).

their replicas in markets where the intellectual property rights of the original inventor are established – like in the case reported by the French periodical La Machine Moderne. The government of a backward country might tolerate or even foster this illegal behavior of the firms in its jurisdiction because imitating foreign know-how is one of the most promising ways to catch up to the economically and therefore politically leading nations. However, this kind of illegal imitation usually only takes place during a transitional period. On the longer run, both the firms and the government of the economically advancing country face strong incentives to change their behavior from violating to respecting international intellectual property rights.

To elaborate this argument, we sub-divide the catching-up process into the two periods imitation and innovation. During the imitation period, firms of the economically backward country use various imitation channels like reverse engineering, visiting international exhibitions and foreign firms, analyzing patent specifications, or hiring foreign craftsmen and engineers to learn from their superior foreign competitors. This new knowledge can be profitably used in their home market because the government of the imitating firms does not enforce the intellectual property rights of the foreign firms in its jurisdiction.[5] In the following period of innovation, the imitating firms adjust the imitated technologies and products to their own technological capabilities and the demand of their home market. During this process of adaptation imitation is abating because the formerly imitating firms gain step by step the competence to develop their own successful innovations. That is why these firms might now lobby for a functioning domestic patent law which does not discriminate against foreign firms to make sure that, in return, their own intellectual property rights will be guaranteed abroad.

Note that the imitation and innovation phases often overlap. Especially during the innovation phase, first, the (illegal) imitation of foreign technology might become less common but does not totally stop, and, second, increasing imitation activities between domestic firms might increase the diffusion of knowledge within the backward country. Because of the latter, the competence to develop innovations spill-over to more and more domestic firms which increases both price and Schumpeterian competition between the growing number of efficient and innovative firms considerably. Sometimes, the firms of the former backward country

[5] To avoid misunderstandings, we want to stress that technological transfer is seldom a one-way-street. During the catching-up process firms in the technologically leading country might also learn from the activities of their foreign imitators. For this "reverse flow" see Jeremy, D. J. (ed.). *International Technology Transfer. Europe, Japan and the USA, 1700-1914*, Aldershot: Edward Elgar.

might even take over the global technological leadership and thereby – like the German machine tool makers – change from ruthless imitators to campaigners for the worldwide enforcement of intellectual property rights.

Catching-up, however, is obviously not possible for every country. One of the necessary preconditions for both successful imitations and innovations is the availability of a sufficient stock and structure of human capital. Aghion supposes that during the imitation phase firms rely primarily on workers with secondary education while for innovation workers with tertiary education are needed.[6] Besides human capital formation, other factors like secure property rights, an incorruptible administration, openness to competition, or financial institutions capable of mobilizing capital for individual firms seem to be also needed for catching-up successfully.[7] Germany went through these institutional reforms in the second half of the 19th century and thereby supplied the domestic firms with the capabilities and resources necessary for imitating and innovating.[8]

Japanese firms of various sectors went successfully through this whole catching-up process in the second half of the twentieth century; the Chinese case mentioned above is obviously a contemporary example for the beginning of this transition period from backwardness to international competitiveness. We will concentrate on the development of the German machine tool industry between 1877 and 1932 which can be understood as a prime model for explaining later catching-up processes. In section 2, we present a case study to demonstrate how this catching-up process worked on the level of an individual firm. Methodologically, however, we rely primarily on data about the patent activities of German and American machine tool makers to analyze the chronological sequence of the catching-up process, the German patent practice discriminating against foreign applicants, and the counteractive measures of the American firms. That is why, in section 3, we discuss the advantages and shortcomings of the patent data that we use to generalize the insights of the case study. In

[6] See Aghion, P. (2008). Higher Education and Innovation. *Perspektiven der Wirtschaftspolitik* 9 (Special edition), pp. 28-45.
[7] See Abramovitz, M. (1986). Catching-up, Forging Ahead, and Falling Behind. *Journal of Economic History* 46, pp. 385-406; Buchheim, C. (2006). What Causes Late Development? Insights from History. *South African Journal of Economic History* 21, pp. 52-83.
[8] For a survey of the institutional reforms in 19th century-Germany see, for example, Ogilvie, S. and Overy, R. (eds.) (2003). *Germany: A New Social and Economic History Volume 3. Since 1800*. Oxford: University Press. See also Grupp, H., Dominguez-Lacasa, I. and Friedrich-Nishio, M. (2002). *Das deutsche Innovationssystem seit der Reichsgründung*. Heidelberg: Physica Verlag. For the successful coevolution of institutions and innovative firms in the German chemical industry see Murmann, J. P. (2003). *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions.* Cambridge: University Press.

section 4, we will describe German machine tool makers' catching-up process and the reaction of their American counterparts in detail. Section 5 will conclude.

2 The case study

To exemplify both the chronological sequence and the imitation channels of the knowledge transfer from American to German machine tool makers we will now have a closer look at the development of the firm *J .E. Reinecker* that was founded 1859 in Chemnitz. This firm concentrated originally on the production of machine parts. Its actual imitation phase began in 1873 when the firm's founder bought at the World's Fair in Vienna a grinding machine produced by the *Brown & Sharpe Mfg. Company*. Inspired by the superior technology, *J. E. Reinecker* used this American product as a model to start up its own machine tool production in Germany.[9] Interestingly enough, this type of imitation strategy had been correctly predicted by an American correspondent at the World's Fair in Vienna who had reported: "*A considerable number of American tools were sold to continental makers, and are probably to be copied at once for the European markets.*"[10] *J. E. Reinecker*, however, learned from this experience to use imported American machine tools as a permanent imitation channel in the following decades. Until 1915, the firm has bought more than 100 machine tools from 21 different American manufacturers. As a general rule, *J. E. Reinecker* acquired only one, rarely two machine tools of the same type.[11] After an American machine tool had arrived in Chemnitz, the process of reverse engineering began. First, the machine tool was completely disassembled, and then, every component was analyzed and recorded with the help of engineering drawings. Based on this information *J. E. Reinecker* became capable to manufacture and sell its own replicas of the American machine tools.

Though, the German firm did not only rely on trade fairs and world exhibitions as a source for innovative knowledge.[12] International trade journals and American patent specifications were also used to learn more about foreign innovations.[13] During the intensification of the imitation process the acquirement of personal, often tacit knowledge became more and more important.

[9] See *J. E. Reinecker 1859-1909*, Chemnitz 1909, p. 10 f.
[10] Thurston, Robert H., Vienna International Exhibition, 1873. Reports on Machinery and Manufacturers with an Account of European Manufacturing Districts, Washington (GPO) 1875, p. 202.
[11] See StA Chemnitz, 31007/131: Schätzungsprotokolle über Betriebsgegenstände, 1915.
[12] See Moser, P. (2005). How do Patent Laws influence Innovation? Evidence from Nineteenth-Century World's Fairs. *American Economic Review* 95, p. I214-I236.
[13] Already in 1897, another German firm, the machine tool maker Schubert & Salzer, employed a translator to scrutinize the sixty international trade journals the firm had subscribed to.See Miller, F. J. (1897). *American and Other Machinery Abroad. Being a Study of the European Field for the Introduction of American Machinery*. New York: Press of the American Machinist, p. 72.

That is why, in 1882, the founder's son traveled to the United States to inspect American plants and to assume temporary employment there. In the publication commemorating the 50th anniversary of *J.E. Reinecker* it is explicitly stressed that the firm owed much of its technological progress to the wide experience the founder's son gained during his one-year stay abroad.[14] In addition, *J. E. Reinecker* hired in 1897 an American expert for machine tool technology who had once presented the innovations of an American firm from Philadelphia at the Chicago world exhibition in 1893.[15] An imitation channel with growing importance was the information about innovative machine tools international resellers distributed among the different firms they represented.[16] The world's largest reseller of machine tools, *Schuchardt & Söhne* in Berlin, for example, informed *J. E. Reinecker* regularly about the latest technological development in the United States.[17]

Due to these continuous and multifaceted transatlantic knowledge transfer and the subsequent learning-by-imitating *J. E. Reinecker* changed fast from a pure imitator of American technology to an independent innovator. Until 1900, this firm had already applied for 37 patents in Germany and five patents in the United States. The number of its work force grew from 90 in 1886 to 2,471 in 1913, its sales volume increased in the same period from 211,377 Mark to 7,038,671 Mark.[18] Even the American trade press acknowledged the outstanding innovativeness of this German firm. Fred Miller, editor of the American Machinist, described the positive impression he had gained during a visit at the *J. E. Reinecker*'s production facility: *[…] they are building machine tools which, though they are modelled in the style of our best work, are yet for the most part as fully original with their builders as tools generally are, or, in fact, can be. There is in the products of this shop much more original work than is to be found in the work of a large proportion of our own shops, and I am convinced that the net result of the fact that such a concern as this chooses to adopt the underlying principles of*

[14] See *J. E. Reinecker Chemnitz 1859-1909*, Leipzig: Meisenbach Riffarth, 1909, p. 15.
[15] See Miller, F. J. (1897). *American and Other Machinery Abroad. Being a Study of the European Field for the Introduction of American Machinery*. New York: Press of the American Machinist, p.76.
[16] In contrast to other industries in which sales agencies acted as "information brokers", machine tool dealers did not charge their clients for new information about the innovations of their competitors. Instead, they used this kind of knowledge transfer as a mean to improve the competitiveness of their clients' products. For the role of international resellers as „information brokers" see Streb, J. (2001). Möglichkeiten und Grenzen der Schumpeterschen Diversifizierung. Die Entwicklung der Firma Freudenberg & Co. Weinheim vom spezialisierten Ledererzeuger zum Kunststoffverarbeiter mit breiter Angebotspalette. *Zeitschrift für Unternehmensgeschichte* 46, pp. 131-159, especially pp. 139-143.
[17] See *J. E. Reinecker 1859-1909*, Chemnitz 1909, pp. 10-15; Miller, F. J. (1897). *American and Other Machinery Abroad. Being a Study of the European Field for the Introduction of American Machinery*. New York: Press of the American Machinist, p.76.
[18] See Hitzbleck, Hans (1927). *J. E. Reinecker Aktiengesellschaft*. Dresden, p. 145.

our American tool designs and to follow them rather than British ideas is a distinct gain for the American tool builder, even in German trade itself.[19]

During the First World War, however, *J. E. Reinecker* lost most of its former innovativeness because of several reasons. First, the Allied trade embargo of Germany isolated the firm from both international competition and new information about the international development of machine tool technology. Second, *J. E. Reinecker* had now neither the incentives nor the resources to invest in new R&D projects because of the one-sided engagement in armament production. The German army ordered the German machine tool makers to stop their production of high-quality machine tools and to manufacture instead high numbers of low-quality machine tools needed to produce ammunition and weapons.[20] Third, the firm's stock of human capital decreased because many experienced machine tool makers were drafted and replaced by unskilled workers. Fourth and consequently, *J. E. Reinecker* decided to use those unskilled workers and therefore most of its production capacity to manufacture ammunition instead of complex machinery because the latter was difficult to produce without an experienced work force. Summing up, the First World War disrupted *J. E. Reinecker*'s innovative momentum of the pre-war years and let the firm fall back again far behind its American competitors in technological terms.[21] That is why *J.E. Reinecker* went back to its well-known imitation strategies after the First World War had ended.

Trying to identify those German product pirates who could be taken to the German patent court, in 1926, the Department of Commerce in Washington and the American Embassy in Berlin became especially aware of the aggressive imitation strategies of the former innovator *J. E. Reinecker*. For example, this firm offered an illegal replica of the "three spindle gear rougher" for only two-thirds of the price demanded by the original American innovator *Gould & Eberhardt*. In another case, *J. E. Reinecker* undersold its American competitor even more. Until 1925, the American firm *Lees-Bradner Company* had sold 75 units of its "spur gear grinders" in Germany for 2,200 Reichsmark per unit. In 1925, however, *J. E. Reinecker* offered its own replica of this innovative machine tool at a price of only 1,200 Reichsmark. Consequently, the Lees-Bradner Company lost not only the German but also the British and

[19] Miller, Fred J. A Notable German Tool Shop. *American Machinist* 44, 3. November 1898, p. 818.
[20] See Bundesarchiv Berlin-Lichterfelde R 8099/259: Stenographischer Bericht über die Besprechung in den Geschäftsräumen des Vereins Deutscher Werkzeugmaschinenfabriken, 5. September 1916, pp. 26-32.
[21] The technological development of the American machine tool industry was not negatively affected by the First World War. Quite the contrary, the steady demand of both the automobile industry and the armament industry for more and more efficient machine tools fostered American machine tools innovations also during war times. See CHSL Milacron, Series Frederick V. Geier, Box 53: "Amortization of Machine Tools", May 1930.

French market.[22] *J. E. Reinecker* was not able to resume its former innovativeness before the late 1920s. Not until 1932, the German firm applied for its first post-war patent in the United States.[23]

The business history of *J. E. Reinecker* suggests that the catching-up process of German machine tool makers occurred in two consecutive steps. The pre-First World War catching-up process is characterized by an imitation phase until the 1890s and an innovation phase until the outbreak of the war. After the technological set back of the First World War, the post-First World War catching-up process started. Machine tool makers such as *J. E. Reinecker* had to rely again on imitation strategies in the 1920s but finally regained their own innovativeness in the early 1930s. This second catching-up process was faster than the first one because the technological gap was smaller and the experiences with various imitation channels were higher in the 1920s than in the mid of the 19th century. In the following sections, we will use patent data to find out if this chronological sequence of the repeated catching-up process really holds for the German machine tool industry as a whole.

3 The patent data

Our analysis of the patenting activities of the American and German machine tool industries is based on different samples of individual machine tool patents, with each single record including information about the year when the patent was granted (or applied for), as well as the name and location of the firm holding the respective patent. To identify the machine tool patents in the total patent population we use the fact that the German patent office, starting with the introduction of the German patent law in 1877,[24] assigned every patent to a particular technological class. Patents covering the technology of the machine tool industry can be found in the patent classes 47 (machine parts), 49 (mechanical metal working), and 67 (grinding and polishing).[25] As these patent classes also contain innovations that do not belong to the machine tool technology we identified the relevant patents with the help of the description of the innovation. Every patent that dealt with machining or chipping metal was selected.

[22] See NARA, RG 151, 420 (Box 1950): D.P. Miller to the Director Bureau of Foreign and Domestic Commerce, November 8, 1926.
[23] See USPTO, patent no. 1,885,628, Arbor support for gear cutting machines.
[24] See Seckelmann, M. (2006). *Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871-1914*. Frankfurt/Main: Vittorio Klostermann, pp. 86-106.
[25] "Machinery patents" can also be found in less obvious classes like 45 (agriculture → agricultural machinery) or 86 (weaving → textile machines) to name just a few. Innovative machine tools, however, were assigned to the three classes 47, 49, and 67.

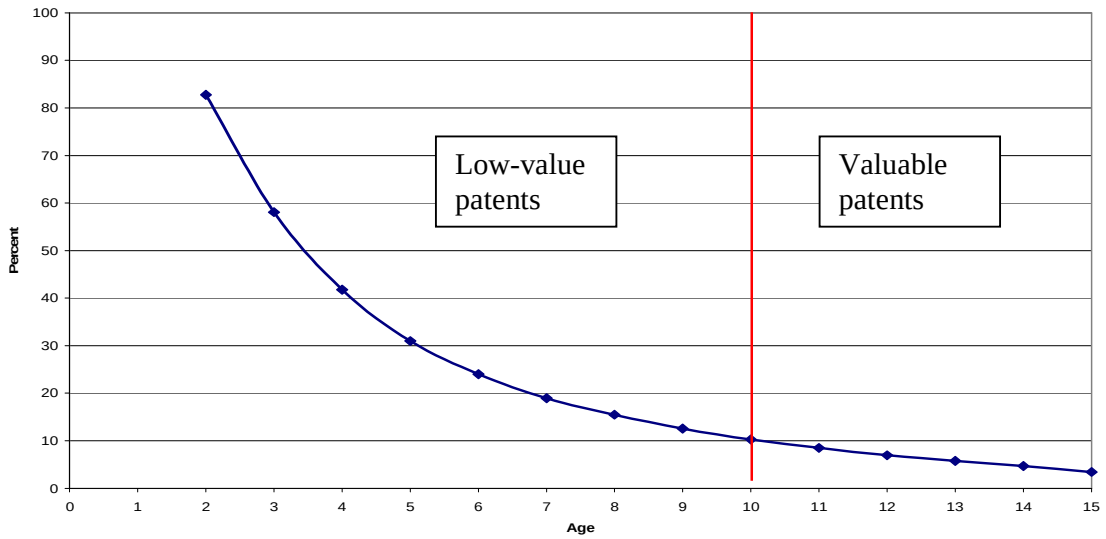
Much is said about the shortcomings of patents as a measure for innovation activities. Griliches has stated: "*Not all inventions are patentable, not all inventions are patents and the inventions that are patented differ greatly in 'quality', in the magnitude of inventive output associated with them.*"[26] The first part of this statement refers to the well-known fact that the propensity to patent varies across industries. Some industries, like the chemical or pharmaceutical industries, try to appropriate the returns of their inventions primarily by patenting, while others prefer keeping their inventions secret instead. It is sometimes claimed that the machine building industry belongs to the later group but we will see in the following that, at least in our period of observation, German and American machine tool makers not only relied on secrecy but also held a considerable amount of patents. This result is in line with Moser's finding who shows on basis of patented and non-patented innovations presented at different World's Fairs that, in the 19th century, U.S. inventors were most likely to patent innovations in machinery.[27] The problem that is addressed in the second part of Griliches' statement is probably the more serious one. Pure patent counts allocate the same weight to every patent, no matter whether it has a high or a low economic value for the patentee. Using the number of patents as an indicator for successful innovation activities therefore leads to a potentially large measurement error. We address this problem by analyzing three different types of patent statistics.

Patents applied for are a measure for inventions which were appraised to be new and potentially profitable by the applying firms. *Patents granted*, in contrast, are a measure for inventions which were judged to be new by the patent office. *Long-lived patents* are an indicator for innovations which became in fact profitable. This later group was identified by Streb et al. using a special feature of the German patent law.[28] According to this law, patent protection could last up to fifteen years but was not for free. Rather, the patentee had to pay at the beginning of each year an increasing renewal fee in order to keep his patent in force. This annual renewal fee came to 50 Marks in the first two years, and grew then by 50 Marks each year up to 700 Marks at the beginning of the fifteenth year. Consequently, a patent holder had to decide annually if he was going to renew his patent for another year or not. The outcome of

[26] Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature* 33, p. 1669.
[27] See Moser, Petra (2010). Do Patents Weaken the Localization of Innovations? Evidence from World's Fairs. Unpublished paper.
[28] See Streb, J., Baten, J. and Yin, S. (2006). Technological and geographical knowledge spillover in the German Empire 1877-1918. *Economic History Review* 59, pp. 347-373.

this decision depended on the patentee's expectations about the future returns and costs of holding the patent. The later were determined by the renewal fees and were therefore foreseeable with certainty. In contrast, the future returns, which could result either from selling the innovation as a temporary monopolist or by licensing another producer to do so, were highly uncertain. Streb et al. assumed that the majority of patent holders renewed their patents only if the present value of the expected future returns exceeded the present value of the future costs. Under this assumption, a long life span of a historical patent undoubtedly indicates its comparatively high private economic value.

Figure 1 The survival rate of German patents[a]



a This calculation is based on information on the patent cohorts 1891-1907. See *Blatt für Patent-, Muster- und Zeichenwesen* (1914), p. 84.

A basic question of this life span approach is how many years a patent had to be in force to be interpreted as a valuable patent. Figure 1 shows for the sample of all German patents granted between 1891 and 1907 that about seventy percent of all patents were already cancelled after just five years. After the fifth year the speed of patent cancellation was decelerating. About 10 percent of all patents were still in force after 10 years, 4.7 percent of all patents reached the maximum age of fifteen years.

As Figure 1 also illustrates, Streb et al. decided to use the cut-off point of 10 years to distinguish valuable patents from low-value patents.[29] The choice of this cut-off point was not

[29] The identification of an individual patent's life span is generally possible because the German patent office published every year the patent numbers of those patents still in force. Since one would have to search for the

arbitrary. Pakes observes that the low renewal fees at the beginning of a patent's life allow the inventor to use the patent as a comparatively cheap option that protects the new knowledge and gives him or her the time to learn more about the technological and economic prospects of the invention.[30] In the view of this fact it would be conceivable to interpret those patents that survived this learning process and lived therefore at least about 5 years as the valuable patents of the patent population. Sullivan, however, came to the result that most of the value of the patent stock built up in the second half of the nineteenth century in Britain and Ireland was concentrated in the upper ten percent of the long-lived patents. Following this hint Streb et al interpret the upper 10 percent of the long-lived patents as the valuable patents of the German patent population and therefore selected all patents that survived at least ten years.[31] This selection process resulted in a data base containing 39,343 valuable patents of the German Empire (1877-1918) and 27,340 valuable patents of the Weimar Republic (1919-1932)[32] – among those all long-lived machine tool patents which were granted to German and foreign machine tool makers.

The relative usefulness of these three patent data sets depends on the particular scientific objective. If a scholar is primarily interested in the firms' invention activities he or she should concentrate on the patents applied for. In cases in which the efficiency of the patent office's screening process is under consideration, a comparison of the patents applied for and the patents granted seems to be advisable. If the main objective is to identify those inventions which became successful innovations it is useful to look first and foremost at the valuable patents. It is important to note that these three types of patents not necessarily display a parallel development over time. Figure 2 shows, for example, that the machine tool makers of

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respective patent number in up to fifteen annual lists, the process of making out the individual life span of one single patent needs at least about 15 minutes. That is why, given the budget constraint of their project, Streb et al. were not able to figure out the exact life span of each of the 800,000 German patents between 1877 and 1932. Choosing instead to use the cut-off point of 10 years, they had to search only for those individual patents that survived at least 10 years.

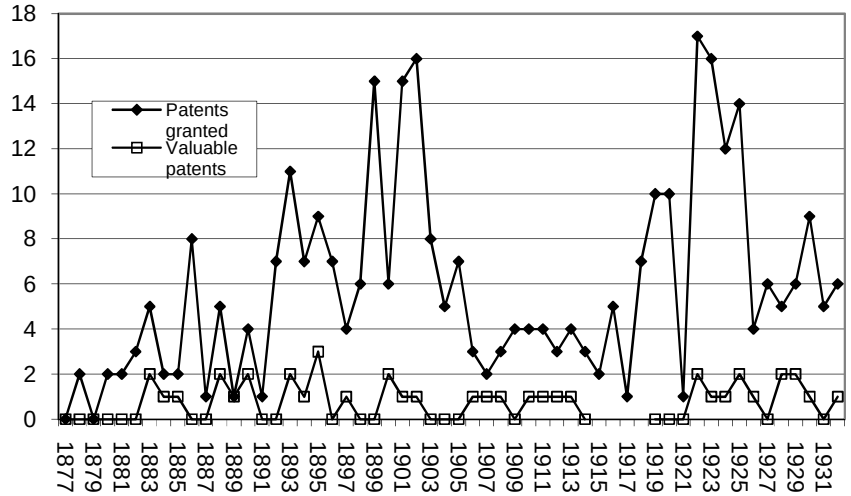
[30] See Pakes, A. (1986). Patents as options: some estimates of the value of holding European patent stocks. *Econometrica*, 54, pp. 755-784.

[31] See Sullivan, R. J. (1994). Estimates of the value of patent rights in Great Britain and Ireland, 1852-1976. *Economica*, 61, pp. 37-58. See also Schankerman, M. and Pakes A. (1986). Estimates of the value of patent rights in European countries during the post-1950 period. *The Economic Journal*, 96, pp. 1052-1076.

[32] For other empirical studies using this patent data set see Baten, J., Spadavecchia, A., Streb, J. and Yin, S. (2007). What made southwest German firms innovative around 1900? Assessing the importance of intra- and inter-industry externalities. *Oxford Economic Papers* 59, pp. i105-i126; Degner, H. (2009). Schumpeterian German firms before and after World War I. The innovative few and the non-innovative many. *Zeitschrift für Unternehmensgeschichte* 54, pp. 50-72; Labuske, K. and Streb, J. (2008). Technological creativity and cheap labour? Explaining the growing international competitiveness of German mechanical engineering before World War I. *German Economic Review*, 9, pp. 65-86; Streb, J., Wallusch, J. & Yin, S. (2007). Knowledge spill-over from new to old industries: The case of German synthetic dyes and textiles 1878-1913. *Explorations in Economic History*, 44, pp. 203-223.

the industrial district Chemnitz had a rather constant annual number of valuable patents while their number of patents granted was especially high in the 1890s and the 1920s. It would therefore be wrong to infer from the rising number of patents granted a similar boom of valuable patents and therefore of innovativeness.[33]

Figure 2 Patents granted and valuable patents of the machine tool makers in Chemnitz[a]



a Source: Baten/Streb patent data base and Richter's patent data.

In this paper, we match the Baten/Streb patent data base (about 66.700 valuable patents for the period 1877-1932) with Richter's patent data about the patenting activities of American and German machine tool makers for four different groups of patent holders which vary in the depth of patent information available:

- 479 German firms which were member of the association of German machine tool makers or were identified as machine tool makers in trade journals. Available are their 425 valuable patents in the German jurisdiction.
- The subgroup of all German machine tool makers of the industrial district of Chemnitz, the birthplace of the German machine tool industry. In addition to their 40 valuable patents, their 388 patents granted including the application date in the German jurisdiction are known.
- 408 American firms which were member of the Association for Manufacturing Technology or its predecessor the National Machine Tool Builders Association or

[33] The region Chemnitz did not participate in the increase in valuable patents of the German machine tool industry in the late 1920s depicted in figure 3 because of decreasing relative innovativeness. See Figure 10.

were identified as machine tool makers in trade journals. Available are their 874 patents granted including the application date and their 62 valuable patents in the German jurisdiction.

- The subgroup of all American machine tool makers of the industrial district of Cincinnati which was along with New England and Philadelphia one of the most important focal points of the American machine tool industry. In addition to their 48 patents granted including the application date and their two valuable patents in the German jurisdiction, their 874 patents granted including their application date in the American jurisdiction are known.

We will use these four patent data sets to analyze the details of German machine tool makers' catching-up process in the following section.

4 The catching-up of the German machine tool makers

Assuming that the number of patents is positively related to firms' innovativeness, Figure 3 shows that, measured by the average annual number of valuable patents of the 479 German machine tool makers, the chronological distribution of patent activities matches our qualitative and anecdotic evidence of the timing of the repeated catching-up process:

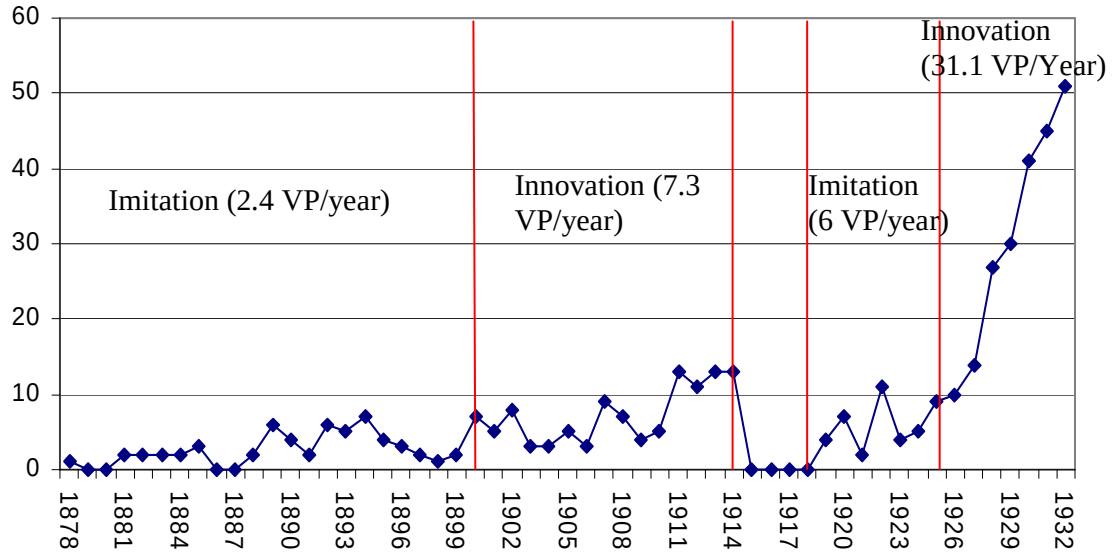
- the first imitation period ((Paris world exhibition 1867)/Introduction of the German patent law 1877 to 1899)[34] with 2.4 valuable patents per year,
- the first innovation period (1900 to the outbreak of the First World War) with 7.3 valuable patents per year,
- the technological setback during the First World War,
- the second imitation period (1919 to 1925) with 6 valuable patents per year, and
- the second innovation period (1926 to 1932, which is the last year covered by our data) with 31.1 valuable patents per year.

The fact that, during the first imitation period, German machine tool makers acquired only a few patents that turned out to be worth to be prolonged for at least ten years suggests that, in the late 19th century, the German firms neglected own R&D projects but relied primarily on

[34] Our qualitative evidence suggests that the first imitation period already started in the late 1860. Since the German patent law was not introduced until 1877, we are not able to analyze the first decade of this imitation period with the help of patent data. Interestingly enough, however, it was apparently the growing imitating activities of German firms in the early 1870s which considerably increased the international political pressure on Germany to introduce a patent law. See Seckelmann, M. (2006). *Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871-1914*. Frankfurt/Main: Vittorio Klostermann, p. 156.

imitating foreign products. Obviously, however, learning-by-imitating created on the longer run the competences that were needed to develop successful innovations on one's own account. As a result, the average number of valuable patents per year of the German machine tool industry tripled in the first innovation period in comparison to the preceding first imitation period.

Figure 3 Valuable patents (VP) of German machine tool makers[a]



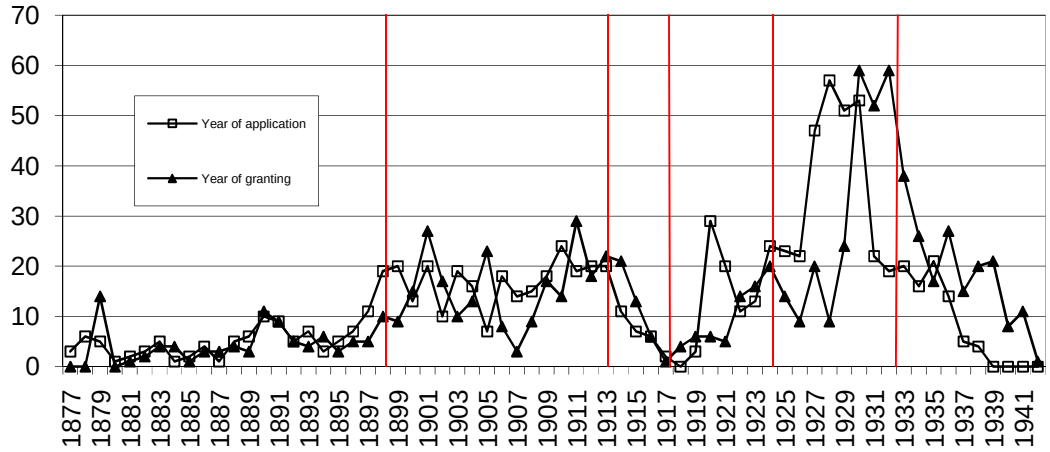
a Source: Baten/Streb patent data base and Richter's patent data.

The absence of valuable German machine tool patents between 1915 and 1918 in Figure 3 does not indicate the total breakdown of innovativeness in this sector but is due to the fact that the German patent office did not publish the name of any patent holder during the First World War. Our case study of the machine tool maker *J. E. Reinecker* suggests, however, that the German machine tool makers in fact fell back into technological backwardness again in this period. Consequently, after the war had ended, the German machine tool makers went back to their well-known imitation strategies which they had already brought to perfection in the 19th century. Any scruples which the German firms might have had regarding the violation of intellectual property rights, had diminished after the confiscation of their U.S. patents by the Office of Alien Property during the war. The American commercial attaché in Berlin summed up in 1926: "*The practice of copying American machinery has therefore extended much more widely since the war than it was even before.*"[35] Due to both their unscrupulousness and their

[35] NARA, RG 151, 420 (Box 1950): D.P. Miller to Director Bureau of Foreign and Domestic Commerce, 8. November 1928.

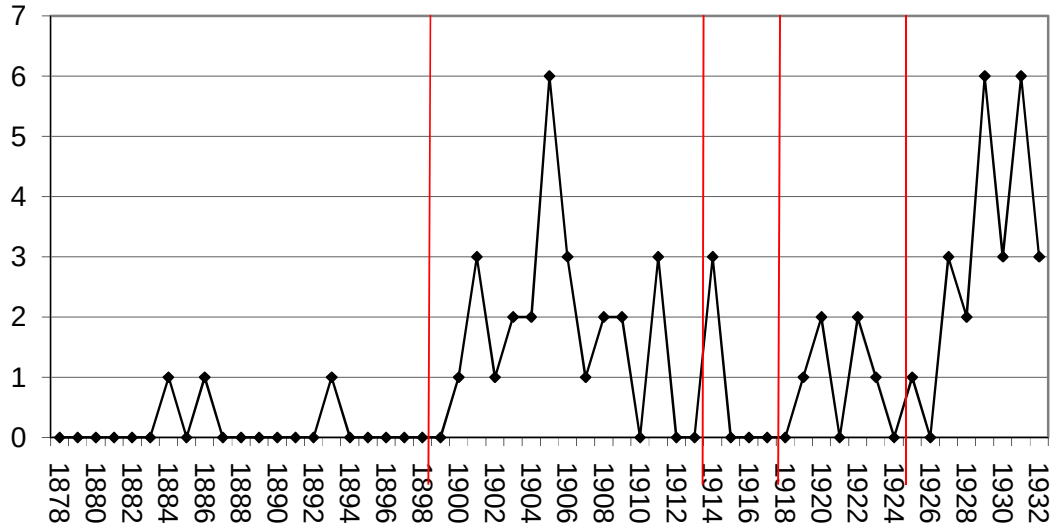
wide experience with imitation strategies the German machine tool makers were now able to catch-up again in just a half decade. In 1926, the German machine tool industry started to pass through its second innovation period with an unprecedented average number of 31.1 valuable patents per year.

Figure 4 Patents granted (with application date) of American machine tool makers in Germany[a]



a Source: Richter's patent data.

Figure 5 Valuable patents of American machine tool makers in Germany[a]

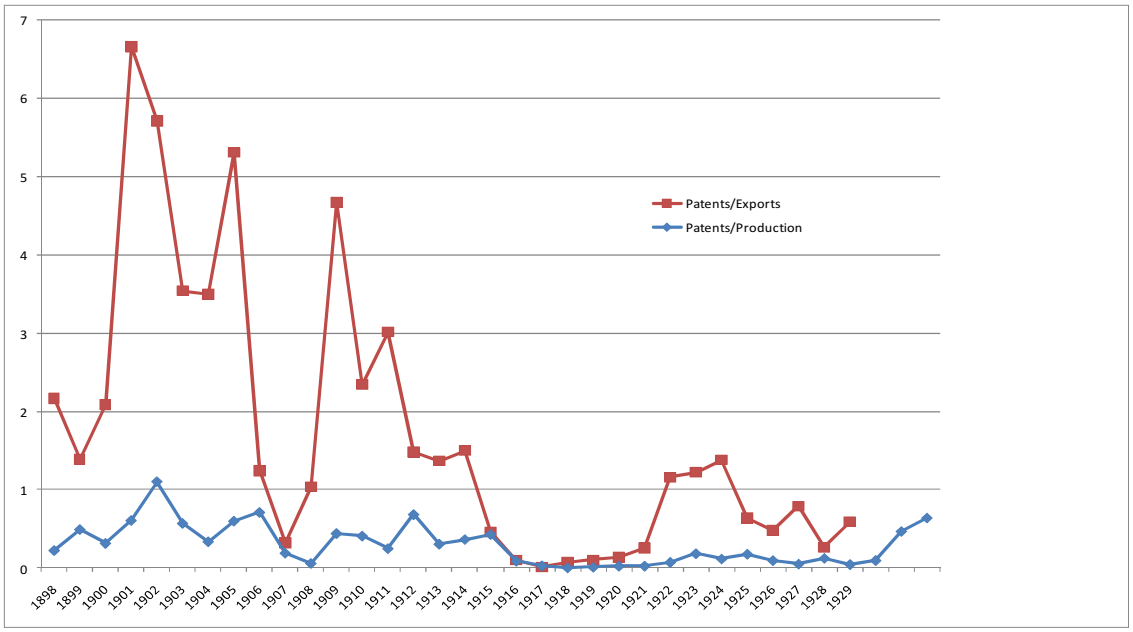


a Source: Baten/Streb patent data base and Richter's patent data.

How did the American machine tool makers react against the imitating strategy of German firms in the late 19th and early 20th centuries? We already know about the various complaints

about the German imitating activities both during the first and the second imitation period. It is reasonable to assume that the American innovators did not only fight with words but tried to protect their intellectual property rights by applying for patent protection at the German market. We would therefore expect that American patenting activities in Germany were especially high during the two imitation periods.[36] Figures 4 and 5 prove that this expectation is wrong. American firms had a comparatively high number of both German patents granted and valuable German patents not during the two imitation periods but during the two innovation periods.[37] How can this discrepancy between our theoretical expectation and the empirical observation be explained?

Figure 6 Valuable patents of American machine tool makers in Germany per million US-Dollar production and per million US-Dollar export[a]



a Source: Robertson (1966); p. 483, Wagoner (1968), p. 362; Wing (1964), p. 268; Richter's patent data.

The surprisingly parallel development of American and German patenting activities suggests that this patent cycle might be positively related to the industry's business cycle. For example, the rise in valuable patents through 1914 might mirror the global growth of machine tool sales

[36] As is true today, the distribution of foreign patents across countries was highly skewed. The United States dominated foreign patenting activities in Germany with a share in all long-lived foreign patents of 29 percent before and 35 percent after the First World War – and were, therefore, Germany's major source for new technological knowledge. See Degner, Harald and Streb, Jochen (2010). Foreign Patenting in Germany, 1877-1932. Unpublished paper.

[37] The American machine tool industry's share in all valuable American patents in Germany is comparatively small and comes to 2.0% in the first imitation period, 3.4% in the first innovation period, 2.5% in the second imitation period, and 2.2% in the second innovation period.

and export, the decline in patents after the First World War might reflect the depressed conditions of the inter-war period. To prove this hypothesis we calculated the annual number of valuable patents of American machine tool makers in Germany per million US-Dollar production and per million US-Dollar export (data for Germany are not available). Figure 6 reveals that there was no constant relationship between the patenting activities and the American machine tool industry's business cycle. Quite the contrary, the relative patenting activities were declining over time. The correlation coefficient between patents and production is -0.17, the one between patents and exports comes to -0,46. We therefore reject the hypothesis that the development of American (and German) patenting activities can be explained by the machine tool industry's business cycle.[38] That is why we have to look for another explanation for the timing of the American patenting activities.

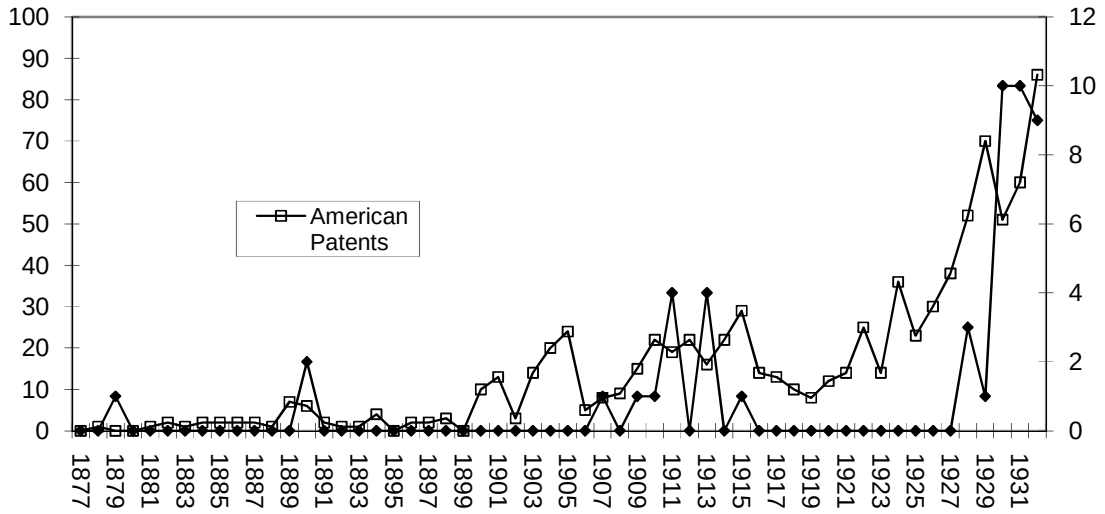
There are two necessary preconditions for patenting activities in a foreign market. First, an innovator will only be prepared to apply for patent protection in a foreign market after he has learned how to use this instrument in his home market. Second, an innovator has to expect to sell his products in the foreign market at a sales volume that justifies the costs that come along with the patenting activities abroad. Both preconditions were not satisfied during the first imitation period. Figure 7 shows that the newly founded American machine tool makers of the industrial district in Cincinnati intensified their patenting activities in their home market not before the turn of the century. Their inexperience with respect to patenting at home might explain why they also abstained from patenting activities in Germany before 1900. However, the increasing number of German patents held by American machine tool makers after 1900, proven by Figures 4, 5 and 7, is not only the result of growing experience but is probably also owed to the fact that, in this period, Germany has become one of the most important foreign market for American machine tool makers who delivered about one quarter of their total exports to German customers.[39] The increased German demand for their products obviously

[38] William Brown claims "that innovations occurs when the demand for machine tools falls". See Brown, W. (1957). Innovation in the Machine Tool Industry. *Quarterly Journal of Economics* 71, pp. 406-425. This hypothesis is also not supported by our data.

[39] See Robertson, R. M. (1966). Changing Production of Metalworking Machinery, 1860-1920. In Brady, D. S. (ed.). *Output, Employment, and Productivity in the United States after 1800.* NBER Books, New York: Columbia University Press, pp. 479-496, here p. 493; Penrose, B. and Williams, J. S. (1912): *Duties on Metals and Manufacturers of Metals.* Committee on Finance, United States Senate, Washington: Govt. Print. Off., p. 236.

convinced American machine tool makers that it has become profitable to get their innovations patented in the German jurisdiction.[40]

Figure 7 Patents granted of the American machine tool makers from Cincinnati in the American and German jurisdictions[a]



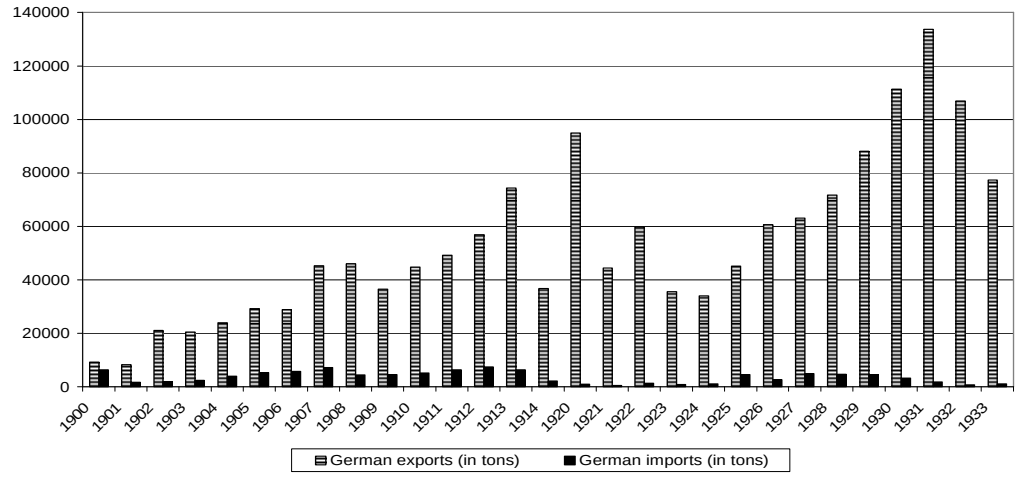
a Source: Richter's patent data.

Interestingly enough, we found no anecdotical evidence that three of the most notorious German imitators of the first imitation period, namely *J. E. Reinecker*, *Pfauter*, and *Wanderer Works*, maintained their imitation strategies during the first innovation period when these three firms also held patents in the American jurisdiction. As these German firms now had a strong interest that their own patents were respected in their American export market, they abstained in return from violating the intellectual property rights of American firms before the First World War. Figure 8 shows that German machine tool makers increased their exports considerably during both innovation periods. This finding confirms our assumption that valuable patents are a reliable indicator for innovativeness and therefore also for international competitiveness.[41]

[40] The average time span the American machine tool makers let pass between the patent application in their home market and the one in the German market decreased from 2.3 years before the First World War to 0.9 years after the First World War.

[41] See Labuske, K. and Streb, J. (2008). Technological creativity and cheap labour? Explaining the growing international competitiveness of German mechanical engineering before World War I. *German Economic Review*, 9, pp. 65-86.

Figure 8 German Exports and Imports of Machine Tools, 1900-1933[a]



a Statitisches Reichsamt (ed.). *Monatliche Nachweise über den auswärtigen Handel Deutschlands.* Berlin 1900-1933.

In the light of the increasing success of German firms in the American market, the German government was now also willing to make some concessions to the American patent holders. Section 11 of the German patent law of 1891 ruled that a patent could be revoked when the patent holder did not manufacture the patented good within the borders of Germany.[42] The purpose of this stipulation was to avert that a foreign patent holder used his German patent only to secure his monopoly in this country but did not employ German labor and did not stimulate German industry. Since the German firms used their American patents in the United States exactly in this unwanted way, the German government arranged with the American government in 1909 that section 11 of the German patent law was in return not applied to American firms.[43]

However, as we have already seen, the German firms reverted fast to their traditional imitation strategies after they had lost their American patents during the war and faced again a technological gap between themselves and their American competitors in the early 1920s. The Americans were well aware of the revitalized imitating activities of the German firms in the 1920s. In 1925, the American trade commissioner Theodor Pilger authored a report in which he listed 64 American machine tool makers whose products were copied by German firms and who were then squeezed out of the German and other export markets by their imitators. Pilger

[42] A similar ruling can be found in section 27 of the British Patents and Design Act of 1907.
[43] See „Abkommen zwischen dem Deutschen Reiche und den Vereinigten Staaten von Amerika, betreffend den gegenseitigen gewerblichen Rechtsschutz vom 23. Februar 1909." Blatt für Patent-, Muster- und Zeichenwesen, 25. August 1909, Nr. 7/8.

suggested as a countermeasure to apply for patents in the German jurisdiction.[44] The American firms obviously followed this advice. Figure 4 shows that the patent applications of American firms in Germany already reached high numbers in the first half of the 1920s, that is during German machine tool makers' second imitation period. However, given the fact that the German patent office needed in this decade on average about three and a half years to grant a patent for which an American machine tool maker had applied for, the number of patents granted increased not until the late 1920s, that is in the second innovation period. In the post-First World War decade, the American firms did in fact try to protect their intellectual property rights against the German product pirates by increasing their German patenting activities in the imitation period but failed to succeed because of the long time span between the patent application and the patent grant.

Table 1 Pendency period (time span between the application and the granting) of patents of machine tool makers from the US and Chemnitz, in years[a]

Period	Pendency period		Disadvantage of the American applicant
	Applicant from Chemnitz	American applicant	
1877-1899	0.7 years	1.2 years	64%
1900-1914	1.3 years	2.2 years	66%
1919-1925	1.7 years	3.7 years	116%
1926-1932	2.3 years	3.6 years	51%

a Source: Richter's patent data.

One might suppose that the long pendency period of the 1920s was determined by the growing complexity of the innovative machine tools. It might also be possible, however, that the German patent authorities consciously delayed the patent grants to American firms to give domestic firms the time they needed to exploit their imitation strategies. Kotabe, for example, claims that a country's patent practices discriminate against foreigners if the pendency period is systematically shorter for domestic applications than for foreign applications.[45] Table 1 reveals that the German patent authorities needed in general more time to process the American patent applications than those of domestic inventors from Chemnitz. On average,

[44] See NARA, RG 151, 420 (Box 1950): W.H. Rastall to Julius Klein, 11. January 1926.
[45] See Kotabe, Masaaki (1992). A Comparative Study of U.S. and Japanese Patent Systems. *Journal of International Business Studies*, p. 157.

this disadvantage comes to about 60%. Between 1919 and 1925, however, the pendency period for American applicants was more than twice as long as the pendency period for domestic applicants. As this disadvantage decreased again in the late 1920s to an all-time low, the quantitative evidence for discriminating patent practices during the second imitation period is strong.

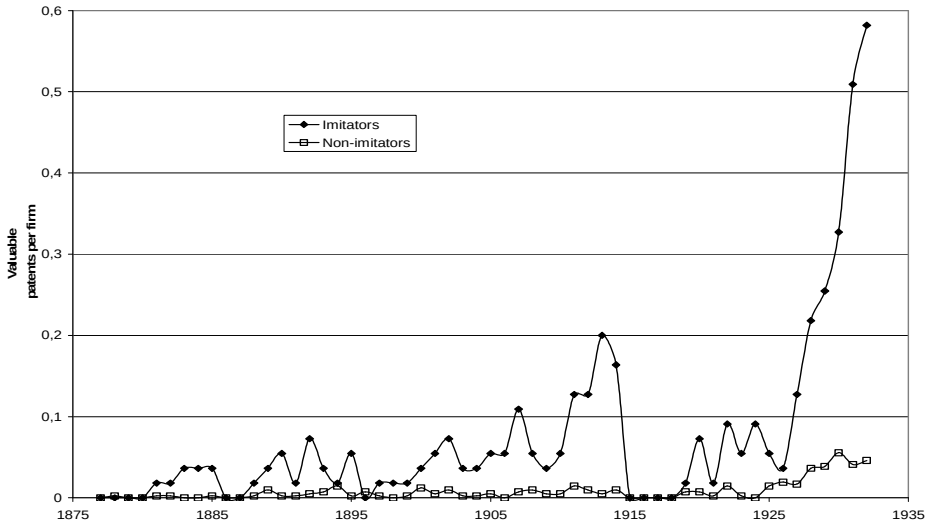
There is also anecdotic evidence for the problems American firms faced trying to protect their intellectual property in the 1920s. Some American machine tool makers needed more than ten years to fight their cases through the German patent court because several German companies joint in order to prevent American patent applications.[46] The problems, American manufacturers had to face when dealing with the German patent office in the 1920s, is illustrated by the experiences of Sol Einstein, design engineer of the Cincinnati Milling Machine Company: "*It was difficult to get a German patent granted due to the opposition from German manufacturers. I therefore was sent to Germany to straighten out the difficulties our attorney experienced. When our opponents found out that I was in Germany to attend a hearing before the patent office, from month to month they postponed the hearings in the hope I would not stay in Germany. Finally after three months of delaying, the hearing was set. With preparation of having a demonstration of an up-to-date centerless grinder at the Singer Sewing Machine Plant and three prior art machines* [...] *set up to the experimental room at the patent office, our opponents were willing to withdraw their position if we would grant them a license for using all twelve machines they had built. I insisted, however, on a ruling by the patent office which finally granted the patent with very broad claims.*" However, "*through the united effort of a large number of German companies, the patent, after four years in existence, was declared invalid. In England, our patent was declared invalid by a judge who stated frankly that he was particularly interested in maintaining the interest of the English people.*"[47] In Germany, it was the Association of German machine tool makers which coordinated the German firms' fight against the American patentees by collecting and encouraging patent appeals.[48]

[46] See Cincinatti Historical Society Library (CHSL), Milacron, Series: Misc. Folders (Schwartz), Box 1, Folder Litigation Compilation; Landesarchiv Berlin, Bestand Ludwig Loewe, A. Rep. 250/01/18/Karton 110 u. 130.
[47] CHSL, Milacron, Series: Executives Personal History (Schwartz), Box B-H, Folder Sol Einstein: Einstein, Sol, I do remember – men, machines, and the plants behind the Cincinatti Milling Machine Company, August 1972, p. 7.
[48] See Staatsarchiv Chemnitz, Bestand Wanderer-Werke, 31030/WW3617: VDW to Wanderer-Werke, 23. January 1931.

Summing up, the degree of innovativeness of domestic firms significantly influenced the level of discriminating German patent practices against foreigners. In the first innovation period, the German patent authorities allowed American firms to hold patents for innovations not produced within the German borders. In the second imitation period, the American disadvantage resulting from a longer pendency period increased considerably but was reduced again to a all-time low in the second innovation period.

The distortive influence of changing patent practices considerably decreased the informative value of German machine tool industry's relative innovativeness measured by the ratio between the valuable patents of German firms (Figure 3) and the valuable patents of American firms (Figure 5). This ratio comes to 0.8 in the first imitation period, 0.6 both in the first innovation period and in the second imitation period, and 1.3 in the second innovation period. Given the exceptional long pendency period for American applicants after the First World War, the "real" ratio of relative innovativeness was probably smaller in the second imitation period and higher in the second innovation period. However, even the distorted figures support our hypothesis about the chronological sequence of the second catching-up process.

Figure 9 Valuable patents per imitating and non-imitating firm[a]



a Source: Baten/Streb patent data base and Richter's patent data.

To prove our basic assumption that learning-by-imitating fostered the development of innovativeness we have to show that the German imitators were more innovative than the

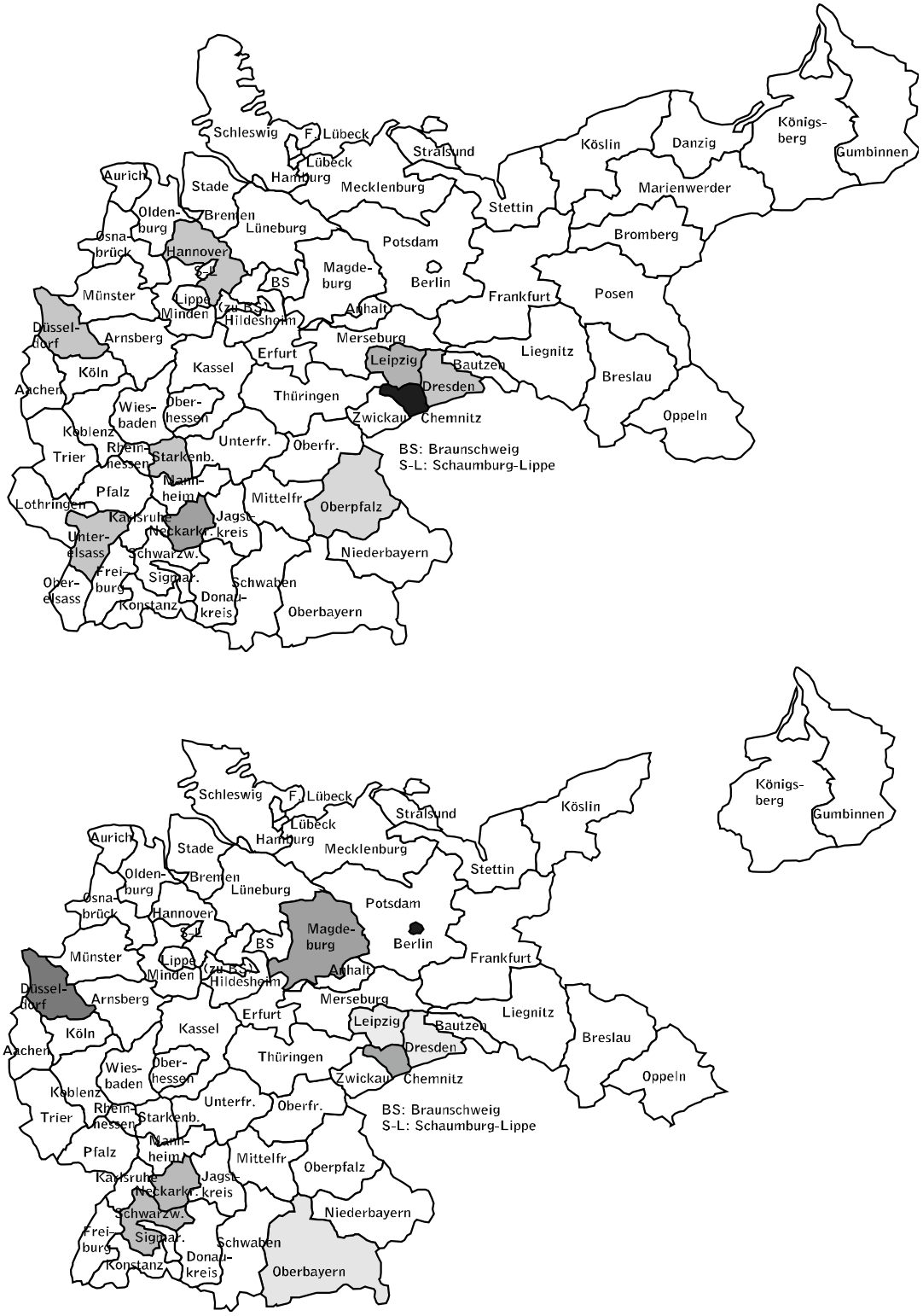
German non-imitators. Fortunately, the Industrial Machinery Division of the American Department of Commerce and the National Machine Tool Builders Association compiled a list of the 55 most notorious German imitators.[49] To answer the question whether these imitators were more innovative than the "non-imitating" (or less-imitating) other German machine tool makers we calculated the annual number of valuable patents per firm for each of these two groups. The results of this calculation are shown in Figure 9. The notorious imitators were far more innovative than the non-imitating firms, especially in the innovation periods. We conclude from this finding that the competence to develop profitable innovations diffused first and foremost within the group of imitating firms. To spend resources for imitation was apparently an excellent strategy to secure long-term growth and survival. Note that this process might have been self-enhancing. Firms that invested ore in imitating strategies probably grew faster than others and had therefore more funds for imitating and innovating in later decades.

Patenting activities in the German machine tool industry were not only uneven distributed across firms but were also geographically clustered in a few administrative districts.[50] Figure 10 shows the core areas of machine tool innovations in the 1890s and the 1920s. The darker the shade the higher the share of this district in all valuable machine tool patents. In the 1890s (1888-1997), machine tool makers located in the three administrative districts of Saxony (Chemnitz, Dresden, Leipzig,) dominated patenting activities with a combined share of 46% in all valuable machine tool patents. In the 1920s (1918-1927), however, the geographical centers of patenting activities had shifted to Berlin (29%) and Magdeburg (12%) in the North, Duesseldorf in the West (17%) and Neckarkreis (9%) and Schwarzwald (8%) in the Southwest. The combined share of the three administrative districts in Saxony had decreased to 15%. One important reason for this relative decline in innovativeness is that knowledge spill-over from successful technical universities in the cities Aachen, Berlin or Stuttgart considerably fostered the innovativeness of the machine tool makers located in their vicinity.

[49] See NARA, RG 151, 420 (Box 1950): D.P. Miller to Director Bureau of Foreign and Domestic Commerce, 8. November 1926.

[50] For the geographical distribution of patent activities in 19th century-America see Sokoloff, K. L. (1988) Inventive activity in early industrial America: Evidence from patent records, 1790–1846. *Journal of Economic History*, 48, p. 813–850.

Figure 10 Core areas of patenting activities (valuable patents) in the German machine tool industry in the 1890s and the 1920s[a]



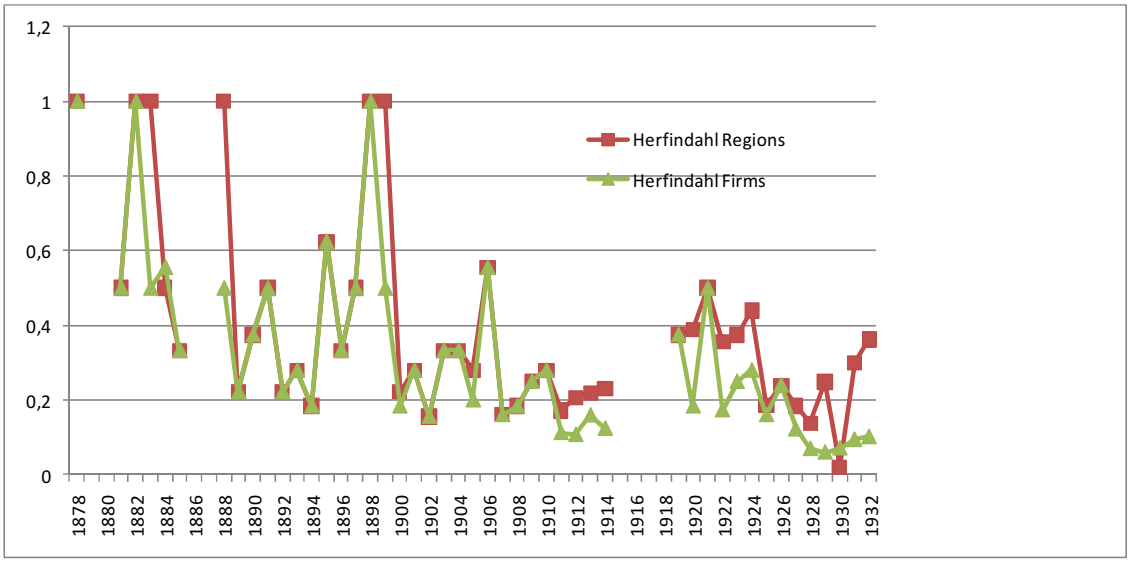
a Source: Baten/Streb patent data base and Richter's patent data.

We claimed at the beginning of this article that innovation periods are usually also periods of knowledge diffusion in which the competences to develop and produce innovative machine tools spill-over to more and more domestic firms. To prove this hypothesis for our historical case we calculated for every year Herfindahl-Indices (*H*) with respect to the distribution of valuable patents across both German firms and German administrative districts. In the following formula, t denotes the year, and *VP* the number of valuable patents held either by firms *i=1...n* (in the case of the Firms' Herfindahl-Index) or in administrative districts *i=1...n* (in the case of the Regions' Herfindahl-Index):

$$H_t = \sum_{i=1}^{n} \left(\frac{VP_{i,t}}{VP_t}\right)^2$$

In general, the smaller the Herfindahl-Index the more equal is the distribution of valuable patents. The Herfindahl-Index comes to one in the case of maximum concentration and to 1/n in the case of an equal distribution of valuable patents. We interpret periods in which the Herfindahl-Index is decreasing as diffusion periods. Figure 11 shows that both the Firms' and the Regions' Herfindahl-Indices are in fact decreasing during the two innovation periods (1900-1914, 1926-1932) which implies that an increasing number of German machine tool makers and German regions were able to develop profitable innovations in these periods. Interestingly enough, both Herfindahl-Indices first also fall in the first imitation period which might reflect the general growth of the number of firms in the still young machine tool industry. During the intensification of the imitation period at the end of the 19th century, however, both Herfindahl-Indices increase again. This indicates the interruption of the former diffusion process and might be explained by the fact that many of the German machine tool makers lacked the resources to engage successfully in the learning-by-imitating process.

Figure 12 Herfindahl-Index of the distribution of valuable patents among German machine tool makers[a]



a Source: Baten/Streb patent data base and Richter's patent data.

The rather surprising result that the the Firms' Herfindahl-Index and the Regions'Herfinahl-Index display a nearly identical development over time can be explained by the fact that the above-average innovativeness of regions is mostly based on the achievement of just a few very innovative firms.[51] Analyzing the patent activities in all German industries, Degner finds out that, from 1877 to 1900, two thirds, and, from 1901 to 1932, between 40 and 55 percent of all long-lived German patents granted to domestic firms were held by only the 30 most-innovative German firms.[52] That this distribution of innovativeness across firms was extremely skewed is emphasized impressively by the fact that more than 266,000 firms with more than five workers existed in Germany in 1930. We conclude that the uneven distribution of innovativeness across regions has to be explained, first and foremost, by the persistent technological advantages of a few very innovative firms located in these regions.

4 Conclusions

The technologically backward German machine tool makers successfully used imitating and counterfeiting activities in the late 19th century and the 1920s to catch-up to their American

[51] Note that the diverging development of both Herfinahl-Indices in the early 1930s resulted from the fact that an increasing number of firms located in Berlin held an increasing number of valuable patents.
[52] See Degner, Harald Degner (2009). Schumpeterian German Firms before and after World War I: The Innovative Few and the Non-innovative Many. *Zeitschrift für Unternehmensgeschichte* 54, p. 62. See also Degner, Harald (2010). *Windows of Technological Opportunity: Do Technological Booms influence the Relationship between Firm Size and Innovativeness?* FZID Discussion Papers 15.

competitors. The German administration supported this strategy by stipulating a patent law that discriminated against foreign patent holders and by prolonging the pendency period for foreign applicants. Parallel to the growing international competitiveness of German firms, however, the willingness to guarantee intellectual property rights of foreigners was also increasing because German firms had now to fear retaliatory measures in their export markets when violating foreign property rights within Germany.

We interpret this development of the German machine tool industry as a model for other historical, contemporaneous and even future catching-up processes. Developing countries may learn from this example that the strict compliance to the international rules of law with respect to intellectual property rights can slow down the speed of technological and economic progress in their domestic industry.[53] Advanced countries may understand, first, that the owed their own development similar imitating strategies in the past, and, second, that illegal imitation usually only takes place during a transitional period. We predict that the copying and counterfeiting activities of the Chinese machine builders which were momentarily tolerated by the Chinese government will end as soon as the Chinese firms will be able to sell advanced and innovative machinery abroad.

[53] See the similar conclusion in Boldrin, M. and Levine D. K. (2008). *Against Intellectual Monopoly*. Cambridge: University Press, p. 281.

References

Abramovitz, Moses (1986). Catching-up, Forging Ahead, and Falling Behind. *Journal of Economic History* 46, pp. 385-406.

Aghion, Phillipe (2008). Higher Education and Innovation. *Perspektiven der Wirtschaftspolitik* 9 (Special edition), pp. 28-45.

Baten, Jörg, Spadavecchia, Anna, Streb, Jochen and Yin, Shuxi. (2007). What made southwest German firms innovative around 1900? Assessing the importance of intra- and inter-industry externalities. *Oxford Economic Papers* 59, pp. i105-i126.

Boldrin, Michele and Levine David K. (2008). *Against Intellectual Monopoly*. Cambridge: University Press.

Brown, William H. (1957). Innovation in the Machine Tool Industry. *Quarterly Journal of Economics* 71, pp. 406-425.

Buchheim, Christoph (2006). What Causes Late Development? Insights from History. *South African Journal of Economic History* 21, pp. 52-83.

Degner, Harald (2009). Schumpeterian German firms before and after World War I. The innovative few and the non-innovative many. *Zeitschrift für Unternehmensgeschichte* 54, pp. 50-72.

Degner, Harald (2010). *Windows of Technological Opportunity: Do Technological Booms influence the Relationship between Firm Size and Innovativeness?* FZID Discussion Papers 15.

Degner, Harald and Streb, Jochen (2010). Foreign Patenting in Germany, 1877-1932. Unpublished paper.

Griliches, Zvi (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature* 33, p. 1661-1707.

Grupp, Hariolf, Dominguez-Lacasa, Icias and Friedrich-Nishio, Monika (2002). *Das deutsche Innovationssystem seit der Reichsgründung*. Heidelberg: Physica Verlag.

Hitzbleck, Hans (1927). *J. E. Reinecker Aktiengesellschaft*. Dresden.

Kotabe, Masaaki (1992). A Comparative Study of U.S. and Japanese Patent Systems. *Journal of International Business Studies*, p. 147-168.

Jeremy, David J. (ed.). *International Technology Transfer. Europe, Japan and the USA, 1700-1914*, Aldershot: Edward Elgar.

Kiesewetter, Hubert (1992). Beasts or Beagles? Amerikanische Unternehmen in Deutschland. In Pohl, H. (ed.). *Der Einfluß ausländischer Unternehmen auf die deutsche Wirtschaft vom Spätmittelalter bis zur Gegenwart*. Stuttgart: Franz Steiner, pp. 165-196.

Labuske, Kirsten and Streb, Jochen (2008). Technological creativity and cheap labour? Explaining the growing international competitiveness of German mechanical engineering before World War I. *German Economic Review*, 9, pp. 65-86.

Miller, Fred J. (1897). *American and Other Machinery Abroad. Being a Study of the European Field for the Introduction of American Machinery*. New York: Press of the American Machinist.

Moser, Petra (2005). How do Pantent Laws influence Innovation? Evidence from Nineteenth-Century World's Fairs. *American Economic Review* 95, p. I214-I236.

Moser, Petra (2010). Do Patents Weaken the Localization of Innovations? Evidence from World's Fairs. Unpublished paper.

Murmann, Johann Peter (2003). *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions.* Cambridge: University Press.

Ogilvie, Sheilagh and Overy, Richard (eds.) (2003). *Germany: A New Social and Economic History Volume 3. Since 1800*. Oxford: University Press.

Pakes, Ariel (1986). Patents as options: some estimates of the value of holding European patent stocks. *Econometrica*, 54, pp. 755-784.

Penrose, B. and Williams, J. S. (1912): *Duties on Metals and Manufacturers of Metals.* Committe on Finance, United States Senate, Washington: Govt. Print. Off.

J. E. Reinecker Chemnitz 1859-1909, Leipzig: Meisenbach Riffarth, 1909.

Richter, Ralf (forthcoming). *Der amerikanische und deutsche Werkzeugmaschinenbau zwischen Konvergenz und Divergenz, 1870-1933.* Bielefeld.

Robertson, Robert. M. (1966). Changing Production of Metalworking Machinery, 1860-1920. In Brady, D. S. (ed.). *Output, Employment, and Productivity in the United States after 1800.* NBER Books, New York: Columbia University Press, pp. 479-496.

Schankerman, Mark and Pakes Ariel (1986). Estimates of the value of patent rights in European countries during the post-1950 period. *The Economic Journal*, 96, pp. 1052-1076.

Seckelmann, Margrit (2006). *Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871-1914*. Frankfurt/Main: Vittorio Klostermann.

Sokoloff, Kenneth L. (1988) Inventive activity in early industrial America: Evidence from patent records, 1790–1846. *Journal of Economic History*, 48, p. 813–850.

Streb, Jochen (2001). Möglichkeiten und Grenzen der Schumpeterschen Diversifizierung. Die Entwicklung der Firma Freudenberg & Co. Weinheim vom spezialisierten Ledererzeuger zum Kunststoffverarbeiter mit breiter Angebotspalette. *Zeitschrift für Unternehmensgeschichte* 46, pp. 131-159.

Streb, Jochen, Baten, Jörg and Yin, Shuxi (2006). Technological and geographical knowledge spillover in the German Empire 1877-1918. *Economic History Review* 59, pp. 347-373.

Streb, Jochen, Wallusch, Jacek & Yin, Shuxi (2007). Knowledge spill-over from new to old industries: The case of German synthetic dyes and textiles 1878-1913. *Explorations in Economic History*, 44, pp. 203-223.

Sullivan, Richard J. (1994). Estimates of the value of patent rights in Great Britain and Ireland, 1852-1976. *Economica*, 61, pp. 37-58.

Wagoner, Harless D. (1968). *The U.S. Machine Tool Industry from 1900 to 1950*. Cambridge, Mass.

Wing, George A. (1964). *The History of the Cincinnati Machine Tool Industry*. Ph. D. Thesis Indiana University.