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Abstract
In this paper, we use both patents' individual life span and foreign patenting activities in Germany to identify the most valuable patents of the 21 most innovative countries (except for Germany) from the European Core, the European periphery and overseas between 1877 and 1932. Our empirical analysis reveals that important characteristics of the international distribution of foreign patents are time-invariant. In particular, the distribution of foreign patents across countries in the late nineteenth and early twentieth centuries was as highly skewed as it was in the late twentieth century – and even dominated by the same major research economies. Our analysis suggests that firms' technological advantages were influenced both by exogenous local factors, such as the countries' resource endowment, and by endogenous factors, such as the national education and research system or the countries' actual stage of economic development.

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1 Technological transfer and foreign patenting

To analyze the volume, direction, and impact of technological transfer empirically, researchers traditionally rely on international data about bilateral trade flows or FDI.[1] A new approach suggested by Eaton and Kortum, Hafner or Kotabe measures the direction of technological transfer by patenting activities in foreign markets.[2] Given the existence of the respective national patent laws, an inventor can apply for a patent not only in his home country, but also in foreign countries. Getting a patent at home or abroad, however, is not cost-free, but incurs not only the fees of filing and renewing the patent, but also the disclosure of the underlying technological knowledge. Weighting the costs and benefits of foreign patenting, most inventors decide to file a patent only in their home country. Only the most promising inventions will also be patented abroad. Even so, firms will seek patent protection only in those foreign countries where two conditions hold: the potential market for their innovation is large, and the probability of imitation is high. Hence, a foreign patent indicates not only the country of origin, but also the destination of the technological transfer.

Analyzing foreign patenting activities in the late twentieth century, Eaton and Khortum come to the conclusion that "*foreign patent applications roughly reflect the scale of research activity in the source country. The United States is the dominant source of foreign patents..., followed by Japan or (in Europe) by Germany*."[3] The authors conclude that productivity growth in other countries is driven mainly by the innovation activities of these leading research economies. Hafner, however, raises serious doubts about whether pure patent counts that provide no information about the individual values of foreign patents can also be used to determine the magnitude of the technological transfer.[4]

Even though we do not know the particular value of an individual foreign patent, we can be quite sure that foreign patents represent an especially valuable part of a country's patent stock. That is why many researchers evaluate the technological strengths of a research economy by

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[1] For a short survey, see Kurt Hafner, "The Pattern of International Patenting and Technology Diffusion," Applied Economics 40 (2008): 2819-37, 2820.

[2] See Jonathan Eaton and Samuel Kortum, "Trade in Ideas: Patenting and Productivity in the OECD," Journal of International Economics 40 (1996): 251-78; Jonathan Eaton and Samuel Kortum, "International Technology Diffusion: Theory and Measurement," International Economic Review 40 (1999): 537-70; Hafner, "Pattern;" Massaki Kotabe, "The Impact of Foreign Patents on National Economy: A Case of the United States, Japan, Germany and Britain," Applied Economics 24 (1992): 1335-43.

[3] Eaton and Kortum, "International Technology," 542.

[4] See Hafner, "Pattern," 2821.

the number and the technological specialization of its foreign patents.[5] Traditionally, they concentrate on foreign patenting in the United States because, first, this country has a large and developed market in which only excellent innovations will take hold, and, second, the U.S. Patent and Trademark Office provides comparatively detailed and long-term patent statistics. Patel and Pavitt, for example, analyze foreign patenting activities in the Unites States in the second half of the twentieth century.[6] They show that, in the late 1980s, Switzerland, Japan (which dramatically improved its position between the 1960s and the 1980s), and Germany were the most innovative countries measured by per capita patenting in the U.S. Sweden, Canada, the Netherlands, Finland, France, the U.K., Denmark, Belgium and Norway followed in descending order. Foreign patenting activities of developing countries that concentrated mainly on imitation strategies were very small – with the notable exception of Taiwan and South Korea, which began to file a considerable amount of U.S. patents in the 1970s and 1980s respectively. To reveal the patterns of technological specialization, Patel and Pavitt used their data to also calculate an index of revealed technological advantage (RTA) for seventeen OECD countries and eleven technological fields. Switzerland, for example, shows particular innovative strength in fine chemicals, Japan in electronics and automobiles, Germany in chemicals and machinery, Sweden in machinery, and the Netherlands in electronics.

The most comprehensive analysis of the long-term development of the international patterns of technological advantage is provided by Cantwell, who computes the RTA index, again based on foreign patenting in the United States, for sixteen industrialized countries and 27 sectors in the periods 1890-1892, 1910-1912 and 1963-1983.[7] One of his most important findings is that countries that were characterized by comparatively rapid and continuous innovation and productivity growth (such as Japan or Western Germany) strengthened their existing patterns of technological advantage over time, while countries with a declining level of innovative activities (such as the U.K.) lost their traditional technological advantages.

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[5] Today, so-called triadic patents that are filed at the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO) are often used to identify a country's best innovations.

[6] See Parimal Patel and Keith Pavitt, "Uneven (and Divergent) Technological Accumulation among Advanced Countries: Evidence and a Framework of Explanation," Industrial and Corporate Change 3 (1994): 759-87.

[7] See John Cantwell, Technological Innovation and Multinational Corporations (Oxford, 1989), 16-48.

Marinova examines the patenting activities of Eastern European countries in the United States between 1976 and 1999.[8] Measured by the number of U.S. patents, the low innovativeness of Eastern European socialist and post-socialist countries is comparable only to the weakest Southern European countries, such as Greece or Portugal. Her analysis also reveals that Eastern European countries display technological strength in the resource-based fields of petroleum, coal and chemicals, and technological weakness in such science-based fields as automobiles or communications – and differ, therefore, considerably from their Western European counterparts.

Most of the studies cited above concentrate on foreign patenting activities in the United States in the second half of the late twentieth century. In this paper, we analyze the patterns of foreign patenting in Germany between 1877 and 1932. We show in the following section that a special feature of German patent law, the annually increasing renewal fees, allows us to resolve the problems of pure patent counts and to identify the most valuable foreign patents on the basis of their individual life spans. The resulting subgroup of long-lived foreign patents represents the excellent innovations of the countries of origin better than the set of all foreign patents used in other studies. Our empirical analysis proves that important characteristics of the distribution of foreign patents in the late twentieth century existed one hundred years before and are, therefore, rather time-invariant. First, we show that the distribution of foreign patents across countries in the late nineteenth and early twentieth centuries was as skewed as that of the late twentieth century – and even dominated by the same major research economies. We will also show that this skewness of the distribution of innovativeness repeats itself in the innovative countries in which just a few firms were responsible for the majority of foreign patenting activities. Second, we demonstrate that in the early twentieth century the major research economies often excelled in the same technological fields that they do today. These findings strongly support Cantwell's view that technological strengths are formed in an accumulative and path-dependent process. In addition, it will become clear that a country's technological advantages are significantly influenced by its resource endowment, its educational and research system, and its actual stage of economic development.

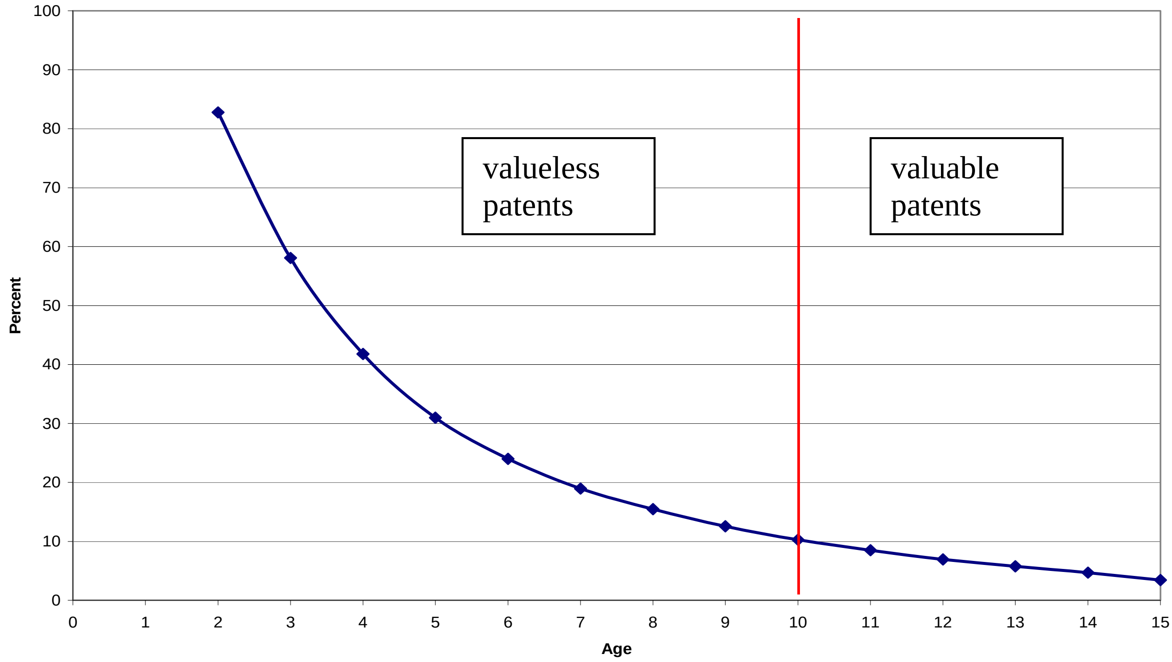
2 The data

Our observation period begins in 1877, with the establishment of the German patent law of 1877 that gave inventors, for the first time in German history, the opportunity to apply for

[8] See Dora Marinova, "Eastern European Patenting Activities in the USA," Technovation 21 (2001): 571-84.

patent protection not only in single German states such as Prussia, but in the whole German Empire.[9] Our data source is the *Baten/Streb patent data base*[10] which lists all valuable patents, including the year of the patent grant, the technological class of the invention and the name and location of the patent holder. The name and location of the patent holder allows us to tell whether a particular patent was held by a German or a foreign patentee, by a private inventor, or by a firm.

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.

In the German Empire, patent protection could last up to fifteen years, but not for free. Rather, at the beginning of each year, the patentee had to pay an increasing renewal fee in order to keep his patent in force.[11] Consequently, a patent holder had to decide annually if he wanted to renew his patent for another year. The outcome of this decision depended on the patentee's expectations about the future returns and costs of holding the patent. The latter were determined by the renewal fees which were known in advance. In contrast, the future returns of a patent were highly uncertain and could arise from two major sources. On the one hand, a

[9] See Margrit Seckelmann, Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871-1914 (Frankfurt/Main 2006), 86-106.
[10] See Jochen Streb, Jörg Baten and Shuxi Yin, "Technological and Geographical Knowledge Spillover in the German Empire 1877-1918," Economic History Review 59 (2006): 347-73.
[11] This annual renewal fee came to 50 Marks in the first two years and then grew by 50 Marks each year up to 700 Marks at the beginning of the fifteenth year.

patentee could use a patent to increase his profits by selling his innovation as a temporary monopolist or by licensing another producer to do so. On the other hand, a patentee could also use his patent to prevent sales of competitors' innovations that had the potential to decrease the market share of his own, already-established products. We assume that, in the German Empire, most patent holders renewed their patent only if the present value of the expected future returns exceeded the present value of the future costs. That is why a long life span of a historical patent is a reliable indicator for its comparatively high private economic value.

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 that about seventy percent of all German patents granted between 1891 and 1907 had already been cancelled after just five years. After the fifth year, the speed of patent cancellation was decelerating. About ten percent of all patents were still in force after ten years, and 4.7 percent of all patents reached the maximum age of fifteen years. In the process of developing their historical patent database, Baten and Streb decided to use the cut-off point of ten years to distinguish valuable patents from valueless ones.[12]

The choice of this cut-off point was not arbitrary. According to the pioneers of this method, the relevant yardstick to distinguish high-value patents from low-value ones lies somewhere between five and 15 years. On the one hand, Pakes observes that, in an early stage of an innovation process, an inventor is often highly uncertain whether his idea can be exploited profitably in the future.[13] The low renewal fees at the beginning of a patent's life allows the inventor to use the patent as a comparatively cheap option that protects the new knowledge and gives him the time to learn more about the invention's technological and economic prospects. As the usually high mortality rates in the early years of a patent cohort indicate, most of the patents turned out to be worthless. Given this fact, it would be conceivable to interpret those patents that survived this learning process and lasted for at least five years as the high-value patents of the sample. On the other hand, Schankerman and Pakes conclude

[12] For more details, see Streb, Baten and Yin, "Knowledge Spillover." See also Jochen Streb, Jacek Wallusch and Shuxi Yin, "Knowledge Spill-over from New to Old Industries: The Case of German Synthetic Dyes and Textiles 1878-1913," Explorations in Economic History 44 (2007): 203-23; Jörg Baten, Anna Spadavecchia, Jochen Streb and Shuxi Yin, "What made Southwest German Firms Innovative around 1900? Assessing the Importance of Intra- and Inter-Industry Externalities," Oxford Economic Papers 59 (2007): i105-i126; Kirsten Labuske and Jochen Streb, "Technological Creativity and Cheap Labour? Explaining the Growing International Competitiveness of German Mechanical Engineering before World War I," German Economic Review 9 (2008): 65-86.

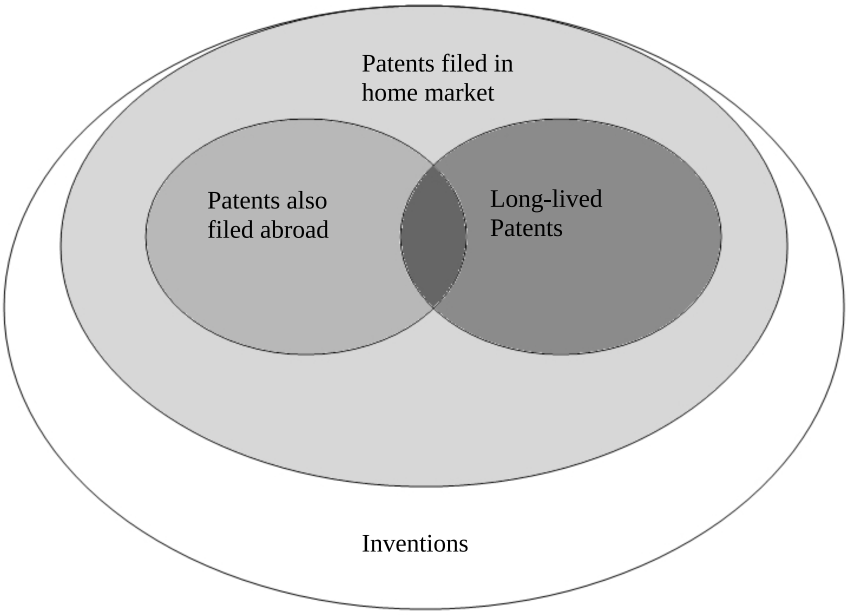
[13] See Ariel Pakes, "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks," Econometrica 54 (1986): 755-84.

that most of the value of the patent stock built up in the post-Second World War period in Britain, France and Western Germany was concentrated in the upper five percent of the long-lived patents.[14] This conclusion implies that only those patents that reached the maximum life span of 15 years should be selected. Baten and Streb, instead, followed Sullivan, whose exploration of British and Irish patents in the second half of the nineteenth century matches their period under consideration.[15] Sullivan interpreted the upper ten percent of the long-lived patents as the high-value patents of the total patent population. Exploiting the information given by the survival rate of Figure 1, Baten and Streb selected all patents that survived at least ten years. This selection process resulted in a database containing 61,631 long-lived patents that were considered the valuable patents of the German Empire and the Weimar Republic. Among those valuable patents were 15,528 patents held by non-German residents.

Much is said about the shortcomings of patents as a measure for innovativeness. Often cited, Zvi Griliches (1990, p. 1669) 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.*"[16] The first part of this statement refers to the well-known fact that the propensity to patent varies across industries. Some industries try to appropriate the returns of their inventions primarily by keeping them secret, while others, such as the chemical or pharmaceutical industries, prefer patenting instead. Because of industries' different propensities to patent it might be misleading to automatically interpret a particular industry's comparatively high number of patents as a sign for its above-average innovativeness. 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, whether or not it has a high or a low economic value for the patentee or the society. Using the number of patents as an indicator for new technological knowledge suitable to foster economic growth, therefore, leads to a potentially large measurement error. To avoid this measurement error, it is necessary to distinguish between patents with a high economic value and patents with a low one.

[14] See Mark Schankerman and Ariel Pakes, "Estimates of the Value of Patent Rights in European Countries during the Post-1950 Period," The Economic Journal 96 (1986): 1052-76.
[15] See Richard J. Sullivan, "Estimates of the Value of Patent Rights in Great Britain and Ireland, 1852-1976," Economica 61 (1994): 37-58.
[16] Zvi Griliches, "Patent Statistics as Economic Indicators: A Survey," Journal of Economic Literature 33 (1990): 1661-707, 1669.

Figure 2 Measuring the value of patents



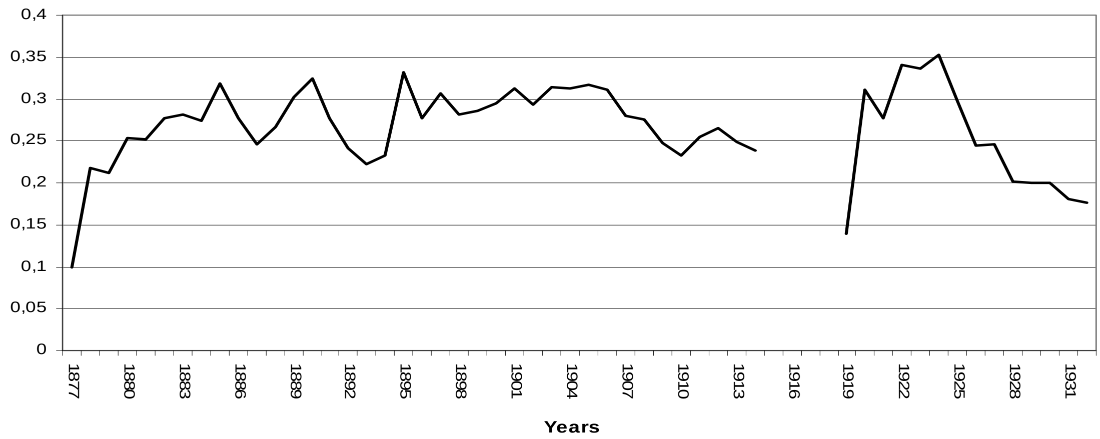
In this paper, we combine two prominent methods to isolate a country's most valuable patents.[17] Figure 2 illustrates our approach. It is clear that domestic patents represent only a subset of all inventions that originated in a particular country. This selection bias is common to (and unavoidable in) all innovation studies that have to rely primarily on patent statistics. In contrast, the problem of pure patent counts stressed by Griliches or Hafner can be considerably reduced. We have explained that a country's most valuable patents can be identified either by their comparatively long life spans or by the fact that they were additionally filed in advanced foreign countries. We use a combination of these two methods in this paper. Our patent data contain, for example, only those patents kept by French innovators that were filed in Germany *and* held there at least ten years. The studies analyzing foreign patenting in the United States have to examine the whole set of foreign patents because there were no annual renewal fees in use. We can limit our analysis to the smaller intersection of foreign patents and long-lived patents, which we call the set of long-lived foreign patents.

[17] A third method is to use the frequency of citation in other patents as a proxy for the value of a patent. See Adam B. Jaffe and Manuel Trajtenberg, Patents, Citations and Innovations: A Window on the Knowledge Economy (MIT, 2002). Gay et al. also combine two methods and analyse the citation frequency of foreign patents to calculate their value. See C. Gay, Christian Le Bas, P. Patel and Karim Touach, "The Determinants of Patent Citations: An Empirical Analysis of French and British Patents in the US," Econ. Innov. New Techn. 14 (2005): 339-50.

3 The innovative few

In the second half of the twentieth century the annual share of patents issued to foreign applicants in all patents increased considerably in most of the leading economies. Kotabe reports that between 1964 and 1988, the foreign patent grant ratio went up from 18.9 percent to 48.0 percent in the U.S., from 38.4 percent to 59.6 percent in Germany, and from 74.7 percent (1969) to 85.0 percent in Great Britain. Only in Japan did the foreign patent ratio decrease from 38.4 percent to 13.4 percent in the same period.[18]

Figure 3 Share of long-lived foreign patents among all long-lived patents in Germany, 1877-1932[a]



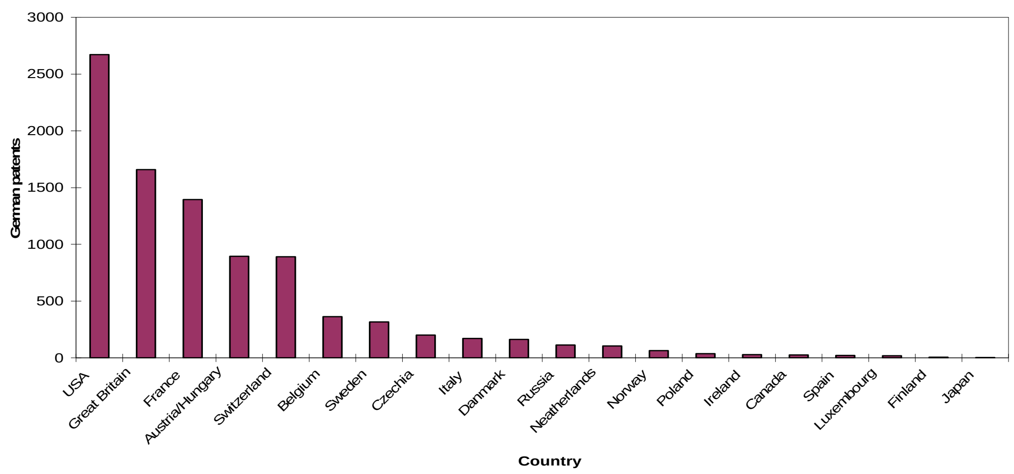
a Source: Baten/Streb patent database.

Figure 3 shows the annual share of long-lived foreign patents among all long-lived patents granted in the respective year in Germany between 1877 and 1932. After the introduction of the German patent law in 1877, foreign innovators realized quickly that is was advantageous to patent their new products and processes in this economically and technologically advancing country. The long-lived foreign patent grant ratio increased from about ten percent in 1877 to more than thirty percent in the mid-1880s. The average annual long-lived foreign patent grant ratio came to 27 percent in the period between 1877 and 1914 and was, therefore, considerably higher than in the United States, where this number was only 8.4 percent in the early 1890s and 11.4 percent in the early 1910s.[19] After the end of the First World War, the annual share of foreign patents among all German long-lived patents returned quickly back to

[18] See Kotabe, "Foreign Patents," 1335.
[19] See Cantwell, "Technological Innovation," 23.

values above thirty percent. From the late 1920s onwards, however, the relative foreign patenting activities in Germany declined continuously. This development reflects the fact that foreign patentees stopped prolonging their German patents after the National Socialists seized power and had began transforming the open German economy into a more autarkic system. Even so, the annual long-lived foreign patent grant ratio still averaged out at 25 percent between 1919 and 1932. Before and after the First World War, Germany was an attractive market for foreign patenting activities.

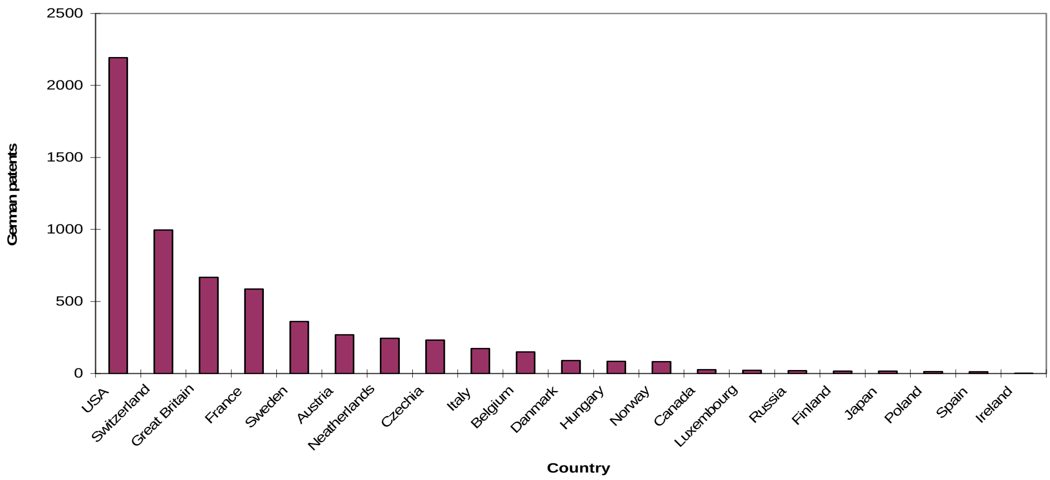
Figure 4 Long-lived German patents (1877-1914) of the twenty most innovative foreign countries before the First World War[a]



a Source: Baten/Streb patent database.

As is true today, the distribution of foreign patents across countries was highly skewed. Figures 4 and 5 display the number of long-lived German patents of the 21 most innovative foreign countries before and after the First World War, respectively. In both sub-periods, the United States dominated foreign patenting activities in Germany with a share of 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. The respective shares of the three most innovative (five most innovative) countries came to 63 percent (82 percent) before and 61 percent (77 percent) after the First World War. Comparing the two sub-periods, the improvement in the Swiss ranking is most remarkable.

Figure 5 **Long-lived German patents (1918-1932) of the twenty-one most innovative foreign countries after the First World War**[a]



a Source: Baten/Streb patent database.

Baten and Jaeger use a panel regression to explain the scale of foreign patenting activities in Germany before the First World War.[20] First, they show that a country's number of long-lived German patents per capita was significantly and positively influenced by its student enrolment rates in primary and secondary schools. Especially in the "high-tech" industries of the Second Industrial Revolution – such as chemicals or electrical engineering – the availability of a sufficient stock and structure of domestic human capital was obviously a necessary precondition for sustained innovativeness.[21] In international economics, gravity models predict that geographical and cultural proximity promotes bilateral foreign trade. Distance also mattered for foreign patenting. Baten and Jaeger demonstrate that an inventor's propensity to patent in Germany decreased ceteris paribus with growing distance between his location and Germany. An explanation for this observation is that the greater distance increased the information and transactions costs of both trading and patenting activities that made foreign patents in faraway countries less profitable. Irrespective of the geographical distance, a country's number of long-lived German patents per capita also increased if its

[20] See Jörg Baten and Kirsten Jäger, "Foreign Patenting in Germany and its Determinants: A Study on 35 Countries, 1820-1914," unpublished paper (2010).
[21] See, for example, Johann Peter Murmann, Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions (Cambridge, 2003), 50-62.

native language was German. Sharing a common language obviously facilitated the knowledge transfer between two countries.

Table 1 Most important countries of origin of foreign patents in Germany and the USA (number of patents in parentheses)[a]

Germany 1877-1914	**USA 1890-1992**	**USA 1910-1912**	**Germany 1918-1932**	**USA 1963-1983**	**Germany 2001**	**USA 2001**
USA (2,673)	UK (2,145)	D (3,961)	USA (2,193)	D (101,863)	USA (85,615)	J (66,578)
GB (1,658)	D (1,378)	UK (2,970)	CH (996)	J (94,046)	J (32,150)	D (27,015)
F (1,394)	CDN (975)	CDN (1,673)	GB (668)	UK (55,028)	GB (13,479)	GB (11,855)
A/H (895)	F (548)	F (1,031)	F (586)	F (38,956)	F (11,744)	F (9,213)
CH (891)	A/H (198)	A/H (439)	S (361)	CH (23,733)	NL (7,738)	CDN (8,364)
B (364)	AUS (147)	S (318)	A (268)	CDN (22,160)	S (7,292)	S (4,762)
S (316)	CH (139)	CH (310)	NL (244)	S (14,621)	I (5,055)	NL (3,631)
CZ (201)	S (101)	AUS (284)	CZ (231)	I (13,299)	CDN (4,055)	I (3,629)
I (172)	B/L (54)	I (175)	I (173)	NL (12,317)	FIN (3,508)	AUS (3,102)
DK (163)	IRL (44)	B/L (149)	B (149)	B/L (5,125)	AUS (3,478)	FIN (2,847)

a Sources: For Germany, 1877-1914 and 1918-1932, long-lived patents, see Baten/Streb patent data base; for USA, 1890-1892, 1910-1912, and 1963-1983, patents granted, see Cantwell, "Technological Innovation," 23; for Germany and USA, 2001, patent applications, see Hafner, "Pattern," 2873. Hafner does not report numbers for Switzerland! Abbreviations: A Austria, AUS Australia, B Belgium, CDN Canada, CH Switzerland, CZ Czechia, D Germany, DK Denmark, F France, FIN Finland, GB Great Britain, H Hungary, I Italy, J Japan, L Luxembourg, NL Netherlands, S Sweden, UK United Kingdom, USA United States of America.

Table 1 shows the most innovative foreign countries in the American and German patent markets for different sub-periods between 1877 and 2001. Note that we do not report American patents held by Americans and German patents held by Germans, respectively, because, as we explained in Section 2, domestic patents are, in general, less valuable than foreign ones. The interaction of the geographical and cultural distance effects discovered by Baten and Jaeger might explain the major differences between the American and the German rankings. Australian and Canadian inventors patented their innovations in the United States rather than in Germany while the opposite was true for inventors from countries such as Austria or Czechia. The most striking feature of Table 1, however, is the long-term persistence of some countries' technological leadership. The United States (in the German patent market), Germany (in the American patent market), Great Britain (or U.K.), and France dominated foreign patenting activities for more than 120 years. This dominance is not only evident in their consistently high rankings, but also in their comparatively very high number of foreign patents.[22] The only country that was able to join this club of original technological leaders was Japan in the second half of the twentieth century.

In another paper, Baten and Jaeger make the statistical observation that a foreign country's patenting activities in Germany in 1910 had a strong long-run impact on its economic growth measured by GDP per capita in 1960. They claim that they have estimated a "*reduced model of human capital path dependency*"[23] but do not explain in more detail how innovative activities before the First World War were able to influence growth patterns after the Second World War. In light of Table 1, we suppose that their regression captures the persistence of technological leadership. The scale of a foreign country's German patenting activities in 1910 is probably a good predictor for the scale of German patenting activities in the 1950s, which, in turn, might have determined its growth path after the Second World War. The existence of such long-run effects also implies that a global business history of the twentieth century has to take into account explicitly the development in the nineteenth century. Until now, however, scholars have not presented a conclusive explanation for both the persistent dominance of particular research economies and the highly-skewed distribution of patenting activities across countries. Cantwell suggests that we should explain backward countries' difficulties to achieve the same level of innovativeness as the traditionally dominating research economies by the fact that new technological knowledge is usually generated in an incremental, cumulative and path-dependent process.[24] As the paths of research and development in particular technological fields usually provide no shortcuts for latecomers, the leading research economies are, in general, far ahead of their followers regarding the development of major innovations. We will come back to this hypothesis in the following section.

The very uneven distribution of innovativeness across countries repeats itself within the innovative countries. Moser shows that the inventors of the English innovations presented at the Great Exhibition of 1851 in London were located predominantly in three districts: Herefordshire, London, and Worcestershire.[25] Streb, Baten and Yin demonstrate that the long-lived German patents granted to German patentees before the First World War were also not

[22] The rankings do not change significantly if we consider foreign patents per capita instead of the absolute number of foreign patents.
[23] See Jörg Baten and Kirsten Jaeger, "On the Persistence of Human Capital and Patent Effects around 1900 on per Capita Income Levels in the 1960s," Brussels Economic Review 52 (2009): 289-304, 300.
[24] See Cantwell, "Technological Innovation," 16.
[25] See Petra Moser, Do Patents Weaken the Localization of Innovations? Evidence from World's Fairs, 1851-1951 (2010), SSRN-id941751.pdf.

uniformly distributed over the different German regions, but were geographically clustered in the districts neighbouring the Rhine and in Greater Berlin and Saxony.[26] Outstanding innovativeness, it seems, is a characteristic of regions rather than of countries. For that reasons, scholars have concentrated recently on the analysis of regional innovation systems.[27] However, firm-level data reveal that the above-average innovativeness of regions is, in turn, often based on the achievement of just a few very innovative firms. Degner presents the astonishing result 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.[28] 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.

Using the examples of American and British firms, Table 2 confirms that foreign patenting activities in Germany were also dominated by a few very innovative firms.[29] The two firms United Shoe Machinery Company and Singer Manufacturing Company, for example, held about fifteen percent of all long-lived German patents granted to all American inventors. In Great Britain, most of the very innovative firms were located in the district of London. As a result, Great Britain's high rank in Figures 4 and 5 reflects the London region's innovativeness and not the whole country's. We conclude that the uneven distribution of innovativeness across countries (and across regions) has to be explained, first and foremost, by the persistent technological advantages of a few very innovative firms located in these countries (and regions).[30] To identify and understand the firm-level determinants for countries' technological leadership is, therefore, one of the most import challenges for global business historians.

Table 2 The American and British firms with the most long-lived German patents before and after the First World War[a]

[26] See Streb, Baten and Yin, "Knowledge Spillover."
[27] See, for example, Bjørn Asheim and Arne Isaksen, "Regional Innovations Systems: The Integration of Local 'Sticky' Knowledge and Global 'Ubiquitous" Knowledge," Journal of Technology Transfer 27 (2002): 77-86; Aners Malmberg and Peter Maskell, Peter, "The Elusive Concept of Localization Economics: Towards a Knowledge-based Theory of Spatial Clustering," Environment and Planning A (2002): 429-49.
[28] See Harald Degner, "Schumpeterian German Firms before and after World War I: The Innovative Few and the Non-innovative Many," Zeitschrift für Unternehmensgeschichte 54 (2009): 50-72, 62. See also Harald Degner, Windows of Technological Opportunity: Do Technological Booms influence the Relationship between Firm Size and Innovativeness? FZID Discussion Papers 15 (2010).
[29] The authors can provide on request the rankings of firms for the other foreign countries listed in Figures 4 and 5.
[30] Cantwell, "Technological Innovation," 18 f, comes to a similar conclusion.

American Firms before the First World War	Location	Long-lived German Patents
United Shoe Machinery Company	Paterson & Boston	312
The Singer Manufacturing Company	Elizabeth, New Jersey	95
Underwood Typewriter Company	New York	55
Automatic Electric Company	Chicago	36
General Electric (and previous companies of Thomas Alva Edison)	Menlo-Park and other places, New Jersey	36
Westinghouse	Pittsburgh	32
The National Cash Register Company	Dayton, Ohio	28
Lanston Monotype Machine Company	New York, Washington, Philadelphia	25
The Aeolian Company	New York	24
Union Trust Company	Washington	21
American Firms after the First World War	**Location**	**Long-lived German Patents**
The Singer Manufacturing Company	Elizabeth, New Jersey	199
United Shoe Machinery Corporation	Paterson und Boston	128
The National Cash Register Company	Dayton, Ohio	103
The Tabulating Machine Company	Washington D.C.	90
Union Trust Company	Washington D.C.	67
Mergenthaler Linotype Company	Brooklyn, New York	63
International General Electric Co Inc	Schenectady, New York	45
Union Special Machine Company	Chicago, Illinois	41
Eclipse Machine Company	Elmira, New York	38
Edward G. Budd Manufacturing Company	Philadelphia	38
British Firms before the First World War	**Location**	**Long-lived German Patents**
Vickers Limited	Westminster and Sheffield	45
Westinghouse Brake Company Limited	London	41
Lanston Monotype Company	London	23
Western Electric Company Limited	London	23
Marconi`s Wireless Telegraph Company	London	17
Westinghouse Electric Company Limited	London	14
The Hotchkiss Ordnance Company Limited	London	12
Babcock & Wilcox Limited	London	9
Anglo-American Inventions Syndicate Limited	London	7
Elmore's German & Austro-Hungarian Metal Company Limited	London	7
The Linotype Company Limited	London	7
British Firm after the First World War	**Location**	**Long-lived German Patents**
Marconi´s Wireless Telegraph Co Ltd	London	22
Pilkington Brothers Limited	St. Helens	20
Camco (Machinery) Limited	London	17
The Westinghouse Brake & Carby Signal Co Ltd	London	15
Western Electric Company Limited	London	15
The Anode Rubber Company Limited	London	11
Minerals Seperation Limited	London	9
Bickerys (1920) Limited	London	5
Scottish Dyes Limited	Grangemouth, Stirling	5

a Source: Baten/Streb patent data base.

4 International patterns of technological specialisation

After analyzing the scale of foreign patenting activities in Germany between 1877 and 1932, we now look at the international patterns of technological specialization in this period. We calculate, for each of the 21 countries listed in Figures 4 and 5, their indices of revealed technological advantage (RTA) in 29 out of the 89 technological classes of the German patent statistic for the two sub periods 1877 to 1914 (before the First World War) and 1919-1932 (after the First World War). For each sub period, p_{ij} denotes the number of long-lived German patents of country *i* in patent class *j*, p_i the number of all long-lived German patents of country *i*, p_j the number of all long-lived German patents in patent class *j* and *p* the total number of long-lived German patents that were granted to patentees located in the 21 designated foreign countries:[31]

$$RTA_{ij} = \frac{p_{ij} / p_i}{p_j / p} \qquad (1)$$

If RTA_{ij} is larger (smaller) than 1, country *i* has an international technological advantage (disadvantage) in patent class *j*. Note that we have not calculated indices of revealed technological advantage for the German inventors because their domestic patenting activities are not directly comparable to the patenting activities of the foreign countries in the German patent market. We have already shown with Figure 2 that foreign patents represent only the most valuable part of all domestic patents and, therefore, differ both in scale and structure from the latter. This conclusion is supported by Pacci, Sassu and Usa, who show that, for the leading research economies in the 1970s and 1980s, the correlation coefficients between domestic and foreign technological specialisation are, in most cases, neither positive nor significant.[32]

To get a more-aggregated picture of the international patterns of technological specialisation, we pre-selected 29 German patent classes and assigned them to ten broader technological fields. These technological fields cover the basic technologies of the First Industrial Revolution (steam power, textile industry, coal and steel industry, railways, machine tools), of the Second Industrial Revolution (motorcar industry, precision engineering, electrical engineering, chemicals), and of the evolving era of mass consumption. We then calculated for

[31] See Cantwell, “Technological Innovation,” 19 f, and Patel and Pavitt, “Technological Accumulation,” 767.
[32] See Raffaele Paci, Antonio Sassu and Stefano Usa, “International Patenting and National Technological Specialization,” Technovation 17 (1997): 25-38, 34.

each of these 29 patent classes the indices of revealed technological advantage for the 21 most important foreign countries in the German patent market. Table A1 in the Appendix reports for each patent class and for both sub-periods (before and after the First World War) the five countries with the highest RTA, given that the RTA is larger than 1. In patent class "Watches (83)," for example, only the Swiss RTA is larger than 1 and, therefore, shown. In a next step, we evaluated a country's strengths in each technological field. We call a country's patenting activities in a particular technological field persistent (indicated by *italics*) if this country displays a comparatively high RTA in at least one patent class of this technological field both before and after the First World War. We call a country's patenting activities in a particular technological field technologically diversified (indicated by **bold letters**) if this country has a comparatively high RTA in at least two patent classes of this technological field during one sub-period. In the technological field "Steam power," for example, the Russian patenting activities in Germany are both persistent and technologically diversified because Russia has a high RTA in patent class "Steam boiler (13)" before and after the First World War and reveals technological advantages in both patent class "Steam boiler (13)" and patent class "Steam engines (14)" in the later sub-period. Table 3 summarizes the results of our evaluation. Lightly-shaded cells indicate persistent or diversified advantages in a technological field; dark shades highlight persistent <u>and</u> diversified advantages.

Table 3 **Technological advantages of the top 21 foreign countries patenting in Germany (p = persistent superior patenting activities within a technological class; d = diversified superior patenting activities in a technological field)**

	Technologies of the First Industrial Revolution					**Technologies of the Second Industrial Revolution**				**(Mass) Consumption**
Country	Steam power	Textile industry	Coal and steel industry	Railways	Machine tools	Motorcar industry	Precision engineering	Electrical Engineering	Chemicals	Foodstuffs, drinks, tobacco, clothes, shoes
European core										
Great Britain		d			p, d			p	p	d
Belgium			p, d		p, d	p				
Luxembourg			p, d							
France		d				p, d	p, d			p, d
Netherlands			d	p			p, d			p, d
Switzerland	p	p, d					p	p	p, d	
European Periphery										
Austria		d			p, d					
Hungary		p, d	p				d			d
Russia	p, d	d	d							
Czechia	p	p	p, d	d						
Poland		d	p, d							d
Denmark				d		p	p			p, d
Norway			p, d						d	
Sweden	p, d		d	p, d	p	p				
Finland										
Ireland										d
Italy		d				p, d				
Spain		p	p, d							
Overseas										
USA		p, d								p, d
Canada			d			d				
Japan			d							

The (inventors of the) countries of the European core revealed technological strength in the old technological fields of the First Industrial Revolution which took place before our observation period and in the new technological fields of the Second Industrial Revolution which happened exactly during our observation period. Great Britain, for example, excelled in the textile industry, machine tools, electrical engineering, chemicals, and mass-consumption technology. In contrast, the Eastern and Southern European countries of the European periphery demonstrated technological strength mostly in the well-known technological fields of the First Industrial Revolution, such as Spain or Poland in the textile, coal and steel industries.[33] This difference suggests that a country’s technological advantages were significantly influenced by its actual stage of economic development. While the economically advanced countries of the European core had already explored the prospects of the more science-based technologies of the Second Industrial Revolution, the less-advanced countries were still engaged primarily in the traditional technological fields of the First Industrial Revolution. This finding supports Cantwell’s hypothesis that backward countries were not able to catch up to the leading research economies’ superior level of innovativeness. However, the Scandinavian countries of Denmark, Norway, and Sweden – often called the “impoverished sophisticates” (high literacy, low income)[34] – achieved technological advantages in some technologies of the Second Industrial Revolution.

A closer look at the performance of individual countries reveals further insights. The availability of domestic natural resources obviously influenced countries’ technological specialisation greatly. Most of the countries with their own natural deposits of coal, iron or other non-ferrous metals, especially Belgium, Luxembourg, Czechia, Poland, Norway,[35] and Spain,[36] displayed strong advantages in the technological field of the coal and steel industry, which included mining technologies for non-ferrous metals.[37] France, the Netherlands and

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[33] In our period under observation, the Basque region concentrated on ore trade while the Catalan economy was engaged mainly in the textile industry. See Joseph Harrison, “Heavy Industry, the State, and Economic Development in the Basque Region, 1876-1936,” in The Economic Development of Spain since 1870, ed. Pablo Martín-Aceña and James Simpson (Aldershot, 1995), 333-49.

[34] See Baten and Jaeger, “Foreign Patenting.”

[35] In Norway, silver, copper, sulphur, iron, and nickel were mined. See Olav Wicken, “The Layers of National Innovation Systems: The Historical Evolution of a National Innovation System in Norway,” in Innovation, Path Dependency, and Policy: The Norwegian Case, ed. Jan Fagerberg, David C. Mowery and Bart Verspagen (Oxford, 2009), 33-60, 45 f.

[36] Spain had rich reserves of iron, lead, sulphur, copper, and mercury. See Charles Harvey and Peter Taylor, “Mineral Wealth and Economic Development: Foreign Direct Investment in Spain, 1851-1913,” Economic History Review 40 (1987): 185-207.

[37] The main European coalfields are listed in Peter Scott, “Path Dependence, Fragmented Property Rights and the Slow Diffusion of High Throughput Technologies in Inter-war British Coal Mining,” Business History 48 (2006): 20-42, 23.

Denmark[38] used their advanced agriculture to concentrate on innovations that fostered the mass consumption of foodstuffs and drinks.

It is not surprising that Italy and France displayed great technological strength in the field of motor cars. Canada, however, which is not renowned for manufacturing automobiles, also revealed some technological advantage in this field before the First World War. One might think that this result is a rather curious statistical artefact of the RTA analysis. But Hawkins claims that Canada had a strong and highly innovative domestic motor car industry in the early twentieth century.[39] Therefore, our analysis of the historical patterns of technological specialisation might also produce information about abandoned national paths of technological development that would be otherwise forgotten. However, the historical data do not reveal the actual technological advantages of Japan and Finland, which were not yet well-developed in the interwar period.

Interestingly enough, Switzerland's technological advantages in precision engineering, electrical engineering and chemicals perfectly mirror the structure of the domestic patenting activities in its neighbouring country Germany.[40] This finding suggests that technological transfer between Germany and Switzerland was intense and bi-directional. The fact that the United States displayed comparatively high technological advantages in manufacturing clothes and shoes highlights this country's large advances in innovative technologies needed to satisfy the demand for cheap mass-consumption goods.[41]

5 Conclusions

In this paper, we used both patents' individual life span and foreign patenting activities in Germany to identify the most valuable patents of the 21 most innovative countries (except for Germany) from the European Core, the European periphery and overseas between 1877 and

[38] See Kevin O'Rourke, "Property Rights, Politics and Innovation: Creamery Diffusion in Pre-1914 Ireland," European Review of Economic History 11 (2007): 395-417.
[39] See Richard Hawkins, "Is Canada Really All that Bad at Innovation? A Tale of Two Industries," International Productivity Monitor 18 (2009): 72-79, 73.
[40] See Streb, Baten and Yin, "Knowledge Spillover," 358.
[41] The reader might wonder why the United States displayed technological strengths only in textiles and mass-consumption technologies with regard to clothes and shoes. This is not a sign of technological weakness but, rather, the result of the method used. Because of their outstanding German patenting activities, the United States set the standard of comparison for our RTA analysis, which means that the share of this country's patents of a particular technological class among all its German patents (the nominator of equation 1) cannot differ much from this technological class's share in all German patents granted to patentees in all observed foreign countries (the denominator in equation 1). Hence, the American RTAs hardly deviate from one and, consequently, do not often show up in Table A1 in the Appendix.

1932. Our empirical analysis revealed that important characteristics of the international distribution of foreign patents are time-invariant. In particular, the distribution of foreign patents across countries in the late nineteenth and early twentieth centuries was as highly skewed as it was in the late twentieth century – and even dominated by the same major research economies. This skewness of distribution can also be found in the innovative countries in which just a few firms were responsible for the majority of foreign patenting activities. Our analysis suggests that these firms' technological advantages were influenced both by exogenous local factors, such as the countries' resource endowment, and by endogenous factors, such as the national education and research system or the countries' actual stage of economic development. In addition, the most innovative firms were apparently able to acquire and transfer technological knowledge not only with the help of foreign direct investment, but also through patenting activities. Understanding these firm-level determinants of countries' technological leadership in more detail is one of the most important future challenges for global business historians.

Appendix: Table A1: Indices of revealed technological advantage[a]

Technological Class	**Before World War I (1877-1914)**					**After World War I (1918-1932)**				
Steam Power										
Steam boiler (13)	L 3.3	*RUS 2.2*	F 2.1	DK 1.6	GB 1.5	PL 6.4	***RUS 4.1***	H 2.9	**S 1.4**	NL 1.4
Steam engine (14)	*S 3.9*	CDN 2.1	*CH 2.0*	*CZ 1.9*	PL 1.5	**RUS 8.6**	***S 4.9***	*CH 2.8*	*CZ 1.7*	I 1.3
Textile industry										
Spinning (76)	IRL 6.2	*E 5.5*	**PL 4.9**	CDN 2.3	***CH 2.0***	*E 11.8*	**I 2.5**	***CH 1.9***	**F 1.8**	**GB 1.6**
Weaving (86)	**PL 4.1**	*CZ 2.6*	***A/H 1.9***	***CH 1.7***	**RUS 1.3**	J 27.2	*CZ 2.8*	**F 2.7**	***CH 2.4***	*H 1.1*
Braiding (25)	N 2.2	**A/H 1.5**	***USA 1.3***	NL 1.3	**RUS 1.2**	**F 3.0**	**I 1.9**	**GB 1.7**	***USA 1.3***	
Sewing (52)	***USA 2.3***	**CH 1.9**				***USA 2.8***				
Coal and steel										
Mining (5)	**PL 29.3**	**RUS 7.1**	***B 3.7***	**NL 2.6**	*A/H 2.4*	**J 24.6**	***B 5.6***	*H 4.9*	**CZ 1.8**	GB 1.3
Metallurgy (40)	J 27.7	**E 7.6**	***PL 6.7***	**NL 4.7**	**N 4.0**	***PL 23.8***	**L 4.7**	**CDN 3.8**	**B 3.5**	**S 1.7**
Ironmaking (18)	***L 39.3***	I 5.8	***CZ 2.5***	***B 2.4***	**RUS 2.2**	***L 10.8***	**J 7.0**	***B 3.2***	***CZ 3.1***	**S 2.0**
Metal processing (7)	***L 12.4***	FIN 11.3	***E 7.2***	***N 5.0***	**CZ 2.4**	***L 15.7***	*E 11.5*	**PL 5.3**	*N 5.1*	**CDN 2.6**
Railways										
Railway construction (19)	**DK 4.0**	B 2.7	F 1.7	CZ 1.6	A/H 1.3	PL 60.4	CH 2.4	GB 1.2	USA 1.1	
Railway operation (20)	FIN 4.2	I 2.2	IRL 2.0	GB 1.5	E 1.3	N 4.7	H 3.5	B 2.9	**CZ 1.5**	**S 1.4**
Signalling equipment (74)	CDK 9.3	*S 3.8*	**DK 3.0**	*NL 2.3*	USA 1.5	RUS 7.1	**CZ 5.0**	*NL 1.8*	***S 1.6***	F 1.2
Machine Tools										
Metal working (49)	PL 3.5	**B 1.6**	***GB 1.6***	USA 1.2		FIN 10.6	L 2.7	***GB 1.7***	CH 1.5	**A 1.1**
Machine parts (47)	CDN 5.6	*S 2.7*	***A/H 2.0***	RUS 1.9	DK 1.6	*S 2.9*	***A 1.5***	**GB 1.3**	F 1.2	
Grinding (67)	CZ 6.0	N 3.2	***B 2.2***	**A/H 1.1**	***GB 1.1***	*B 5.1*	***GB 2.2***	DK 1.9	USA 1.2	
Motorcar industry										
Combustion engines (46)	*S 3.1*	***I 2.3***	***F 2.2***	**CDN 1.9**	*DK 1.8*	***I 2.5***	*DK 1.7*	***F 1.6***	CH 1.2	*S 1.0*
Vehicles (63)	IRL 7.0	***I 3.8***	**CDN 2.0**	***F 1.8***	*B 1.5*	***I 3.2***	*B 2.5*	***F 1.5***	CZ 1.5	GB 1.2
Precision engineering										
Scientific Instruments (42)	J 9.8	*NL 1.4*	USA 1.3	**F 1.2**	GB 1.1	IRL 27.9	E 4.7	**H 2.6**	CZ 2.1	***NL 1.8***
Watches (83)	*CH 5.5*	***F 1.0***				*CH 3.5*	***F 1.6***			
Photography (57)	PL 9.3	*DK 1.3*	***F 2.4***			FIN 4.3	***F 3.6***	*DK 2.4*	**NL 2.4**	**H 1.7**
Electrical engineering										
Electrical engineering (21)	I 1.9	*CH 1.3*	A/H 1.1	*GB 1.1*	USA 1.1	B 1.8	NL 1.8	N 1.4	*GB 1.3*	*CH 1.2*
Chemicals										
Synthetic Dyes (22)	***CH 7.2***	PL 2.3	E 1.9			***CH 4.2***	J 3.2	**N 2.0**	CZ 1.9	
Chemical prozesses (12)	I 1.9	***CH 1.3***	A/H 1.1	*GB 1.1*	USA 1.1	B 1.8	NL 1.8	**N 1.4**	*GB 1.3*	***CH 1.2***
(Mass) Consumption										
Foodstuffs (53)	CDN 13.1	**IRL 11.8**	***DK 6.3***	*NL 3.3*	**F 1.7**	***DK 16.6***	N 7.3	**H 1.8**	***NL 1.2***	B 1.0
Drinks (6)	L 28.2	**IRL 3.7**	**PL 2.9**	***DK 2.7***	***F 2.5***	***DK 4.2***	*F 3.3*	CH 2.7	**NL 2.3**	**H 2.2**
Tobacco (79)	FIN 70.5	RUS 23.1	**PL 4.5**	***USA 1.1***		**H 3.1**	A 2.9	S 2.2	***USA 1.6***	**GB 1.2**
Shoes (71)	***USA 3.2***					***USA 2.7***				
Clothes (3)	**PL 4.8**	**F 2.0**	B 1.5	***USA 1.5***		CZ 7.1	**GB 1.4**	***USA 1.3***		

a **Bold** letters indicate that the country displayed before or after the First World War a comparatively high RTA in at least two patent classes of a technological field.
Italic letters indicate that the country displayed a comparatively high RTA in a patent class both before and after the First World War.
Abbreviations: A Austria, B Belgium, CDN Canada, CH Switzerland, CZ Czechia, DK Denmark, E Spain, F France, FIN Finland, GB Great Britain, H Hungary, IRL Ireland, I Italy, J Japan, L Luxembourg, N Norway, NL Netherlands, PL Poland, RUS Russia, S Sweden, USA United States of America..

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