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The German Market for Patents during the "Second Industrialization," 1884–1913: A Gravity Approach

Using newly collected patent assignment data for late nineteenth- and early twentieth-century Germany and a standard econometric approach from the international trade literature —the gravity model—we demonstrate the existence of border effects on a historical technology market. We show that the geographic distance between assignor and assignee negatively affected the probability of patent assignments, as well as the fact that a state or international border separated the two contracting parties. Surprisingly, we show that the effect of a state border within Germany was nearly as large as the effect of an international border.

New production technologies have the power to shift the production-possibility frontier of an economy outward at a given amount of factor inputs. Alternatively, newly invented products enlarge the set of goods and services available to consumers. Yet, enlarging the set of available products or shifting the production possibility frontier outward does not imply that production takes place on the frontier. The allocation of technology in an economy may be inefficient. One way to improve the allocation of technology is to generate tradable intellectual property rights, e.g., patents. Beyond improving the allocation of technology in the economy, trade shifts the production possibility further outward since it increases the incentive to innovate. The inventor can simply sell the patent to a specialized producer and focus his own efforts on the next invention. Consequently, per-capita incomes increase due to the better allocation of technology and due to the higher rate of innovation.[1] This argument applies to national as well as to international exchange

[1] Daniel F. Spulber, "Innovation and International Trade in Technology," *Journal of Economic Theory* 138, no. 1 (2008): 1–20.

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of patents. Therefore, a government that aims at maximizing growth should aim at minimizing barriers of trade in technology.

Yet, transfer of technology over space is far from frictionless. At least since the seminal work of Adam Jaffe, Manuel Trajtenberg, and Rebecca Henderson, it is well known that knowledge spillovers as measured by patent citations are geographically limited. Moreover, the same authors have demonstrated that not only geographic distance, but also state borders within the United States inhibit knowledge spillovers.[2] The impact of geographic distance and US state borders on knowledge spillovers has been controversially debated. Nonetheless, the existence of international barriers to knowledge spillovers is undisputed.[3] Similar results have been reported for Europe: distance, borders, and linguistic barriers as measured by patent citations negatively affect knowledge spillovers.[4]

Historical research has also provided evidence of knowledge spillovers and transfers of intellectual property rights. In particular, Naomi Lamoreaux and Kenneth Sokoloff demonstrated that about one-third of all US patents were assigned during the late nineteenth and early twentieth centuries.[5] Tom Nicholas has also highlighted patent assignments over large geographic distances within the United States.[6] In particular, individual inventors already supplied a national market with their ideas during the early twentieth century.[7] Furthermore, Petra Moser demonstrated that the rise of patenting activity in the chemical industry weakened the localization of innovation substantially.[8] Patent assignments

[2] Adam Jaffe, Manuel Trajtenberg, and Rebecca Henderson, "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *Quarterly Journal of Economics* 108, no. 3 (1993): 577–98.

[3] Peter Thompson and Melanie Fox-Kean, "Patent Citations and the Geography of Knowledge Spillovers: A Reassessment," *American Economic Review* 95, no. 1 (2005): 450–60; Rebecca Henderson, Adam Jaffe, and Manuel Trajtenberg, "Patent Citations and the Geography of Knowledge Spillovers: A Reassessment: A Comment," *American Economic Review* 95, no. 1 (2005): 461–64; Peter Thompson and Melanie Fox-Kean, "Patent Citations and the Geography of Knowledge Spillovers: A Reassessment: A Reply," *American Economic Review* 95, no. 1 (2005): 465–66; Wolfgang Keller, "Geographic Localization of International Technology Diffusion," *American Economic Review* 92, no. 1 (2002): 120–42.

[4] Per Botolf Maurseth and Bart Verspagen, "Knowledge Spillovers in Europe: A Patent Citation Analysis," *Scandinavian Journal of Economics* 104, no. 4 (2002): 531–45.

[5] Naomi R. Lamoreaux and Kenneth L. Sokoloff, "Inventors, Firms, and the Market for Technology in the Late Nineteenth and Early Twentieth Centuries" in *Learning by Doing in Markets, Firms, and Countries*, ed. Naomi R. Lamoreaux, Daniel M. G. Raff, and Peter Temin (Chicago, 1999), 19–60; Naomi R. Lamoreaux and Kenneth L. Sokoloff, "Market Trade in Patents and the Rise of a Class of Specialized Inventors in the Nineteenth-Century United States," *American Economic Review* 91, no. 2 (2001): 39–44.

[6] Tom Nicholas, "Spatial Diversity in Invention: Evidence from the Early R&D Labs," *Journal of Economic Geography* 9, no. 1 (2009): 1–31.

[7] Tom Nicholas, "The Role of Independent Invention in US Technological Development, 1880–1930," *Journal of Economic History* 70, no. 1 (2010): 57–82.

[8] Petra Moser, "Do Patents Weaken the Localization of Innovations? Evidence from World's Fairs," *Journal of Economic History* 71, no. 2 (2011): 363–82.

in a national patent market also contributed to the performance of the Japanese and the British economy during the same period.[9] Turning to Germany, Jochen Streb, Jörg Baten, and Shuxi Yin showed that patenting activity was highly concentrated and that patenting activity in one district positively affected patenting activity in nearby districts. Their findings document knowledge spillovers in Germany between the 1870s and the 1910s.[10] Carsten Burhop has recently provided more direct evidence of patent assignments and thus the transfer of technology. He demonstrated that a substantial fraction of the patents granted in Germany between 1877 and 1913 have been assigned.[11]

In addition, David Gilgen evaluated the international transfer of patented technology by looking at aggregate patenting data. His indicator of international technology transfer is the number of patents granted to Germans in other countries and the number of patents granted to foreigners in Germany. He shows that between the 1890s and World War I about one-third of all German patents were granted to foreigners. Major sources of imported technology were the United States, the United Kingdom, France, and Austria-Hungary. Moreover, Gilgen demonstrates that Germans were active in patenting technology in Britain and the United States.[12] In contrast to Gilgen, we use patent-level data, whereas he is using aggregate national statistics. Moreover, we are also investigating patent transfers within Germany, whereas Gilgen is only looking at international patenting activity. Finally, we use the patent fees paid before a patent transfer as an indicator of patent value, whereas Gilgen treats all patents equally.

We contribute to the debate by combining German patent assignment data collected by Burhop as well as newly collected data from the same data source as Burhop's data with a workhorse model of the international trade literature, the gravity equation. To our knowledge, this is the first attempt to capture technology transfer by patent assignment data in the context of a standard international trade model. In

[9] Tom Nicholas, "Independent Invention during the Rise of the Corporate Economy in Britain and Japan," *Economic History Review* 64, no. 3 (2011): 995–1023.

[10] Jochen Streb, Jörg Baten, and Shuxi Yin, "Technological and Geographical Knowledge Spillovers in the German Empire, 1877–1918," *Economic History Review* 59, no. 2 (2006): 347–73.

[11] Carsten Burhop, "The Transfer of Patents in Imperial Germany," *Journal of Economic History* 70, no. 4 (2010): 921–39.

[12] David Gilgen, "Die Schaffung eines globalen Marktes für Innovationen—Chancen und Grenzen globaler Institutionen, 1880–1914," in *Deutschland als Modell? Rheinischer Kapitalismus und Globalisierung seit dem 19. Jahrhundert*, ed. David Gilgen, Christopher Kopper, and Andreas Leutzsch (Bonn, 2010), 315–59. Gilgen's work is based on aggregate data (i.e., the number of patents granted to Germans in the United States during a certain year), whereas we use microdata (i.e., the assignment of a certain patent from a certain firm to another firm during a certain year). Moreover, Gilgen uses the national state as geographic entity, whereas we geo-code each patent.

particular, we want to assess if and to what extent geographical distance, intranational—i.e., borders between German states—and international borders negatively affect the frequency of patent assignments. Such a negative effect of borders is usually reported for trade in goods and services.[13] In particular, Holger Wolf has reported a negative effect for modern intranational trade between US states and Nikolaus Wolf reported it for pre-1914 Germany: Not only the external but also Germany's internal administrative borders restricted the flow of goods and services.[14] However, an investigation using historical patent transfer data is—to the best of our knowledge—so far unavailable.

Our key finding is a significantly negative effect of both distance and borders on patent flows. Running a regression with the number of patent assignments between city pairs as the dependent variable, we find that patents behave very similarly to other commodities. They are traded less frequently over long distances and less frequently across state and national borders. We thus find evidence that even within Germany the market for technology was not fully integrated during the late nineteenth and early twentieth centuries. Moreover, we find that the value of patents increases the frequency of their being traded and the probability of their being traded over longer distances, similar to evidence in trade that more valuable commodities are shipped over longer distances.[15] Once we interact distance with a proxy for patent value, we find that distance poses a much lower barrier to transfers to higher-valued patents than to lower-valued patents, which is a quite intuitive result.

The remaining parts of the article are organized as follows. We start with a section providing historical background information. In the next section, we describe the data sources and present some descriptive statistics. We then outline the econometric approach, present the estimation results, and finally conclude the article.

Historical Background

From the 1870s onward, the incorporation of science into industrial production and the industrialization of scientific research characterized

[13] James E. Anderson and Eric van Wincoop, "Gravity with Gravitas: A Solution to the Border Puzzle," *American Economic Review* 93, no. 1 (2003): 170–92, is the seminal article in the field of international trade in goods and services. They show that international borders reduce trade by 20 to 50 percent.

[14] Holger C. Wolf, "Intranational Home Bias in Trade," *Review of Economics and Statistics* 82, no. 4 (2000): 555–63; Nikolaus Wolf, "Was Germany Ever United? Evidence from Intra- and International Trade, 1885–1933," *Journal of Economic History* 69, no. 3 (2009): 846–81.

[15] David Hummels and Alexandre Skiba, "Shipping the Good Apples Out? An Empirical Confirmation of the Alchian-Allen Conjecture," *Journal of Political Economy* 112, no. 6 (2004): 1384–1402.

the German innovation system. In particular, firms from the chemical and pharmaceutical industries made increasing use of the growing reservoir of scientifically trained chemists—either by employing them for in-house research or by cooperating with them.[16] Apart from heavy investment in universities and other research facilities, an important political contribution was the enactment of the first unified German patent law in 1877. In the preceding years, there existed a patchwork of numerous patent legislations in the individual German states, and in many cases the state authorities regarded patents as privileges rather than as rights.[17] As a result of the enactment of the patent law, inventions covered by the law became a nationwide tradable good.

Case studies of innovation procurement suggest a significant flow from outside inventions into new products.[18] However, only some evidence exists from studies that focus on either the research activities or the general history of specific companies. In his study on the synthetic-dye-research programs of BASF and Hoechst, Carsten Reinhardt gives a detailed account of the companies' cooperation with individual researchers.[19] In addition, he mentions technology-transfer agreements that these companies signed with other companies. For the pharmaceutical research activities of Bayer, Hoechst, and Merck, Wolfgang Wimmer provides some information about these companies' exchanges of technology with individual researchers and with other firms.[20] Similar information about technology transfer with companies and the cooperation with individual researchers is available in Werner Abelshauser's monograph on the corporate history of BASF, Burhop's article on Merck, Reinhardt's work on pharmaceutical research at BASF, and Reinhardt and Travis's study on Heinrich Caro, BASF's head of research during the

[16] There are numerous studies on the linkage between the state, universities, and the chemical industry. See, e.g., Peter Borscheid, *Naturwissenschaft, Staat und Industrie in Baden, 1848–1914* (Stuttgart, 1976); Johann Peter Murmann, *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions* (Cambridge, UK, 2003); Walter Wetzel, *Naturwissenschaften und chemische Industrie in Deutschland: Voraussetzungen und Mechanismen ihres Aufstiegs im 19. Jahrhundert* (Stuttgart, 1991).

[17] For the history of the patent laws of different German territories, see Alfred Heggen, *Erfindungsschutz und Industrialisierung in Preußen, 1793–1877* (Göttingen, 1975); Margrit Seckelmann, *Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871–1914* (Frankfurt am Main, 2006), 57–106. The long lasting and complex negotiation process that preceded the enactment of the patent law in 1877 is documented in Arndt Fleischer, *Patentgesetzgebung und chemisch-pharmazeutische Industrie im Deutschen Kaiserreich, 1871–1918* (Stuttgart, 1984).

[18] Wolfgang Wimmer, *"Wir haben fast immer was Neues": Gesundheitswesen und Innovationen in der Pharma-Industrie in Deutschland, 1880–1935* (Berlin, 1994); Carsten Burhop, "Pharmaceutical Research in Wilhelmine Germany: The Case of E. Merck," *Business History Review* 83 (Autumn 2009): 475–503.

[19] Carsten Reinhardt, *Forschung in der chemischen Industrie: Die Entwicklung synthetischer Farbstoffe bei BASF und Hoechst, 1863–1914* (Freiberg, 1997).

[20] Wimmer, "*Wir haben fast immer was Neues.*"

late nineteenth century.[21] Furthermore, Manfred Pohl, Peter Strunk, Wilfried Feldenkirchen, and—last but not least—Sigfrid von Weiher and Herbert Goetzler mention that firms from the field of electrical engineering were also involved in the transfer of technology.[22] Thus, business historians have already investigated some aspects of technology procurement.

Our article goes beyond the state of the art in two dimensions. First, we are not focusing on individual firms, great inventors, or important inventions, but on systematic evidence about the transfer of technology. Second, we incorporate geographic distance as an important explanatory variable with respect to the transfer of technology embodied in patents. Yet, our approach is limited with respect to the type of technology and to the legal type of transfer we are looking at. More specifically, we only investigate the transfer of technology codified in patents, and we are only evaluating the complete transfer of a patent (i.e., buying and selling a patent), whereas we do not cover other types of legal transfers, especially licensing agreements. This focus implies that the patent law—specifying the property right to be traded—and the civil law—governing the buy-and-sell contract—build the legal backbone of our article.

In 1877, the first federal patent law in Germany replaced a patchwork of state-specific legislations. Subsequently, inventors had to learn the principles of the new patent law since it was an entirely new law and not the extension of one state law (e.g., the Prussian patent legislation) to the other German states. Moreover, the learning base of inventors varied with their place of residence; for example, until 1877 some states had a technical examination of patent applications (e.g., Prussia), whereas other states granted a patent without technical examination (e.g., Bavaria). Furthermore, some states (e.g., Hamburg and Bremen) had no patent law at all. Such state-wise differences in the pre-1877 period may imply border effects that slowly disappeared after 1877.

The new German patent law specified at first the qualities of a patent. In particular, according to §1 of the patent law (PatG), a patent can be granted for a new invention if the invention is of potential economic

[21] Werner Abelshauser, ed., *Die BASF: Eine Unternehmensgeschichte* (Munich, 2002); Burhop, "Pharmaceutical Research in Wilhelmine Germany"; Reinhardt, *Forschung in der chemischen Industrie*; Carsten Reinhardt and A. S. Travis, *Heinrich Caro and the Creation of the Modern Chemical Industry* (Dordrecht, 2000).

[22] Manfred Pohl, *Emil Rathenau und die AEG* (Berlin, 1988); Wilfried Feldenkirchen, *Siemens: Von der Werkstatt zum Weltunternehmen* (Munich, 2003); Peter Strunk, *Die AEG: Aufstieg und Niedergang einer Industrielegende*, 2d ed. (Berlin, 2000); Sigfrid von Weiher and Herbert Goetzler, "Weg und Wirken der Siemens-Werke im Fortschritt der Elektrotechnik, 1847–1980: Ein Beitrag zur Geschichte der Elektroindustrie," *Zeitschrift für Unternehmensgeschichte, Beiheft 21* (Stuttgart, 1981).

use. Thus, German patents can be considered as commodities. Food, drugs, and chemical products could not be patented, but the patent law covered the processes employed.[23] The patent covered the German territory, i.e., the patent holder had the exclusive right to use the patented technology in Germany. In addition, the policy interdicted importing patent-protected products from other countries by third parties (§4 PatG). Thus, the economic value of a German patent depended on the size of the market for the protected product or process within Germany. Since the German economy grew over time, the market potential for a patent holder increased, too. Assuming constant transaction costs, growing market size should lead to growing transfer activity over time. Furthermore, a growing market for patents may lead to the emergence of specialized intermediaries—e.g., patent lawyers—inducing declining transaction costs and increasing market size. We therefore expect a growing transfer activity over time.

Transaction costs included the legal and administrative costs. The patent office can register patent assignments and has to register changes in ownership if it gets knowledge about such a change. No fee was raised for such a registration. However, the buyer and the seller of a patent had to provide a legal certificate from the local court or from a *Notar*.[24] However, there was no legal obligation on the part of buyers or sellers to inform the patent office. Yet, all patent rights belonged to the person registered at the patent office.[25] This policy implies that the registered patent owner has the exclusive right to use the patent—a strong incentive to register the assignment at the patent office.

The patent law did not regulate the legal act governing the transfer of a patent. This omission is quite important to mention, since the contract law governing buying and selling of a patent had been a state law until nationwide legislation came into force in January 1900 (Bürgerliches Gesetzbuch, BGB).[26] At least from 1900 onward, the seller of a patent had additional duties, which the contract did not necessarily define well (Treu und Glauben).[27] For example, the patent seller not only

[23] §1 PatG "Patente werden erteilt für neue Erfindungen, welche eine gewerbliche Verwertung gestatten. Ausgenommen sind: 1. Erfindungen, deren Verwertung den Gesetzen oder guten Sitten zuwiderlaufen würde; 2. Erfindungen von Nahrungs-, Genuß- und Arzneimitteln, sowie von Stoffen, welche auf chemischem Weg hergestellt werden, soweit die Erfindungen nicht ein bestimmtes Verfahren zur Herstellung der Gegenstände betreffen."

[24] Felix Damme, *Das deutsche Patentrecht* (Berlin, 1906), 92.

[25] §19 (2) PatG "Tritt in der Person des Patentinhabers oder seines Vertreters eine Änderung ein, so wird dieselbe, wenn sie in beweisender Form zur Kenntnis des Patentamtes gebracht ist, ebenfalls in der Rolle vermerkt und durch den Reichsanzeiger veröffentlicht. Solange dies nicht geschehen ist, bleiben der frühere Patentinhaber und sein früherer Vertreter nach Maßgabe dieses Gesetzes berechtigt und verpflichtet."

[26] Damme, *Patentrecht*, 387.

[27] Josef Kohler, *Handbuch des deutschen Patentrechts in rechtsvergleichender Darstellung* (Mannheim, 1900), 581–82.

had to provide the patent but also all information necessary to actually use the patent. Such an extensive duty to inform may imply personal contact of buyer and seller, leading to distance-dependent transaction costs.

In addition, while the property right (the patent) was defined identically all over Germany since 1877, the contract law governing the transfer of rights varied from state to state until 1900. Moreover, the contract law in force in the German states during the pre-1900 period was quite heterogeneous. For example, most parts of Prussia and Bavaria had a contract law based on traditional German and Roman legal systems (Preußisches Allgemeines Landrecht since 1794, Codex Maximilianeus Bavaricus Civilis since 1751), whereas other German territories (Baden, Württemberg, Elsass-Lothringen) used a French-style civil code from the Napoleonic era. Furthermore, the unified civil law enacted in 1900 was an entirely new law, and it was not based on any former state law. Consequently, we can expect state-border effects during the pre-1900 period, and we may find slowly disappearing border effects from 1900 onward.

With respect to international patent transfers—which Gilgen recently considered—one should keep in mind that foreigners had the same rights as Germans, but foreigners had to appoint a representative residing in Germany, usually a patent lawyer, to act for the foreign inventor (§12 PatG). In addition, German was the only language accepted by the patent office (§33 PatG). Both regulations increased the transaction costs for foreigners, and thus we expect a border effect between Germany and other countries. An international border effect may also result from the fact that the German patent law differed in some respect from other countries' legislation.

Four features distinguish the German patent law from the laws in the United States or the United Kingdom. First, in Germany, a patent was granted to the person registering it at the patent office, not to the actual inventor. Consequently, inventions made by employed inventors were typically granted to the firms they worked for. This policy makes assignments at issue much less frequent in Germany compared to the United States.[28] Second, the patent office made a detailed technical examination of the invention, and usually settled questions of patent infringements in the period between publication of the patent application and the granting of the patent.[29] Between 1877 and 1913, about 60 percent of the patent applications did not pass the technical examination

[28] Carsten Burhop and Thorsten Lübbers, "Incentives and Innovation? R&D Management in Germany's Chemical and Electrical Engineering Industries around 1900," *Explorations in Economic History* 47, no. 1 (2010): 100–11.

[29] Margrit Seckelmann, *Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871–1914* (Frankfurt am Main, 2006), 257–60.

by the patent office. In addition, 1.5 percent of the published patent applications were appealed and not granted. Once the patent was granted, it represented a very secure intellectual property right. The patent office repealed only 0.3 percent of the patents. Moreover, the number of patent infringements was extremely low, and only a few dozen cases were brought to the patent court each year.[30] Third, since it was compulsory to put the patent into use within three years after it had been issued, independent inventors had a strong incentive to assign their patents to firms when they lacked resources to comply within three years. Fourth, the patentee had to pay an annual fee to keep the patent active. This fee was 50 marks for the first year and 50 marks for the second year of protection, but thereafter the fee increased substantially by 50 marks per year up to the maximum annual fee of 700 marks for the fifteenth and final year of protection. Therefore, the cumulated fee over the maximum period of patent protection of fifteen years was 5,300 marks (ca. $1,260), about 6.5 times the annual per capita income in 1913.[31]

The differences between the German patent law and foreign patent laws made the assessment of the potential value of a German patent more difficult for foreigners. Thus, differences in patent legislation can result in a border effect. However, foreigners may learn the specific regulations of the German patent law, and we may expect a declining international border effect over time.

Data Sources and Descriptive Statistics

The data we use in this article have been collected from the annual patent register (*Verzeichnis der vom Kaiserlichen Patentamt im Jahre [. . .] erteilten und noch in Wirkung stehenden Patente*). More specifically, Section 5 of the patent yearbook contains a register of all patents that were still in force during a certain year and for which the patent office registered a change in ownership.

For example, the patent number 92,717 was transferred in 1900 to Firma Karl Ernst Maaz in Langburkersdorf, a small village in Saxony. Using the patent number, we can identify the original patent holder—either by using the annual patent register or by using the online archive

[30] Burhop, "The Transfer of Patents in Imperial Germany," 927. The importance of secure property rights for the emergence of a patent market in the United States has been highlighted by B. Zorina Khan and Kenneth L. Sokoloff, "'Schemes of Practical Utility': Entrepreneurship and Innovation among 'Great Inventors' in the United States, 1790–1865," *Journal of Economic History* 53, no. 2 (1993): 289–307; and by B. Zorina Khan, "Property Rights and Patent Litigation in Early Nineteenth-Century America," *Journal of Economic History* 55, no. 1 (1995): 58–97.

[31] Burhop, "The Transfer of Patents in Imperial Germany," 927–28.

of the German patent office. The patent was granted on 3 June 1896 to Karl Wiessner, living in Dresden, the capital of Saxony, about 37 kilometers west of Langburkersdorf. In addition, we know from these two pieces of information that until the transfer Wiessner paid at least the patent fees for 1896 (50 marks), 1897 (50 marks), 1898 (100 marks), and 1899 (150 marks)—in total 350 marks. We take this amount as the (minimum) patent value.

The first set of assignment data was published in 1884. Thereafter, annual data until 1913 are—in principle—available.[32] For a sample of patents, relevant data have already been registered. In particular, the patent number, the technology class, the name and place of residence of the original patent holder, the year the patent was issued and the year the patent was assigned. The data contain only a subsample of observation information about the name and place of residence of the new patent holder. We collected the missing information. In addition we coded the old and the new patent owner to be an individual or a firm, and we constructed dummy variables indicating if the patent transfer was related to a change in the legal form of the patent holder (i.e., an inheritance or the change of the legal type of enterprise).[33] Furthermore, using the information about the place of residence of the old and the new owner of a patent, we calculated the distance (in kilometers) between them, and we constructed dummy variables if the patent crosses an intranational or international border in the course of assignment.

While the data contain a lot of information, a few drawbacks should be kept in mind.[34] First, the transfer register did not list patent assignments agreed upon between the issue of the patent and the publication of the next patent yearbook (usually in March of the following year). This point could be important if assignments at issue were important. Indeed, assignments at issue were important in the United States, since inventions of employed inventors were first granted to the inventor and then assigned to the firm employing him. This type of assignment was most likely unimportant in Germany since the employer registered the patent. Second, some assignments were done for legal reasons. The patent office regularly assigned patents if the legal form of the firm holding the patent changed. Furthermore, the patent office registered transfers from an individual to another individual as an inheritance. The latter two types of transfers do not relate to technology market transactions, and we excluded them from our dataset. Third, the economic value of patents varies substantially, but it is usually unobservable. Standard

[32] The patent office did not publish the data for 1888.
[33] See Burhop, "The Transfer of Patents in Imperial Germany," 930–32 for more details.
[34] See ibid., 928–30, on this point.

proxies for the value of patents are the number of years a patent is in force, the patent fees paid, and the number of citations received.[35] Citations are unavailable for German patents from the late nineteenth and early twentieth centuries. In contrast, the number of years a patent was in force and the fees paid is observable. Our preferred proxy for the lower bound of the patent value is the fee paid before the transfer, since this is an obvious lower bound for the price demanded by the assignor. Fourth, the transfer data are censored since the patent office stopped the publication of those data in 1914. In practice, about 80 percent of all assignments were accomplished during the first four years after issue. Therefore, censoring may be problematic for patents issued after 1909.[36] To address this problem econometrically, we controlled for the year of issue and also clustered standard errors around the year of issue in our statistical model. Fifth, we looked only at realized transfers, not at all possible transfers; i.e., we ignored the zeros of non-assigned patents. Thus, we investigated trade data conditioned on the fact that there is trade at all.[37] By implication, all of our estimates on trade costs need to be interpreted as lower bounds.

Our database contains 13,559 patent assignments for the period 1884 to 1913. Table 1 shows some key descriptive statistics. About two-thirds of all patent assignments refer to activities within one German state; i.e., neither a national nor an international border was crossed. Around 23 percent of all assignments were agreed upon between two parties residing in different German states. More than 10 percent of all transfers involved a contracting party residing outside Germany. On average, the patent was assigned about 2.7 years after the year of issue, and they transcended about 428 kilometers (about 265 miles). Splitting the sample into two subsamples—the first running from 1884 until 1899, the second running from the unification of private law in 1900 until 1913—demonstrates that the key characteristics of patents remain very similar. Splitting the sample with respect to another dimension—namely if a border was crossed or not—yields two important insights: Patents assigned across intranational or international borders tend to be more valuable and they tend to be assigned over a longer distance.

[35] Zvi Griliches, "Patent Statistics as Economic Indicators: A Survey," *Journal of Economic Literature* 28, no. 4 (1990): 1661–1707; Hariolf Grupp, Iciar Dominguez-Lacasa, and Monika Friedrich-Nishio, *Das deutsche Innovationssystem seit der Reichsgründung* (Heidelberg, 2002); Rainer Metz and Oliver Watteler, "Historische Innovationsindikatoren: Ergebnisse einer Pilotstudie," *Historical Social Research* 27, no. 1 (2002): 4–129.

[36] Censoring could be a problem for all patents issued after 1899 since the maximum lifetime of a patent was fifteen years.

[37] This problem has been highlighted, for example, by Elhanan Helpman, Marc Melitz, and Yona Rubinstein, "Estimating Trade Flows: Trading Partners and Trading Volumes," *Quarterly Journal of Economics* 123, no. 2 (2008): 441–87.

Table 1
Descriptive Statistics

	Data by Period		
	1884–1913	*1884–1899*	*1900–1913*
Number of patent assignments	13,559	3,411	10,148
Assignment within German state (%)	66.5	66.7	66.4
Assignment across German state border (%)	23.1	21.4	23.7
International assignment (%)	10.4	11.8	9.9
Mean age of assigned patent in years	2.7	2.9	2.5
Mean distance between assignor and assignee in kilometers	428	386	442
	Data by Border		
	No Border Crossed	*German State Border Crossed*	*International Border Crossed*
Number of patent assignments	9,013	3,135	1,411
Mean age of assigned patent in years	2.6	2.9	3.2
Mean distance between assignor and assignee in kilometers	97	807	1,934

Source: Authors' calculations using patent assignment database.

Information included in Table 2 illustrates some differences among the ten most active fields of technology transfer. It turns out that the mean age of patents at the time of assignment did not vary much. Only between 2.4 and 3.2 years passed between issue and assignment of a patent. More variance among technology fields can be observed with respect to the distance or the borders transcended. On the one hand, some technologies were fairly local. About 92 percent of all patent assignments in the field of civil engineering and construction were within one state, and the mean distance between assignor and assignee was only 102 kilometers. A similar picture can be observed with respect to patents covering domestic appliances. Eighty-five percent of assignments were within the border of one German state, and the mean distance between assignor and assignee was less than 100 kilometers. On the other hand, some types of technology were traded on a national or even international market. For example, about one-third of all patent assignments in the area of printing machines and typewriters were across international borders. Another third of patent assignments were

Table 2
Assignment by Field of Technology

Technology Field	*Distance (km)*	*Years since Patent Issue*	*International Border Crossed (%)*	*State Border Crossed (%)*	*No Border Crossed (%)*
Electrical engineering	364	2.7	17.8	18.6	63.6
Domestic appliances	97	2.4	5.5	9.2	85.3
Mechanical metal processing	458	3.2	19.0	23.8	57.2
Chemistry	208	2.7	9.8	15.3	74.9
Mechanical and optical instruments	772	2.5	17.0	20.8	62.2
Printing machines and typewriters	898	3.2	33.3	34.0	32.7
Machine parts	333	2.4	14.9	16.4	68.7
Railway technology	310	2.4	14.5	16.9	68.6
Pharmaceuticals	151	2.4	14.5	16.1	69.4
Civil engineering & construction	102	3.0	3.5	4.4	92.1

Source: Patent assignment database; authors' calculations.

across German states' borders. Consequently, the mean distance transcended by patents from this technology class was fairly large.

Beyond descriptive statistics over the whole sample period, Figure 1 shows the evolution of three key variables between 1889 and 1913. It turns out that the mean amount of fees paid by a patent holder before a transfer was quite stable over time. The average fees paid before the transfer fluctuated around 350 marks. Moreover, the mean distance between buyer and seller of a patent was also quite stable over time, fluctuating around 400 kilometers. Furthermore, the number of transferred patents included in our database increased over time, from about 320 per year around 1890 to about 420 per year around 1910.

Finally, we would like to point out that patent assignments within cities were quite important. There were 6,665 out of 13,559 patent assignments that concerned activities with the assignor and assignee residing in the same city. In particular, assignments within Berlin account for a large number of observations. To account for this fact, we included a Berlin dummy variable in our econometric approach.[38]

[38] We do not use the name of assignors or assignees as an important descriptive category since our research focuses on the geographic dimension of patent assignments, not on the organization of innovations in firms and industries. In contrast to recent findings from business history, the patent market was not highly concentrated. The average person or firm

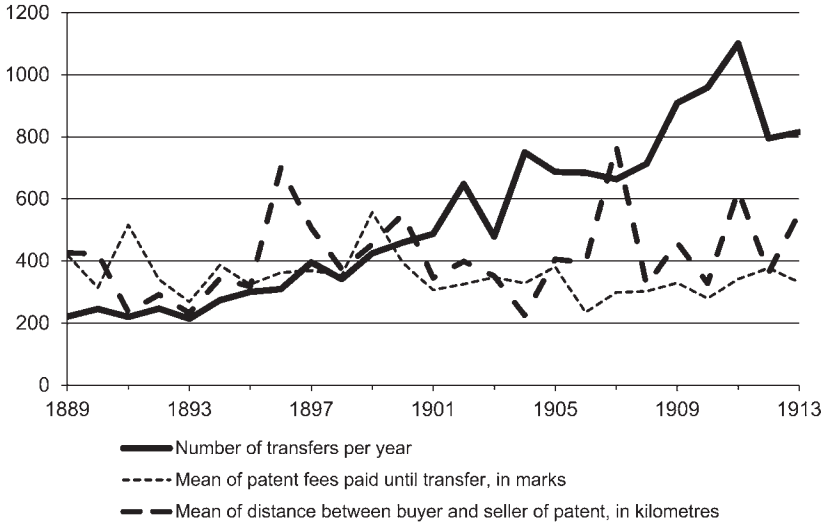

Figure 1. Time series of patent transfers and of patent characteristics. (Source: Patent transfer database, authors' calculations.)

Econometric Method: The Gravity Equation

We interpret patent assignments as trade in innovations and estimate the effect of frictions (distance and borders) on this trade within the framework of a gravity equation. Let us start at a most general level. We define the (empirical) "gravity equation" as a relationship where the predicted volume of an economic interaction between two locations, i and j (regions, cities), is a function of unilateral factors specific to either location i or j, and bilateral frictions τ_{ij} between them. Relevant unilateral or location-specific factors can be the local population, number of firms, or some other measure of local economic activity. As James E. Anderson discussed, empirical research has found that such a gravity equation fits a wide range of economic interactions very well.[39] Apart from the well-known applications to trade data, the gravity equation has also been found to describe well migration flows, foreign direct

included in our dataset sold 1.4 patents and acquired 1.6 patents. The five most important firms contributed only 4 percent of all trading activity. The most active firms on the patent markets were firms from the electrical-engineering industry, whereas the most active inventors were the large firms from the dyestuff and chemical industries. See Harald Degener, "Schumpeterian German Firms before and after World War I: The Innovative Few and the Non-Innovative Many," *Zeitschrift für Unternehmensgeschichte* 54, no. 1 (2009): 50–72.

[39] James E. Anderson, "The Gravity Model," *Annual Review of Economics* 3, no. 1 (2011): 133–60.

investment, more broadly defined capital flows, and, notably, geographical patterns of technology diffusion.[40] After a surge in empirical studies, the more recent literature has focused on theoretical foundations for these findings.

In summary, model economies will generate a "gravity equation" under three conditions: first, depending on supply and/or demand conditions, locations specialize in certain activities; second, demand for interaction between locations can be described by a CES or related system; third, the bilateral frictions between locations increase with geographical distance (for example, in the form of iceberg transport costs).[41] It has been shown that a host of different models fulfill these conditions and thus can generate gravity equations. Given that the focus of our article is empirical, it is therefore sufficient to discuss whether these three conditions are plausible for the market of patent assignments in Germany prior to 1914.

The first two conditions imply that there is a wide range of differentiated goods—in our case specific patents—in the economy, which in equilibrium are exchanged between a wide range of locations. Streb, Baten, and Yin show that patenting activities were geographically concentrated, but that concentration was far from complete.[42] They also illustrate that regions did specialize in certain industries and notably that clusters of (internally even more specialized) firms characterized locations. While Berlin had a large share in nearly every kind of patenting industry, the Rhine region dominated the chemical industries, and Saxony was particularly strong in mechanical engineering and textiles. Note that depending on the characteristics of locations and the level of bilateral frictions, many possible interactions between locations can be inactive in gravity models. We observe in our data a lot of patent

[40] Scott L. Baier and Jeffrey H. Bergstrand, "The Growth of World Trade: Tariffs, Transport Costs, and Income Similarity," *Journal of International Economics* 53, no. 1 (2001): 1–27; Jonathan Eaton and Samuel Kortum, "Technology, Geography, and Trade," *Econometrica* 70, no. 5 (2002): 1741–79; Anderson and van Wincoop, "Gravity with Gravitas," 170–92; Jeffrey Grogger and Gordon H. Hanson, "Income Maximization and the Selection and Sorting of International Migration," *Journal of Development Economics* 95, no. 1 (2011): 42–57; Keith Head and John Ries, "FDI as an Outcome of the Market for Corporate Control: Theory and Evidence," *Journal of International Economics* 74, no. 1 (2008): 2–20; Swati Gosh and Holger C. Wolf, "Is There a Curse of Location? Spatial Determinants of Capital Flows to Emerging Markets," in *Capital Flows and the Emerging Economies: Theory, Evidence, and Controversies*, ed. Sebastian Edwards (Chicago, 2000), 137–58; Wolfgang Keller, "Geographic Localization of International Technology Diffusion," *American Economic Review* 92, no. 1 (2002): 120–42.

[41] Alan V. Deardorff, "Local Comparative Advantage: Trade Costs and the Pattern of Trade," University of Michigan Research Seminar in International Economics Working Paper no. 500 (2004).

[42] Streb, Baten, and Yin, "Technological and Geographical Knowledge Spillovers in the German Empire."

assignments between firms within Berlin, but also within and between many other locations. In total we have 2,620 unique pairs in our sample, of which 43 percent trade more than once and 27 percent more than three times during the sample period. Moreover, a CES-demand system implies that patents are incomplete substitutes, that there will be a positive demand for every produced variety at all locations (conditional on the level of frictions), and that demand-shifters (like income shocks) do not affect the composition of patent assignments. For example, a region specialized in textile products will not systematically increase its demand for dyestuff patents in response to an income shock. This fact makes sense if, for example, regional specialization is largely determined by supply side factors such as the location of resources or internal economies of scale. The first two conditions for a gravity equation are therefore plausible in our context. The third condition requires that frictions between locations increase in geographical distance, or put differently, that proximity makes interactions less costly and therefore more frequent.

Knowledge, as an intangible, seems to be much less affected by spatial frictions than other goods. But there is evidence for substantial costs of transferring knowledge between locations. While the codification of knowledge in the form of patents eases their transfer over distance, several factors stand against this. First, patent assignments are directly related to innovative activities, which in turn tend to be geographically clustered with spatially limited spillovers and input-output linkages. This relationship has two effects on the geography of patent assignments. On one hand, firms will tend to buy patents from neighboring firms because they tend to be of a related industry. On the other, even with patents the codification of knowledge is hardly ever complete and firms will be better equipped to use other firms' patents if they operate in a similar industry or have access to experts nearby. Second, patent assignments may be related to trade in intermediary inputs, such as machinery or parts thereof or service personnel to install or repair machinery. To the extent that the costs of these activities increase with distance, distance affects patent assignments.

In our approach, we want to extend the standard formulation of bilateral frictions in two ways. First, we want to allow for the possibility that the characteristics of goods (patents), notably their value, affect the probability of trade. The iceberg formulation implies that frictions are proportional to the value of traded goods. However, it is reasonable to assume that more valuable goods, or patents for that matter, can overcome frictions more easily than other goods. The simplest way to allow for this assumption is to add a fixed-cost component to the formulation of frictions, which is independent of the characteristics of goods. With

this, the effect of frictions will decline with a higher value of goods (the Alchian-Allen effect). Next, we expect that non-distance-related trade costs arising along administrative borders affect patent assignments. Legal costs to apply for a patent or to assign it are likely to increase with differences in legal systems, often exacerbated by language differences as discussed in the section on historical background. So we extend our formulation of bilateral frictions to allow for this possibility.

On this background, it is useful to follow the approach put forward by James E. Anderson and Eric van Wincoop for the estimation of a gravity equation on commodity trade.[43] At any point in time, the frequency of patent assignments X from region or city i to region or city j can be explained by the relative economic size of the place of residency of the assignor and assignee, expressed here as the proportion of the product of the assignors economic activity Y and the assignees activity E in overall economic activity. Additionally, assignments depend on the bilateral resistance to trade patents (denoted by t, which is one plus the "tariff equivalent" of trade barriers) relative to the overall barriers to trade of the respective trading partners (i.e., the inward "multilateral resistance" P and the outward "multilateral resistance" Π). The elasticity of substitution between product or patent varieties from different exporters i is denoted by σ. The gravity model (ignoring the time index) is then formulated as:

$$X_{ij} = \frac{Y_i E_j}{Y}\left(\frac{t_{ij}}{P_j \Pi_i}\right)^{1-\sigma} \tag{1}$$

Most of the variables in (1) are not directly observable to us. However, all these variables except the bilateral barriers to trade are region- or city-specific, but not pair-specific. As a result, it is still possible to consistently estimate the average effect of trade barriers in (1) by introducing two sets of time-varying dummy variables. These sets of dummy variables, denoted $A^k_{i,t}$ and $A^k_{i,t}$, are specific to each region. They take the value of one whenever a region enters the equation as an exporter or importer, respectively.

To identify trade barriers we need to make some assumptions about their structure. Here we will assume that trade in patents, i.e., the frequency of patent assignments between locations, declines with geographical distance (e.g., due to factors correlated with distance such as knowledge spillovers or similarity in specialization patterns) and with administrative borders (e.g., due to red tape, taxes, etc.) in the following form (dropping again the time index):

$$t_{ij} = fc + dist_{ij}^{\gamma_1} e^{\gamma_2 border_{ij}} \tag{2}$$

[43] Anderson and van Wincoop, "Gravity."

where *fc* stands for a fixed cost associated with each patent assignment, *dist* is the geographical distance between two locations, and *border* is a dummy variable equal to one whenever an administrative border is crossed and zero else. With this functional form, estimates of γ_1 and γ_2 have a straightforward interpretation. Given distance and the elasticity of substitution σ, we can calculate the percentage decrease of the frequency of patent assignments implied by crossing a border simply as

$$100(1 - e^{\gamma_2}) \tag{3}$$

with *e* denoting Euler's constant. Moreover, we can use the expression in (2) to state the effect of crossing a border in terms of its distance-equivalent simply as $distequ = e^{\gamma_2 border/\gamma_1}$.

We use two specifications for our dependent variable. In one version, we treat each patent the same and simply add the number of patent transfers between two cities over some period of time. In a second specification we exploit the fee structure to value each patent assignment assuming that the patentees' willingness to pay high fees reflects the market value of patents. In this case, we weight each assigned patent by the cumulated fees that the patentee had to pay between year of issue and year of assignment. In each specification, we control for unobserved region-specific effects, distinguishing between cases where a region enters as a buyer and cases where it enters as a seller. This approach will pick up basic differences in economic and innovative activity, but also variation in price levels or differences in multilateral resistance between regions that would affect our estimate of trade barriers, i.e., distance and border effects. Given the special position of Berlin, we add an extra control whenever the German Empire enters the sample. We also show that including a separate control for the average value of transferred patents mainly improves the fit of the model, but has little effect on the coefficients of interest unless we add interaction effects. Moreover, we control for the average year of issue for all pairwise patent assignments and cluster standard errors around the year of issue to allow for heterogeneity around the year of issue. This method should control for possible censoring effects mentioned earlier but also for variation in the sample that is time-specific but not specific to any of the city pairs and is not picked up by other variables.

What do we expect to find? To start with, many of the region-specific effects will be significant with a negative or positive sign, picking up differences in innovative activity, industrial specialization, income, and the like. Especially we expect to see a strong positive "Berlin" effect, given the extraordinary position of Berlin in Germany's economy during the Kaiserreich. Next, we expect to find that bilateral frictions matter in several ways. We expect to see a negative effect of

distance on the frequency of patent assignments, which should be small relative to the usual finding for commodity trade flows. As a benchmark, Anne-Célia Disdier and Keith Head report from a meta-analysis of studies using the gravity equation a distance coefficient of −0.9.[44] We also expect to find that borders limited the frequency of patent assignments, where national borders might exert a stronger influence compared to intranational borders. Finally, we expect to see that in general more valuable patents are more frequently assigned than less valuable patents, because for them any level of bilateral frictions would impose a relatively smaller barrier.

Results and Discussion

We first present results with the unweighted number of transfers between city pairs as dependent variable (Table 3, models 1–3).

To start with column 2 (Basic model), we find a significant negative effect of distance on the frequency of patent assignments. A doubling of distance implies, *ceteris paribus*, a reduction in the frequency of assignments by 8.9 percent. This is an order of magnitude smaller than the distance effects found in the literature on commodity trade flows. For comparison, Nikolaus Wolf estimates (statistically significant) coefficients on distance between −1.3 and −1.6 for commodity trade flows in Germany, 1880–1913.[45] While our result needs to be seen as a lower bound estimate, we think that this result is rather plausible. Distance mattered for patent assignments, but it mattered much less than for commodity trade. In addition, we find that crossing a state border reduces that frequency by about 20 percent, and crossing the external border of Germany reduces it by about 24 percent.[46] These border effects can also be expressed in terms of distance. Crossing a German state border has the same effect as increasing the distance between buyer and seller by about 13 kilometers.[47] The impact of an international border equals about 22 kilometers.[48] But again, the estimated coefficients are smaller than those estimated for commodity trade in the Kaiserreich.[49] We also find—not surprisingly—that much of the transfer

[44] Anne-Célia Disdier and Keith Head, "The Puzzling Persistence of the Distance Effect on Bilateral Trade," *Review of Economics and Statistics* 90, no. 1 (2008): 37–41.

[45] Wolf, "Was Germany Ever United?" 846–81.

[46] Applying formula (3) we can calculate the effect of borders on trade as 100 * (1 − exp(−0.228) for state borders, and 100 * (1 − exp(−0.277) for external borders.

[47] The distance equivalent of the state border effect can be calculated as exp (−0.228/−0.089).

[48] The distance equivalent of the external border effect can be calculated as exp (−0.277/−0.089).

[49] Wolf, "Was Germany Ever United?" Table 2.

Table 3
The Effect of Distance and Borders on the Frequency of Patent Assignments (Unweighted), 1884–1913

Coefficient (t-stat)	*Basic Model*	*Control for Patent Value*	*Control and Interaction with Patent Value*
Log distance	−0.089 (−6.27)***	−0.090 (−6.45)***	−0.119 (−7.69)***
Log distance × highvalue	—	—	0.058 (4.79)***
International border	−0.277 (−3.86)***	−0.271 (−3.91)***	−0.263 (−3.99)***
German state border	−0.228 (−3.52)***	−0.225 (−3.75)***	−0.220 (−3.72)***
Berlin Dummy	0.679 (8.74)***	0.674 (9.28)***	0.651 (9.28)***
Log mean year of issue	14.788 (1.01)***	43.706 (3.51)***	41.452 (3.40)***
Log mean value of patents	—	0.259 (8.99)***	0.142 (4.31)***
Seller effects	Yes	Yes	Yes
Buyer effects	Yes	Yes	Yes
Constant	−110.633 (−1.00)	−329.356 (−3.50)	−312.156 (−3.39)
Adjusted R^2	0.118	0.191	0.201
Root MSE	0.891	0.854	0.848
Number of observations (city pairs)	2,614	2,614	2,614

Source: Authors' calculations.
Robust standard errors, clustered on mean year of issue.
*** Significant at the 0.1% level.

activity involves buyers or sellers in Berlin, reflecting Berlin's special position in the Kaiserreich.

Next, in column 3, we include a control for the average value of patents as approximated by the fees that patentees had to incur between the issue and the assignment date of the patent. We find that, indeed, more valuable patents are more often assigned. In the last column, we interact the value of assigned patents with distance and see that for more valuable patents distance poses less of a barrier. *Highvalue* is a dummy variable equal to one if the value of the patent is above the

Table 4
The Effect of Distance and Borders on the Frequency of Patent Assignments (weighted by patent value), 1884–1913

Coefficient (t-stat)	*Basic Model*	*Control for Patent Value*	*Control and Interaction with Patent Value*
Log distance	−0.088 (−4.37)***	−0.090 (−6.45)***	−0.119 (−7.69)***
Log distance × highvalue	—	—	0.589 (4.79)***
International border	−0.303 (−2.59)***	−0.271 (−3.91)***	−0.263 (−3.99)***
German state border	−0.240 (−2.06)***	−0.225 (−3.75)***	−0.220 (−3.72)***
Berlin Dummy	0.701 (6.03)***	0.674 (9.28)***	0.651 (9.28)***
Log mean year of issue	−97.025 (−3.85)***	43.706 (3.51)***	41.452 (3.40)***
Log mean value of patents	—	1.259 (8.99)***	1.142 (34.69)***
Seller effects	Yes	Yes	Yes
Buyer effects	Yes	Yes	Yes
Constant	735.091 (3.86)***	−329.356 (−3.50)***	−312.156 (−3.39)***
Adjusted R^2	0.110	0.714	0.717
Root MSE	1.507	0.854	0.848
Number of observations (city-pairs)	2,614	2,614	2,614

Source: Authors' calculations.
Robust standard errors, clustered on mean year of issue.
*** Significant at the 0.1% level.

median in the sample. With this, we find that the net effect of geographical distance for high valued patents is only about half the effect for the sample mean.

In Table 4 we use the number of patent assignments between cities, valued with the cumulated fees payable between date of issue and assignment as dependent variable. This specification is a bit closer to the standard framework used in gravity models. However, this has very little effect on the estimated distance and border coefficients, whether we add again a control for the mean value of assigned patents at the right

hand side (column 3) or not (column 2). Column 3 simply replicates the results from Table 2 with the modified dependent variable. The most notable finding that we get for both specifications of the dependent variable is that distance and administrative borders mattered. Surprisingly, not only the external border of the German Empire but also internal state borders (say between Bavaria and Prussia) did reduce the frequency of patent assignments. Given that we control for Berlin, this is not just an artifact of the high frequency of intra-Berlin assignments.

Using the simple formula (3) from the previous section we can calculate by how much the frequency of patent assignments is reduced compared to the sample mean once an administrative border is crossed. If we take the results from either Table 3 (column 3) or Table 4 (column 3) as a benchmark, we can calculate that crossing an internal border (e.g., between Bavaria and Prussia) reduced the frequency of assignments by about 20 percent. Instead, crossing the external border of the German Empire reduced the frequency of assignments by about 24 percent. The difference between these two border effects is not significant. Whenever both state and external borders had to be crossed, this reduced the frequency of assignments by an impressive 39 percent. These effects are substantially smaller than those reported by Nikolaus Wolf in 2009 for commodity trade in the Kaiserreich based on a sample of domestic and international trade flows, 1880–1913. Here, crossing an internal state border reduced commodity trade by 37 percent; crossing the external border reduced trade by 69 percent. Still, our estimation results—and another look at Table 1—suggest that these effects are not only statistically but also economically significant. Hence, not only the market for commodities such as rye or manufactured products continued to be fragmented before 1914, but also the market for innovations was far from integrated.

Finally, we explore whether the effect of distance and borders changed over time. Given that the German Empire was still a young state, we might expect that it took time to create a common market for goods and also for technologies. The year 1900 lends itself as a suitable breakpoint, because it is roughly in the middle of our sample and due to the nationwide introduction of the Bürgerliches Gesetzbuch (BGB), which provided a unified regulation of contracts, including contracts on the transfer of patents. Table 5 shows how the effect of distance and borders changed after 1900.

We see that the distance effect tends to increase over time, while the effect of borders remains largely unchanged. Again using our formula (3) from the previous section, we can calculate by how much the frequency of patent assignments is reduced compared to the sample mean once an administrative border is crossed before and after 1900.

Table 5

The Effect of Distance and Borders on the Frequency of Patent Assignments (weighted by patent value) before and after the Unification of Contract Law in Germany

Coefficient (t-stat)	*1884–1899 Unbalanced*	*1900–1913 Unbalanced*	*1884–1899 Balanced*	*1900–1913 Balanced*
Log distance	−0.066	−0.088	−0.085	−0.090
	(−3.68)***	(−5.60)***	(−2.20)**	(−1.91)*
International border	−0.179	−0.314	−0.348	−0.214
	(−1.97)*	(−4.18)***	(−1.41)	(−0.89)
German state border	−0.216	−0.264	−0.408	−0.548
	(−2.55)***	(−4.17)***	(−2.51)**	(−2.91)***
Berlin dummy	0.303	0.682	0.358	0.556
	(3.25)***	(7.93)***	(2.50)**	(3.05)***
Log mean year of issue	16.298	60.227	42.667	159.213
	(0.66)	(2.30)**	(1.11)	(2.71)***
Log mean value of patents	0.200	0.271	0.319	0.483
	(5.12)***	(7.92)***	(4.67)***	(6.72)***
Seller effects	Yes	Yes	Yes	Yes
Buyer effects	Yes	Yes	Yes	Yes
Constant	−122.55	−454.13	−321.35	−1201.16
	(−0.65)	(197.82)**	(290.73)	(442.93)***
Adjusted R^2	0.724	0.706	0.730	0.623
Root MSE	0.733	0.874	0.961	1.241
Number of observations (city pairs)	1,059	1,927	372	372

Source: Authors' calculations. Robust standard errors, clustered on mean year of issue.
*Significant at the 5% level; **significant at the 1% level; ***significant at the 0.1% level.

According to the results in columns 2 and 3 (unbalanced sample), crossing an internal border reduced the frequency of patent assignments by about 19 percent before 1900 and by 23 percent thereafter. Interestingly, we find a much stronger increase in the effect of crossing an international border (from 16 percent before 1900 to 27 percent thereafter). If we take into account that the effect of distance increased, we find that the effect of internal borders as a share of trade frictions within the Kaiserreich declined after 1900. This result is what we would have expected from the unification of private law with the introduction of the BGB.

However, the fact that the set of city pairs that traded patents during the first and the second period changed complicates the interpretation

of these results. Among the 1,059 pairs that traded before 1900 and the 1,927 that traded after 1900, only 372 pairs actually traded in both periods. If we restrict our attention to this "balanced" sample, we find that there was indeed a slight increase in the effect of distance-related frictions and some increase in the effect of intra-German borders, while the estimated coefficients on the international border are not significant. All these results need to be interpreted with great caution, as they are based on only a handful of observations (those for which we have data on both periods and where the international border was crossed). Note also that our sample contains only realized patent assignments but not those that were prevented by prohibitively high barriers to trade. Hence, our estimates of distance and border effects must be considered as lower bounds for the true obstacles to trade in innovation.

Conclusion

In 1914, Germany had been politically united for more than four decades. Nonetheless, markets for technology were not fully integrated. This is one major—and perhaps surprising—finding of this article. Using patent assignment data for the period 1884 to 1913 and a standard regression approach from the international trade literature—the gravity equation—we find that the geographic distance between assignor and assignee negatively affected the likelihood of patent assignments. Beyond distance, administrative borders within Germany as well as Germany's international borders negatively affected the probability of patent assignments. This finding is perhaps not surprising with respect to international patent transfers—foreigners perhaps did not know the details of German patent law, or they did not speak German—but it seems to be surprising with respect to the internal borders. The effect of the border between, say, Prussia and Saxony was nearly as large as the border between Prussia and France. Prussia and Saxony shared the same language and the same patent law—but they were not fully integrated with respect to technology transfers. This mirrors similar findings for commodity market integration in late-nineteenth and early-twentieth-century Germany as well as comparable results for the modern American patent market. Even in the modern United States, knowledge spillovers are partially detained by state borders.

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