Cologne Economic History Paper

Universität zu Köln
Seminar für **Wirtschafts- und** Unternehmensgeschichte

No. 1 (2012)

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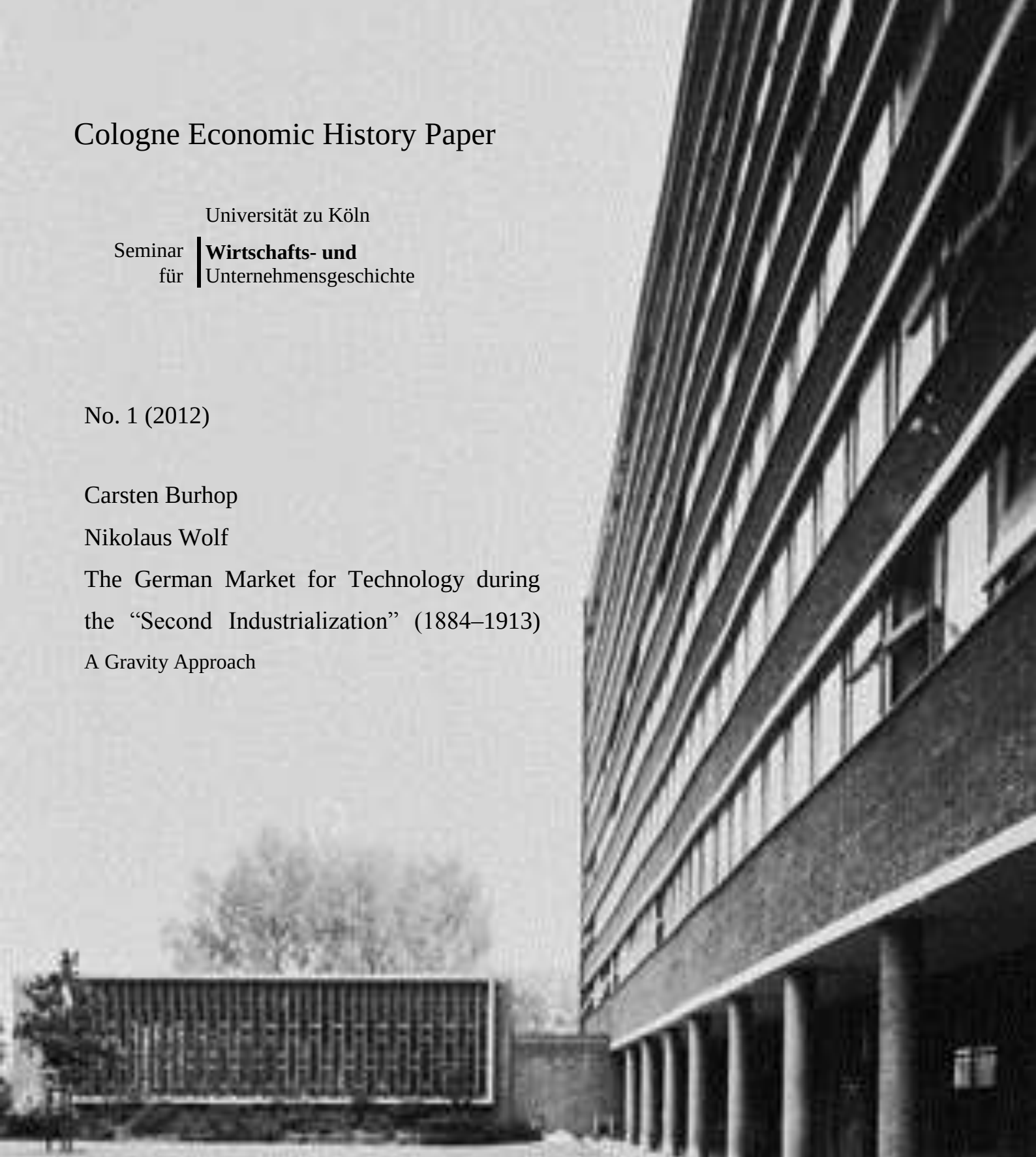
A Gravity Approach



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The German Market for Technology during the "Second Industrialization" (1884-1913) A Gravity Approach

Carsten Burhop and **Nikolaus Wolf***

Abstract

Using newly collected patent assignment data for late 19th and early 20th century Germany and a standard econometric approach from the international trade literature – the gravity model – we demonstrate the existence of border effects on an historical technology market. We show that the probability of patent assignments was negatively affected by the geographic distance between assignor and assignee as well as by the fact that the two contracting parties were separated by a state or international border. Surprisingly, we show that the effect of a state border within Germany was nearly as large as the effect of an international border.

JEL-Classification

N 73, O 30, F 19

Keywords

Economic History; Germany; pre-1913; Technology markets; border effects

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I. Introduction

Trade and economic exchange enhance economic welfare since division of labour and specialisation of production foster growth and efficiency. This holds for trade in goods and services as well as for trade in intellectual property. Beyond standard gains from trade arguments, however, trade in intellectual property rights has a noteworthy effect on welfare. The public good character of innovations allows multiple users to combine research and development (R&D) efforts to employ the same innovation. Consequently, trade in technology enables producers to draw the best innovation from a larger pool of inventions. This, in turn, shifts the production possibility frontier of participants outwards and increases per capita income.[1] This argument applies to national as well as to international exchange of innovations. Consequently, to maximize growth, barriers of trade in innovations should be minimized.

Yet, transfers of knowledge over space are 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, it has been demonstrated that not only geographic distance, but also state borders within the United States inhibit knowledge spillovers.[2] The impact of geographic distance and U.S. 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: knowledge spillovers as measured by patent citations are negatively affected by distance, borders, and linguistic barriers.[4]

Evidence of knowledge spillovers and transfers of intellectual property rights has also been provided by historical research. In particular, Naomi Lamoreaux and Kenneth Sokoloff demonstrated that about one third of all U.S. patents were assigned during the late 19th and early 20th century.[5] Patent assignments over large geographic distance

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[1] Daniel F. Spulber, „Innovation and international trade in technology“, Journal of Economic Theory, 138 (1), 2008, 1-20.

[2] Adam Jaffe, Manuel Trajtenberg, and Rebecca Henderson, „Geographic localization of knowlegde spillovers as evidences by patent citations“, Quarterly Journal of Economics xx (1993): 577-598.

[3] Peter Thomson and Melanie Fox-Keane, “Patent citations and the geography of knowledge spillovers: A reassessment”, American Economic Review, 95 (1), 2005, 450-460. Rebecca Henderson, Adam Jaffe, and Manuel Trajtenberg, “Patent citations and the geography of knowledge spillovers: A reassessment: A comment”, American Economic Review, 95 (1), 2005, 461-464. Peter Thomson and Melanie Fox-Keane, “Patent citations and the geography of knowledge spillovers: A reassessment: A reply”, American Economic Review, 95 (1), 2005, 465-466. Wolfgang Keller, “Geographic localization of international technology diffusion”, American Economic Review, 92 (1), 2002, 120-142.

[4] Per Botolf Mauerseth and Bart Verspagen, „Knowledge spillovers in Europe: A patent citation analysis”, Scandinavian Journal of Economics, 104 (4), 2002, 531-545.

[5] Naomi R. Lamoreaux and Kenneth L. Sokoloff, “Inventors, firms, and the market for technology in the late nineteenth and early twentieth Centuries” in: Naomi R. Lamoreaux, Daniel M.G. Raff, and Peter Temin, *Learning by doing in markets, firms, and countries*, Chicago: University of Chicago Press 1999, 19-60.

within the United States have also been highlighted by Tom Nicholas.[6] In particular, individual inventors supplied a national market with their ideas already during the early 20th 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 on a national patent market contributed also 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. This can be taken as evidence of knowledge spillovers in Germany between the 1870s and the 1910s.[10] More direct evidence of patent assignments and thus knowledge spillovers has recently been provided by Carsten Burhop. He demonstrated that a substantial fraction of the patents granted in Germany between 1877 and 1913 have been assigned.[11]

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 knowledge spillovers by patent assignment data in the context of a standard international trade model. In particular, we want to assess if and to what extent geographical distance, intra-national – 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.[12] A similar finding has been reported for modern intra-national trade between US states by Holger Wolf and pre-1914 Germany by Nikolaus Wolf: not only the external but also Germany's internal administrative borders restricted the flow of goods and

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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, Papers & Proceedings, 91, 2001, 39-44.

[6] Tom Nicholas, "Spatial diversity in invention: Evidence from the early R&D labs", Journal of Economic Geography, 9 (1), 2009, 1-31.

[7] Tom Nicholas, „The role of independent invention in U.S. technological development, 1880-1930", Journal of Economic History, 70 (1), 2010, 57-82.

[8] Petra Moser, "Do patents weaken the localization of innovations? Evidence from World's fairs", Journal of Economic History, 71 (2), 2011, 363-382.

[9] Tom Nicholas, „Independent invention during the rise of the corporate economy in Britain and Japan", Economic History Review, 64 (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 (2), 2006, 347-373.

[11] Carsten Burhop, „The transfer of patents in Imperial Germany", Journal of Economic History, 70 (4), 2010, 921-939.

[12] James E. Anderson and Eric van Wincoop, „Gravity with gravitas: A solution to the border puzzle", American Economic Review, 93 (1), 2003, 170-192 is the seminal paper in the field of international trade in goods and services. They show that international borders reduce trade by 20 to 50 percent. Holger C. Wolf (2000), "Intranational Home Bias in Trade," Review of Economics and Statistics, 82, 555-63 shows that state borders inside the U.S. also negatively affect trade in goods.

services.[13] 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 patent assignments between city pairs as 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 find thus evidence that even within Germany the market for technology was not fully integrated during the late 19th and early 20th century. Moreover, we find that the value of patents increases the frequency of them being traded and the probability of them being traded over longer distances, similar to evidence in trade that more valuable commodities are shipped over longer distances.[14] 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 paper are organized as follows. In Section II, we describe the data sources and present some descriptive statistics. In Section III, we outline the econometric approach, followed by the presentation of the estimation results in section IV. The final Section V concludes the paper.

II. Historical background, data sources, and descriptive statistics

In 1877, the first federal patent law in Germany replaced a patchwork of state-specific legislations with the aim to both foster innovative activity and help the diffusion of knowledge. 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 makes assignments at issue, which were important in the United States, much less frequent in Germany.[15] Second, a detailed technical examination of the invention was made by the patent office, and questions of patent infringements were usually settled in the period between publication of the patent application and the granting of

[13] Holger C. Wolf, "Intranational home bias in trade", Review of Economics and Statistics, 82 (4), 2000, 555-563. Nikolaus Wolf, „Was Germany ever united? Evidence from intra- and international trade, 1885-1933", Journal of Economic History, 69 (3), 2009, 846-881.

[14] David Hummels and Alexandre Skiba, „Shipping the good apples out? An empirical confirmation of the Alchian-Allen conjecture", Journal of Political Economy, 112 (6), 2004, 1384-1402.

[15] 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 (1), 2010, 100-111.

the patent.[16] Between 1877 and 1913 about 60 percent of the patent applications did not pass the technical examination 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: only 0.3 percent of the patents were repealed by the patent office. Moreover, the number of patent infringements was extremely low and only a few dozen cases were brought to the patent court each year.[17] Third, since it was compulsory to put the patent into use within three years after it has been issued independent inventors had a strong incentive to assign their patents to firms when they lacked resources to do so. Fourth, the patentee had to pay an annual fee to keep the patent active. This fee was 50 marks for the first 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 15 years was 5,300 marks (ca. $1,260), about 6.5 times the annual per capita income in 1913.[18]

Secure intellectual property rights, high patent fees, and compulsory patent use may have stimulated the transfer of patents. Indeed, Burhop has shown that at least 8.3 percent of all patents granted in Germany between 1877 and 1913 have been assigned during this period – a rate similar to the one observed in the modern United States.[19]

Using the same data source as Burhop, namely the annual *Verzeichnis der vom Kaiserlichen Patentamt im Jahre […] erteilten und noch in Wirkung stehenden Patente*, we extend his data base of all transferred patents. The first set of assignment data was published in 1884. Thereafter, annual data until 1913 are – in principle – available.[20] Burhop already registered the patent number, the technology class, the name and place of residence of the original patent holder, the year the patent has been issued and the year the patent has been assigned. Yet, Burhop's data contain only for a sub-sample of observation information about the name and place of residence of the new patent holder. We collected the missing information. In addition – and following Burhop in this respect – we code the old and the new patent owner to be an individual or a firm and we

[16] Margrit Seckelmann, *Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871-1914.* Frankfurt am Main: Klostermann, 2006, pp 257-260.

[17] Burhop, „Transfer", p. 927. The importance of secure property rights for the emergence of a patent market in the United States has been highlighted by Zorina B. Khan and Kenneth L. Sokoloff, „Schemes of practial utility: Entrepreneurship and innovation among ‚Great inventors' in the United States, 1790-1865", Journal of Economic History, 53 (2), 1993, 289-307; and by Zorina B. Khan, „Property rights and patent litigation in early nineteenth century America", Journal of Economic History, 55 (1), 1995, 58-97.

[18] Burhop, „Transfers", p. 927-928.

[19] Burhop, „Transfers", p. 930.

[20] The patent office did not publish the data for 1888.

construct 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).[21] Furthermore, using the information about the place of residence of the old and the new owner of a patent, we calculate the distance (in kilometres) between them and we construct dummy variables if the patent crosses an intra-national or international border in the course of assignment.

While the data contain a lot of information, a few drawbacks should be kept in mind.[22] First, 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) was not listed in the transfer register. This could be an important point if assignments at issue are 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 is most likely unimportant in Germany since the employer registered the patent in Germany. Second, some assignments were done for legal reasons: patents were regularly assigned if the legal form of the firm holding the patent changed. Furthermore, transfers from an individual to another individual as an inheritance were registered by the patent office. The latter two types of transfers do not relate to technology market transactions and they were excluded from our dataset. Third, the economic value of patents varies substantially, but it is usually unobservable. Standard 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.[23] Citations are unavailable for German patents from the late 19th and early 20th century. 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 fees 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.[24] To address this problem econometrically, we control for the year of issue and also cluster standard errors around the year of issue in our statistical model. Fifth, we look

[21] See Burhop, „Transfers“, p. 930-932 for more details.

[22] See Burhop „Transfers“, p. 928-930 on this point.

[23] Zvi Griliches, „Patent statistics as economic indicators: A Survey“, Journal of Economic Literature, 28 (4), 1990, 1661-1707. Hariolf Grupp, Iciar Dominguez-Lacasa, and Monika Friedrich-Nishio, *Das deutsche Innovationssystem seit der Reichsgründung*. Physica-Verlag, Heidelberg, 2002; Rainer Metz and Oliver Watteler, „Historische Innovationsindikatoren: Ergebnisse einer Pilotstudie“, Historical Social Research, 27 (1), 2002, 4-129.

[24] It could be a problem for all patents issued after 1899 since the maximum lifetime of a patent was 15 years.

only at realized transfers, not at all possible transfers, i.e. we ignore the zeros of non-assigned patents. Thus, we investigate trade data conditioned on the fact that there is trade at all.[25] By implication, all of our estimates on trade costs need to be interpreted as lower bounds.

TABLE 1: DESCRIPTIVE STATISTICS

	Panel A: Data by period		
	1884-1913	1884-1891	1891-1913
Number of patent assignments	13,559	904	12,655
Assignment within German state	70.4 %	69.9 %	70.4 %
Assignment across German state border	18.9 %	19.4 %	18.9 %
International assignment	10.7 %	10.7 %	10.7 %
Mean age of assigned patent in years	2.7	3.1	2.7
Mean distance between assignor and assignee in kilometres	425	288	436
	Panel B: Data by border		
	No border crossed	German state border crosses	International border crossed
Number of patent assignments	9,524	2,588	1,424
Mean age of assigned patent in years	2.6	2.9	3.2
Mean distance between assignor and assignee in kilometres	97	807	1,934

Source: Own calculations using patent assignment database.

Our database contains 13,559 patent assignments for the period 1884 to 1913. Table 1 shows some key descriptive statistics. About 70 percent of all patent assignments refer to activities within one German state, i.e., neither a national nor an international border

[25] 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 (x), 2008, 441-487.

was crossed. Around 19 percent of all assignments were agreed upon between two parties residing in different German states. Nearly 11 percent of all transfers involve 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 425 kilometres (about 264 miles). Splitting the sample into two sub-samples – the first running from 1884 until the patent law reform in 1891, the second one running from 1891 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.

TABLE 2: ASSIGNMENT BY FIELD OF TECHNOLOGY

Technology field	Distance in km	Years since patent issue	International border crossed	State border crossed
Electrical engineering	364	2.7	17.8 %	18.6 %
Domestic appliances	97	2.4	5.5 %	9.2 %
Mechanical metal processing	458	3.2	19.0 %	23.8 %
Chemistry	208	2.7	9.8 %	15.3 %
Mechanical and optical instruments	772	2.5	17.0 %	20.8 %
Printing machines and typewriters	898	3.2	33.3 %	34.0 %
Machine parts	333	2.4	14.9 %	16.4 %
Railway technology	310	2.4	14.5 %	16.9 %
Pharmaceuticals	151	2.4	14.5 %	16.1 %
Civil engineering & construction	102	3.0	3.5 %	4.4 %

Source: Patent assignment database; own calculations.

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 varies not 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 are fairly local. About 92 percent of all patent assignments in the field of civil engineering & construction are within one state and the mean distance between assignor and assignee is only 102 kilometres. A similar picture can be observed with respect to patents covering domestic appliances. 85 percent of assignments are within the border of one German state and the mean distance between assignor and assignee is less than 100 kilometres. On the other hand, some types of technology are 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 are across international borders. Another third of patent assignments are across German states border. Consequently, the mean distance transcended by patents from this technology class is fairly large.

Finally, we would like to point out that patent assignments within cities were quite important. 6,665 patent assignments concern 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 include a Berlin dummy variable into our econometric approach.

III. Econometric method

We interpret patent assignments as trade in innovations and estimate the effect of frictions (distance and borders) on this trade within the framework of the now standard micro-founded formulation of a gravity model from James Anderson and Eric van Wincoop.[26] We modify their approach, whenever necessary, for some characteristics of our data. One important modification concerns the definition of the geographic unit. Studies of border effects in international trade typically consider trade between countries. In contrast, our data refer to the region or city of residency of the assignee and assignor and we use this more nuanced geographic information.

Following the approach put forward by Anderson and van Wincoop, 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

[26] James E. Anderson and Eric van Wincoop, „Gravity with gravitas: A solution to the border puzzle", American Economic Review, 93 (1), 2003, 170-192. James E. Anderson and Eric van Wincoop, "Trade costs", Journal of Economic Literature, 42 (3), 2004, 691-751.

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 is then formulated as (ignoring the time index):

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

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 $A_i^{k,t}$ and $A_j^{k,t}$, 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, 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):

$$t_{ij} = dist_{ij}^{\gamma 1} e^{\gamma 2 border ij} \qquad (2),$$

where *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 $100(1-e^{\gamma 2})$.

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 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 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 capital 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 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-pair and is not picked up by other variables.

IV. 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 model 1, 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 just below 10 percent. In addition we find that crossing a state border reduces that frequency and crossing the external border of Germany reduces it even more. We also find – not surprisingly – that much of the transfer activity involves buyers or sellers in Berlin. Next, if we consider model 2 and include a control for the average value of patents as approximated by the fees patentees had to incur between the issue and the assignment date of the patent, we find that more valuable patents are more often assigned. If we interact in model 3 the value of assigned patents with distance we 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 median in the sample. With this, we find that the net-effect of geographical distance for high valued patents is about half the effect for the sample mean.

Table 3: the effect of distance and borders on the frequency of patent assignments (unweighted), 1884-1913

Coefficient (t-stat)	Model 1	Model 2	Model 3
Log distance	-0.089 (-6.27)	-0.090 (-6.45)	-0.119 (-7.69)
Log distance X 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)
Adj. R2	0.118	0.191	0.201
Root MSE	0.891	0.854	0.848
# of observations	2614	2614	2614

Robust standard errors, clustered on mean year of issue.

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. As shown in column 2 (model 4), 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 (model 5) or not (model 4). Column 4 (model 6) 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 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 artefact of the high frequency of intra-Berlin assignments.

Using the formula from section III we can calculate by how much the frequency of assignments is reduced compared to the sample mean, once an administrative border is crossed. If we take the results from either model 2 or model 5 as benchmark, we can calculate that crossing an internal border (e.g. between Bavaria and Prussia) reduced the frequency of assignments by around 20 percent. Instead, crossing the external border

of the German Empire reduced the frequency of assignments by circa 23 percent. The difference between these two border effects is not significant. Whenever both, state and external border had to be crossed, this reduced the frequency of assignments by a massive 39 percent. Without further investigation we can conclude 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 so the market for innovations was far from integrated.

Table 4: the effect of distance and borders on the frequency of patent assignments (weighted by value), 1884-1913

Coefficient (t-stat)	Model 5	Model 6	Model 7
Log distance	-0.879 (-4.37)	-0.090 (-6.45)	-0.119 (-7.69)
Log distance X 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)
Adj. R2	0.110	0.714	0.717
Root MSE	1.507	0.854	0.848
# of observations	2614	2614	2614

Robust standard errors, clustered on mean year of issue.

Finally, we explore, whether the effect of distance and border 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 1891 lends itself as a suitable breakpoint, due to patent law reform enacted during this year. Table 5 shows how the effect of distance and borders changed over time.

Table 5: variation over time, 1884-1891 vs. 1892-1913

	1884-1891, unbalanced	1892-1913, unbalanced	1884-1891, balanced	1892-1913, balanced
Coefficient (t-stat)	Model 7	Model 8	Model 9	Model 10
Log distance	-0.054 (-2.73)	-0.0896 (-6.04)	-0.049 (-1.73)	-0.107 (-1.76)
International border	-0.269 (-1.75)	-0.291 (-4.12)	-0.511 (-1.86)	-0.530 (-2.01)
German state border	-0.298 (-2.53)	-0.246 (-4.06)	-0.557 (-2.65)	-0.739 (-3.04)
Berlin Dummy	0.259 (2.11)	0.676 (8.42)	0.328 (1.96)	0.658 (2.78)
Log mean year of issue	4.858 (0.09)	54.120 (2.92)	-13.020 (-0.18)	151.562 (3.36)
Log mean value of patents	1.131 (26.68)	1.264 (38.79)	1.186 (23.69)	1.156 (17.04)
Seller effects	Yes	Yes	Yes	Yes
Buyer effects	Yes	Yes	Yes	Yes
Constant	-36.341 (-0.09)	-407.99 (-2.92)	98.496 (0.18)	-1139.842 (-3.36)
Adj. R2	0.760	0.708	0.731	0.588
Root MSE	0.725	0.852	0.852	1.262
# of observations	505	2357	248	248

Robust standard errors, clustered on mean year of issue.

We see that the distance effect tends to increase over time, while the effect of borders remains largely unchanged. The interpretation of these results is complicated by the fact that the set of city-pairs that traded patents during the first and the second period changed. Among the 506 pairs that traded 1884-1891 and the 2,358 that traded 1892-1913, only 248 pairs traded actually in both periods. If we restrict our attention to this 'balanced' sample we find that – while the average distance and border effects for this smaller subset tend to be higher than in the full sample – there was hardly a tendency that the barriers to trade declined. If anything, we find a slight increase in the effect of distance and borders (especially internal borders) on the frequency of patent assignments over time. 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.

V. Conclusion

In 1914, Germany has 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 likelihood of patent assignments was negatively affected by the geographic distance between assignor and assignee. Beyond distance, administrative borders within Germany as well as Germany's international borders negatively affected the probability of patent assignments. This is perhaps not surprising with respect to international patent transfers – foreigner perhaps did not know the details of the 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 the commodity market integration in late 19th and early 20th 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.