FOREIGN PATENTING IN GERMANY AND ITS DETERMINANTS: A STUDY ON 35 COUNTRIES, 1880-1914

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ABSTRACT

This paper explores the determinants of the number of important patents in Germany for 35 countries around the globe. We study the potential influence of patent laws, institutional quality, and primary and secondary schooling. Controls for distance, imports to Germany, and economic structure are included. Investment in schooling did in fact determine adjusted patent rates. Moreover, patent laws and institutions that protected other property rights had a promoting effect in the period 1880-1914.

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1. INTRODUCTION

How many important patents did economies around the world achieve between 1880 and 1914, and what determined their success or failure? In this study, we test a number of hypotheses that have been discussed intensively in the previous literature. For example, while the standard hypothesis about patent laws sees a positive impact of protection on the propensity to innovate, this view has recently been contested: secrecy, or the lag time it takes to adapt innovations, or special assets necessary to do so can also prevent imitation.[1] Hence, we test the following hypothesis in this study:

Hypothesis 1: Patent laws had a positive influence on the number of important patents.

Moreover, investment in schooling could have been a main determinant of patenting success in the late 19th century, as endogenous growth theory would suggest. This dominant strand of growth theory connects permanent growth success with the self-reinforcing effects of a sufficiently high human capital stock. Nelson and Phelps (1966) created a framework in which educated people are more often innovators, arguing that education speeds up the process of technical diffusion. In contrast, many empirical studies have found that during the industrial revolution, schooling and human capital were relatively unimportant.[2] For the more recent period, Pritchett – "Where has all the education gone" – has discussed the phenomenon that additional schooling did not increase GDP per capita in developing countries.[3] These results would contradict the view that primary schooling was important, hence the empirical test is clearly important. The late 19th and early 20th century, in contrast, has been described as a period of transformation to schooling-based innovativeness.[4] Khan and Sokoloff have emphasized the importance of accumulated human capital for inventors, which makes the

[1] See, for example, Boldrin and Levine, "Intellectual Property;" and Moser, "Patent Laws 2003."
[2] Mokyr, *Lever of Riches*; Mitch, "Human Capital;" and Allen, "Progress and Poverty."
[3] Pritchett, "Education."

activity of inventors a necessary, but not sufficient precondition for innovation, i.e. the process of transforming inventions into economically useful applications.[5] Furthermore, and our study will emphasize this point, a certain level of education is not only necessary for the inventor and innovator himself, but also for the labor force that will transform his innovation into profits and growth, thereby generating a stronger incentive to patent. We study whether schooling-based technological progress occurred already around 1880:

Hypothesis 2: Schooling had a positive effect on the propensity to obtain important patents.

Finally, we could imagine that strong patent laws might be an outcome of strong property rights in general, with the latter being the actual driving force behind innovativeness. Hence, we also quantify the effect of institutional quality:

Hypothesis 3: Constraints on the executive's right to expropriate property had a positive effect on important patents.

In order to improve our understanding of the important human capital growth phase of 1880 - 1914, a number of studies have focused on the patent history of the U.S., although it is very difficult to distinguish important and unimportant patents in the U.S. case.[6] Kenneth Sokoloff and coauthors have also addressed the issue of the limitations of patent counts in several papers.[7] We argue that it is particularly promising to focus on the German patent market when asking the crucial question about determinants of important patents. Germany was not only a country where important new technology was developed, but also an important market for patent rights. No less than 9,100 important patents -- that had been granted to foreigners between 1880 and 1914 -- were prolonged for ten years. Every year, a patent

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[4] Mokyr, *Lever of Riches.*

[5] Khan and Sokoloff, "Institutions."

[6] Bailey, *American Pageant*, p.533. Figures for the U.S. include all patents that were granted, not only high value patents with a life span of at least 10 years. The following figures for Germany refer to high value patents that were prolonged for 10 years.

[7] Sokoloff and Khan, "Democratization;" Lamoreaux and Sokoloff, "Inventors;" and Khan and Sokoloff, "Institutions."

holder had to pay a substantial fee, which he would only do if the expected patent value exceeded the cost.[8] This prolongation mechanism is important for our study because many economists have pointed out the relevancy of patent rates as a valuable indicator of inventiveness, although it is very important to distinguish between less and more important patents.[9] We will discuss this below.

Even at first glance, the totalized numbers of high value patents per country (today's borders) in the German Empire in Table 1 provide important insights. Patents were granted to citizens of a wide range of countries, including the most advanced nations of the time, as well as countries that we would not think of as economically advanced at the time such as Uruguay, Vietnam, Guatemala, Argentina, and China. Looking at each country's total number of patents over the whole time period, we see that the U.S. was the leading nation, followed by the UK, France, Switzerland, and Austria. It was not always the case that the U.S. had most 10-year patents in Germany. Between 1880 and 1884, not only the UK, but also France was still ahead of the U.S. in total numbers. The U.S. surpassed France only in the late 1880s. The UK was the leader up to the 1890s, and only in the late 1890s did the U.S. take the lead in German foreign patents. All in all, 35 nations (today's borders) had important patents in Germany. We observe an increase in Scandinavian patent applications during this period. This matches the catch-up process of the Scandinavian countries which turned from "impoverished sophisticates" (high literacy, low income) into modern industrial nations. Some "small" countries such as Switzerland and (today's) Czech Republic had remarkably high numbers of patents. Switzerland had most German patents in the electrical engineering and chemical industries (especially coloring, varnish, lacquer, coating, adhesive and chemical processes), whereas the Czech Republic's patents were distributed across more diversified industries.

[8] For a critical account, see McLeod et al., "Inventive Activity."

[9] See, for example, Bosworth et al., *Quality*; or Lamoreaux and Sokoloff, "Inventors."

Clusters of Czech's German patents are to be found in combustion plants and chemical processes. Given the Czech history of the 20th century, with a national income that continues to be much lower than that of its western neighbors, one might not have expected this high innovative potential in the pre-WWI period. Switzerland is an example of a country with a high number of patents that had initially no patent protection, whereas Scandinavia and the Czech Republic (being part of the Habsburg Empire) had a similar level of patent protection as Germany.[10] It will be important to assess the influence of patent legislation in more detail below.

[Insert Table 1]

The main goal of this paper is to explore the determinants of foreign patents in Germany, as described in the hypotheses above. Yet when taking per capita patents in Germany as a proxy for innovativeness, we need to control for a number of factors. We argue that the residual after controlling for imports to Germany, economic structure, distance and same language measures a country's propensity to innovate. This adjustment accounts for the fact that neighboring countries with a common language and/or cultural background tended to have more patents in Germany and foreign investors with imports to Germany might be likely to patent there.

The study is organized as follows: section 2 briefly reviews the literature on renewal data and the German patent system, and data and measurement strategies are described. Section 3 provides a simple empirical model and a list of explanatory variables in our basic regression model whose results are reported in section 4. This chapter also includes extensions of the basic model as well as a comparison with foreign patenting in the U.S. Section 5 summarizes our findings.

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[10] Lerner, "Patent Protection."

2. DATA

2.1. HISTORICAL OVERVIEW: THE GERMAN PATENT SYSTEM AND THE IMPORTANCE OF THE PATENT LAW OF 1877

Among others, Nirk has emphasized that Germany had no nationwide law for the protection of inventions before 1877 for several reasons: before the foundation of the German Empire, Germany was split into 39 different states and each state had its own patent policy, if at all.[11] Also, the constitution of 1871 did not solve the fragmentation of patent protection in the former sovereign states immediately. A German patent authority was established under the patent act in May 1877. This act replaced the formerly existing, rather vague privileges and monopolies by a standardized Germany-wide patent protection system. Khan has highlighted that the German national patent law of 1877 was so sophisticated that it also had a strong influence on the patent policies of various countries, such as Argentina, Austria, Brazil, Denmark, Finland, Holland, Norway, Poland, Russia and Sweden.[12]

Almost simultaneously, 14 countries[13] ratified the Paris Convention in 1883 in order to harmonize the protection of intellectual property. The German Empire did not join this convention at first, but became party to the Convention in 1903. After 1903, the number of foreign patents strongly increased. This treaty was the first milestone towards the equal treatment of foreign and national intellectual property, as foreign patent applicants had hitherto been discriminated in many countries.[14]

2.2. HOW CAN WE DISCRIMINATE UNIMPORTANT PATENTS? THE CONCEPT OF HIGH-VALUE PATENTS

[11] Nirk, *100 Jahre Patentschutz*, pp.345-402.
[12] Khan, "Intellectual Property."
[13] Belgium, Brazil, Ecuador, El Salvador, France, Great Britain, Guatemala, Italy, the Netherlands, Portugal, Serbia, Spain, Switzerland, and Tunis.

Patent counts that compare different countries with their national patent statistics have been heavily criticized as an indicator of innovation, because the vast majority of patents had little economic impact, and the share of important innovations that became patents varied from country to country. Schankerman and Pakes and others have emphasized that simple patent counts do not mirror the quality of innovations.[15] Various methodologies have thus been adopted to approximate the value of patents. Jaffe and Trajtenberg measure patent value based on the number of citations from more recent patents, whereas Pakes and Schankerman analyze the survival rates of patents.[16] They find that patents with a higher life span had a higher private economic value than patents which existed only for short periods. Renewal rates and fees proxy the patent value, as an inventor had to decide if he was going to renew his patent or not. The decision to hold a patent was clearly influenced by the renewal fees. Patent holders were only willing to keep their patents in force if the current value of the remaining expected future returns exceeded the present value of remaining future costs. Consequently, valuable patents were held longer. One important feature of the patent law was the annual patent renewal decision. The patent owner had to decide each year if he was going to renew his patent for another year or not. According to German law, an annually rising fee had to be paid to the German patent authorities for each year of maintaining a patent. The fee was 50 Marks for the first year, and increased annually to up to 700 Marks for the fifteenth year, making the maximum total for 15 years 5,300 Marks. 5,300 Marks were 1,261 US $ in 1900 and correspond to 25,767 US $ in 2005 real terms, using the GDP deflator.[17] This allows us to identify the more profitable patents: while the fee was substantial enough to deter unimportant patents by amateurs, it was not excessively high compared with the expected profit from

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[14] Patel, "Patent System;" Singer, *Patentsystem*, p. 14.
[15] Schankerman and Pakes, "Value of Patent Rights."
[16] Jaffe and Trajtenberg, "Market Value"; Schankerman and Pakes, "Value of Patent Rights"; and Schankerman "Patent Protection."

important individual patents. We define "important patents" as patents that were renewed for ten years, because they must have been profitable enough to rationalize the cost of renewal.

McLeod et al. have stated that the above assumptions are only valid for inventors who can handle credit constraints.[18] High renewal fees might have prevented some patent holders (who lacked access to capital) from extending their theoretically valuable patent because they might have been unable to reach (or realize) a decision as to whether the expected future returns of their patent would exceed the discounted future costs including interest payments, were they obliged to borrow money to pay the fees. Risk aversion also played a large role here. Especially patentees from less developed countries might not have been able to renew valuable inventions because credit markets were less developed. In contrast, if credit markets were sufficiently developed, an innovator would simply borrow the money. Our historical data set does not allow us to control for capital constraints for those countries, but due to the large dimension of our data set, lacking access to capital should not affect our study much over this time period, although it might have played a role for some individual inventors.

We have to admit that some institutional changes of the rules might explain a part of the rise in patents from 1900-04 and the following two five-year periods, as the German government exempted patentees from paying renewal fees during WWI.[19] As a result, some patentees that would otherwise have decided not to prolong a marginally important patent took the chance of prolonging it for free. Hence, we have to run the regressions below separately for each individual five-year group, and control for this aspect using time dummies in our joint panel analysis.

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[17] Lerner, "Patent Protection" estimated that 15 years would cost $22,694 in 1998 Dollars. He found that Germany in 1900 had a higher patent fee than 60 countries in the entire time period of 1850-1999.
[18] McLeod et al., "Inventive Activity."
[19] The sharp decrease of the patent cohorts' mortality rates during war times is reported in Table 3 in Streb, Baten, and Yin, "Knowledge Spillover."

In sum, the decision to prolong for ten years allows us to distinguish important from unimportant patents, as patent holders in Germany had to pay a high fee to keep their patent in force.

2.3. MEASUREMENT STRATEGIES: GERMAN PATENTS PER CAPITA BY COUNTRY OF ORIGIN

Our prime source is the patent directory "Verzeichnis der im Vorjahre erteilten Patente" which was published each year by the German patent office. It lists all patents granted in the preceding year including the name of the patentee (person or firm), the location of the patent holder (town and country), the patent class code and patent number, and a short description of the invention patented. Our rich database consists of almost 34,000 high value patents that were granted to residents or foreigners in Germany between 1880 and 1913. For the purpose of this paper, we filter out those ca. 9,100 patents that were held by patentees from 35 countries. Some summary statistics are shown in Table 2.

[Insert Table 2]

Who were the patent holders that lived in non-European countries? Were they perhaps mostly German migrants? We do not know much about investors from countries with smaller numbers of inventions. Emilio Magoldi had two inventions in the field "machine parts" in Buenos Aires, and his Italian-sounding name is quite typical for Argentina. Similarly, all patents from Uruguay went to T.L. Carbone from Montevideo, clearly also not a German migrant. The only patent from Vietnam was given to Adolphe Doutre from Saigon, probably a member of the French colonial upper class of what was Cochin China at the time. The Guatemalan patents were granted to people with Spanish and Italian-sounding names like Roberto Okrassa or Grote & Pinetta, but "Grote" could also have been a German. In the case of Brazil, patent holders had names like Mello, Benedetti, or Bandeira, hence probably descendants of Italian and Portuguese ancestors. All three Chinese patent holders, in contrast, were clearly of German origin, two of them living in the German colony of Tsingtao: Joseph Brilmayer, Leopold Schmidt-Harms, and Dipl.-Ing Konrad Baetz. But most patent-holders even of the smaller and poorer nations were probably not German migrants.

The variable that we will try to explain in the next section is the number of per capita patents in the quinquennials between 1880 and 1914.

This paper aims at constructing data using two strategies established by Maddison, who created the most renowned worldwide compilations of GDP estimates.[20] Clearly, his worldwide studies also stimulated a lot of criticism, but even taken with a grain of salt, his strategies meant substantial progress. Like Maddison, we focus on today's borders for the aggregation of patents per capita. This is an advantage because long-run studies can later build on this paper.[21] A potential disadvantage is that data on countries that were not independent could be misinterpreted. For instance, Bulgaria belonged partially to the Ottoman Empire, which had no patent laws. Counting Turkey and Bulgaria as two independent cases can be misleading when, for example, the choice between patent systems is to be explained. This is not the aim of our study. In contrast, dividing the number of patents that were granted to inhabitants of those two geographical units by the total number of inhabitants seems an acceptable strategy, as we know the city of residence for each patent-holder.[22] This latter

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[20] Maddison, *Monitoring*; Maddison, *World Economy*.

[21] This data set will be freely available on the internet page of the new human capital data hub, which will be created by the ESF GlobalEuroNet Initiative.

[22] A second element of the Maddison tradition is to assume similar developments in nearby countries in order to interpolate some data. This can be justified more easily in some cases than in others, for which more research is clearly needed. For example, we find it plausible to assume similar schooling rates for Uruguay and Argentina, whereas Asian schooling rates are much more likely to contain measurement errors because the "nearby countries" are either small or not so near after all. We will report results both for the full sample and for the non-interpolated cases only.

We should also point out the limitations of this interpolation: it is clear that the likely measurement error would become very important if subsequent researchers used our data for studies that cover only a few countries (especially those poor regions that we measured with a large margin of errors, such as China, etc.). In those cases, our measures should be cross-checked with additional indicators, and any future revision of our estimates is welcome.

exercise, which we will do in the following, is unproblematic using today's boundaries. However, we have also checked the main results using historical boundaries.[23]

2.4 Comparison with Moser's sample[24]

A comparison of our indicator "important foreign patents" with similar measures compiled by others indicates that our sample is broadly comparable. Moser, for example, analyses data from two exhibitions (exhibitions at the Crystal Palace in London in 1851 and the Centennial Exhibition in Philadelphia in 1876) for 22 Northern European countries that exhibited in seven industrial categories (making the total number of observations 154).[25] Moser argues that her primary source is superior to traditional patent counts because different countries had different patent systems, whereas inventions displayed at exhibitions were more homogenously selected, and awards were a measure of the relative importance of the inventions.[26] Of course, exhibitions were not only events that distributed information about new technologies. They were also entertainment shows seeking to attract people and educate them. Therefore, a certain bias towards spectacular and enjoyable exhibits for the masses seems likely. Some economically important innovations might have remained at home, whereas scientific instruments that were suitable for entertaining demonstrations might have been presented even though they had not much economic impact.

Despite the differences between the sources and our method of distinguishing important from unimportant patents, we can compare our sample with Moser's. After adjusting for distance and economic structure, we find a high correlation between the number of exhibits and per capita patent numbers in Germany. Figure 1 shows a comparison of our per

[23] See a working paper version available from the authors.
[24] Moser, "Patent Laws 2003."
[25] See also the shorter version: Moser, "Patent Laws 2005."
[26] Compared with our approach, she does not control for distance, which is justified because of the similar geographical proximity of all her countries to their respective host countries.

capita patent numbers in Germany in 1885 with Moser's sample from exhibitions, i.e. the number of exhibits at the 1851 Crystal Palace exhibition in London. Moser found that Belgium and Switzerland had the highest numbers of exhibits, followed closely by Saxony. Württemberg, Prussia, France, Austria, the Netherlands, and the Scandinavian countries occupied the middle and lower middle position, while Russia ranked lowest among these "Northern European" countries. Given that we have no data on the four German states, we show the remaining eight countries (with some measurement error) in Figure 1. When plotting Moser's values against our values for 1885 in a scattergram (we assign the same exhibition value to Norway and Sweden because Moser gives only one value for both), we find a general correspondence between the two studies in the pattern of patenting rates across countries. Both Switzerland and Belgium had very high German patenting rates in 1885 and most exhibits in 1851, whereas Russia is the laggard in both cases. As Figure 1 shows, Austria had the second-highest German patenting rate of these eight countries, but only the fourth-highest number of exhibitions. Austria's higher ranking and Belgium's slightly worse ranking also reflect the relative human capital growth rates of the two countries between 1851 and 1885. Austria grew from a relatively poor country to one of the rich economies of Europe, whereas Belgium was already an industrialized country and experienced more modest development in the late 19th century. We conclude that our ranking of the aforementioned countries is similar to Moser's. Our importance-weighted patent statistics and her exhibits measure similar degrees of innovativeness, despite the different institutional circumstances. This makes us believe that the measurement is quite robust (but our data set includes many more countries, of course).

[Insert Figure 1]

3. WHAT DETERMINES THE NUMBER OF IMPORTANT PATENTS?

3.1. Control variables: geographical and cultural distance, and Economic structure

We distinguish between variables that we want to control and variables that could be determinants of innovativeness (on the latter, see section 3.2 below). We also use a variable that approximates a key feature of the economic structure of each country, the land-labor-ratio. If this ratio was higher, the country was more likely an agricultural economy and less likely an industrial one.

What motivated a foreign inventor to apply for a German patent, given that the cost is the highest in the world? If he lived in another country with a good patent system, he would be protected in his own market from German and other competitors. A patent in Germany would only be worth the cost, if (A) he wanted to sell his innovative product in Germany (or sell a licence), or (B) he lived in a country without a good patent system, and seeks protection against German competitors for his own country, most likely a country geographically close to Germany, or at least with close trading relationships. Hence we will test in the following whether interaction terms between strength of the foreign patent system and (1) distance and (2) the intensity of trading relationships (measured by the imports to Germany) plays a role. We took the imports to Germany from the German Statistical Yearbook (various years), and related it to German GDP.[27]

Another potential influence could have been geographical and cultural proximity. Countries more remote from Germany had higher information and transaction costs. In addition, the weight of commodities played a major role if countries conducted commercial operations with Germany after filing a patent there. In contrast, cultural proximity in the form of a common language or cultural history could also have had an impact on the propensity to

[27] The values are quite small, given that they are expressed as fractions of GDP between 0 and 1. The necessity to take logs transformed this variable into negative values (See Table 2).

patent or trade.[28] We expect a higher propensity to patent if there were no language barriers. As a result of this, we examine the impact of geographical proximity, represented by the exogenous variable "Distance to Germany," and cultural proximity as represented by the exogenous variable "German language" on high value patents between 1880 and 1914. Log distance ranges from 5.27 to 9.83 (Table 2).

[Insert Table 2]

3.2. DETERMINANTS OF THE TECHNOLOGICAL COMPONENTS OF HUMAN CAPITAL: SCHOOLING, PROPERTY PROTECTION, AND PATENT LAWS

After controlling for the variables mentioned above, we are particularly interested in the influence of schooling and institutions on the propensity to patent.

During the crucial period of economic development under study, differences in schooling rates were large (see also Table 2). While it might be intuitively clear to most economists that schooling increases the potential innovativeness of a country, this has never been studied quantitatively. Moreover, schooling comes at a large cost: taxation needs to be significantly higher if comprehensive schooling is to be provided to a large share of the population. Lindert has called primary public education "…the kind of education that involves the greatest shift of resources from upper income groups to the poor."[29] He discusses a number of positive and negative influences on the decision to introduce large-scale tax-financed primary schooling. In many countries, powerful elites prevented the public financing of primary education, especially if they were mainly involved in agriculture: from the point of view of a member of the landed elite, why should one sacrifice via taxation a large proportion

[28] Dunlevy, "Immigration."
[29] Lindert, *Growing Public Vol. 1,* p. 87.

of one’s income for the schooling of poor day-laborers who mainly performed manual tasks on one’s estate? And even if there had been a willingness to sacrifice that income, would not more educated laborers be a threat, triggering a land reform or socialist revolution that would eventually take away one’s land and status? Lindert argues that the gradual process of extending the franchise from non-voting autocratic states to various forms of “elite democracies” in which only the richer half of the male population was allowed to vote, for example, and only thereafter to full democracies was important in this regard: during this democratization process, attitudes changed in favor of tax-financed mass-schooling. According to Lindert, the rise of democracy was in turn caused by religious diversity (countries which had almost 100% Protestants or Catholics were rather slow in this development), previously lost wars, and other factors.[30] Especially at the beginning of mass-schooling, decentralized decision-making also played a role: some regions were more willing to sacrifice income for schooling because their economic structure was more human capital-orientated.[31]

[30] Lindert, *Growing Public Vol. 1.*

[31] Lindert gives the French, English, Prussian, and U.S. cases as examples. In France, the restoration period after 1815 saw a very slow progress in tax-financed schooling. But even after the expansion of the franchise around the mid-century, schooling investments were local: the regions northeast of the famous Calvin-Calvados line achieved a considerable level of literacy, partly because their economic structure was complementary to schooling investments, and partly because they felt obliged to meeting the standards of a civilized world. Only after the defeat of the French army in the Franco-Prussian war of 1870/71, a substantial increase of government spending on schooling was initiated. Hence, while democracy and the extension of the franchise preceded the expansion of schooling, a considerable lag of 3-4 decades has to be taken into account. The French case also shows that decentralized decisions were favorable to schooling at an early stage. The decentralized decision-making structure enabled the Northeast with its education-demanding economic structure to invest more into human capital. However, for expanding the schooling effort to the Southwest, a centralized decision-making process was necessary. For Germany, Lindert stresses again the importance of decentralized schooling investments in the western part of Germany. This helps him explain the puzzle why Prussia, in particular, expanded schooling so early in spite of being ruled by kings with a conservative, anti-modern attitude. Yet again, the perceived obligation not to look bad by international standards might have been a powerful driving force here, as well as the defeat in the Napoleonic wars. The U.S. case was similar in one aspect: regional schooling propensity played a large role. In contrast, this was missing in England until late in the 19th century. Hence, in the U.S., early democracy could lead to mass-schooling, whereas in the British case, the 19th century did not see rapid human capital formation (although the British had been education leaders up to the 18th century, jointly with the Dutch). Lindert, *Growing Public Vol. 1.*

Lindert's dataset contains information about student enrolment rates in primary and secondary schools between 1870 and 1920 for most of the countries that applied for patents in Germany. We would argue that the propensity to invent, patent and innovate is driven by the general commitment a society feels towards education and knowledge creation. If the society spends a lot of resources on primary schooling, it will also produce good universities and technical schools from which innovators will emerge. Moreover, school investment will give poorer people with excellent technical skills the chance to develop those.

Another potentially important determinant is patent protection. Many theoretical studies have considered the effects of patent protection on the propensity to innovate. The orthodox view is that the relationship should be positive, given the high fixed costs of R&D that do not yield temporary monopoly profits without protection, given that knowledge has many features of a public good.[32] Others have argued that there are alternative strategies for protecting knowledge, especially in industries that produce commodities which do not easily reveal their technology of production.[33] Still others have suggested that many patents are only copies of earlier patents that are sufficiently altered for acceptance by the patent commission.[34] This depends on the expertise of the commission, of course. In order to test this result for the later period of 1880-1914, we include a dummy variable for the existence of patent protection in the host country in our regressions.[35]

Already bivariate correlations indicate that distance from Germany is negatively correlated with patenting, whereas schooling is positively correlated (Table 3). Among the explanatory variables, institutional constraints are positively correlated with schooling

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[32] Nordhaus, "Technological Change;" Klemperer, "Scope of Patent Protection;" and Gilbert and Shapiro, "Patent Length."
[33] Moser, "Patent Laws 2003."
[34] Schäffle, *Absatzverhältnisse*; Schäffle, *Bau und Leben.*
[35] Lerner, "Summary Tables."

intensity, hence we have to be aware of potential multicollinearity, whereas most other correlations are not very pronounced.

[Insert Table 3]

4. RESULTS

4.1. WHAT DETERMINES HIGH-VALUE PATENTING IN GERMANY?

We run negative binominal regressions of patent numbers by country and 5-year-period (Table 4). We have chosen the negbin model here, as patents can be considered to be events, or “counts” in the econometric language, and the negative binomial model is a robust econometric tool to estimate this kind of data. As control variables, we include distance to Germany, land-labor ratios, imports to Germany, and the population in the country, as the number of patent events needs to be compared to the population of the respective country. Our main explanatory variables of interest are schooling and patent protection. Schooling is included using lagged enrolment rates (in logs) as a explanatory variable. The lags avoid contemporaneous correlation.[36] Lerner’s evidence on the existence of patent laws functions as explanatory variable in lagged form, i.e. his classification for 1875 for the patent cohorts 1880-84 to 1895-99, and the classification for 1900 for the cohorts 1900-04 to 1910-19.[37] Note that only a modest number of countries had no patent protection: Switzerland, Holland, China, Romania, Japan, Indonesia, Bosnia, and Turkey in 1875; and the same group except Switzerland, Turkey, Bosnia, and Japan in 1900.

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[36] We also perform some special tests for the endogeneity structure in a separate appendix available from the authors.
[37] Lerner, “Summary Tables.”

Although the number of countries for which all explanatory variables are available is quite small, the lagged enrolment variable has a strong positive effect which is significant for all seven time periods. Given the small number of cases, our expectation was that this variable might turn insignificant in at least some of the early cross-sections, but it explains the propensity to acquire high value patents in Germany in a quite robust way. This result is very important, as it reveals the mechanism by which endogenous growth works: schooling not only augments labor productivity directly, but also stimulates innovativeness.

The existence of patent protection turns out to have had a positively significant impact on high value patents in the last two periods. Hence in those negative binomial regressions with small numbers of cases, we find the schooling hypotheses supported, whereas the influence of patent protection seems limited to only the last periods, which are represented by slightly higher numbers of cases.

Apart from this, our control variable "imports to Germany" is always positive and mostly significant. It matters for the propensity to patent in Germany more than the raw distance to the country, although this result might also be caused by the small numbers of cases per cross-section. The coefficient of land-labor ratio is not significant at all, whereas population has a varying influence.[38]

[Insert Table 4]

Given the small number of cases in cross-sectional regressions for only one period each, we now turn to panel regressions (Table 5). As dependent variable we use the number of

[38] We also ran regressions with historical borders. We aggregated the European empires by historical boundaries. The basic results are confirmed.
We also estimated a cross-sectional model using secondary schooling rates instead of primary schooling, using the log-linear specification lagged one decade. The log secondary education has a positive effect on patenting

patents per capita. In addition to the regression model above, we include time and continent dummy-variables among the control variables. We use a random effects model to allow for time-invariant dummy variables in the models. In column 1-3, we include all countries with patents in Germany, whereas the remaining columns 4-5 present only countries which had at least five important patents over the whole period. In columns 2 and 5, we include secondary instead of primary schooling. We include as control variables again distance to Germany, land-labor ratios, and imports to Germany. Given that we have in the panel regression a larger number of observations, we can also include German language, and an interaction term between distance and imports to Germany. Remember that an individual might want protection against German competitors for his own country, most likely a country geographically close to Germany, or at least with close trading relationships. Hence we tested the interaction terms between strength of the foreign patent system and (1) distance and (2) the intensity of trading relationships (measured by the imports to Germany). The interaction with imports had a significant coefficient (column 3), whereas the interaction with distance was positive, but did not reach conventional levels of significance (p-values of 0.15 and 0.13). As it is frequently the case with interaction terms, there is considerable multicollinearity between the base variables and the interaction term, which has probably caused this insignificance. We conclude that the substantial size of the coefficients is more important here and that hence both control variables should be included in the model.

Among the other control variables, distance is more efficiently estimated in the panel regressions and turns significantly negative here. German language has a positive influence in those regressions. The land-labor ratio is interestingly also positive, once the other variables are controlled for. There seems to be *ceteris paribus* no "curse of land" for investors.

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activities that is significant at the 10%-level for the time period between 1885-94 and 1900-14, although the effect is weaker than that of primary schooling in most cases. (Tables available from the authors)

As a main result, all five panel regressions confirm the importance of schooling for the propensity to patent in Germany. The coefficients for secondary schooling seem even larger, but it should be taken into account that the standard deviation of secondary schooling was also lower. If we multiply the coefficients with one standard deviation each, we obtain in column (1) for primary schooling 0.70*0.59=0.41, which is slightly less than a quarter of the standard deviation of log patent rates (1.77). In column (2), we obtain for secondary schooling 3.38*0.124=0.42, hence almost the same economic impact of secondary schooling on patenting as for primary schooling. Both schooling variables are statistically as well as economically significant.

The existence of patent protection in the host country increases the number of high value patents by 0.7% in the regressions in columns 1 and 2, and by an even larger amount once the interaction term with patents is included. The inclusion of the interaction term between distance and patent protection leads to insignificance and even reversal of the sign of the coefficient. The positive effect seems to be picked up by the interaction term. Hence, although in general positive, the effect of patent protection is slightly less robust, compared to the influence of schooling.

Finally, we included institutional constraints on the executive, which normally has a strong impact in long-run growth regressions of income.[39] The reasoning behind this is that the risk of expropriation by a monarch or dictator was a strong disincentive for potential entrepreneurs to invest, so that tradesmen could be expected to migrate to other countries with more institutional checks on their political executive. According to our initial hypothesis 3, a similar reasoning could well apply to intellectual investments in innovations and patents: a political system that did not protect its entrepreneurs against expropriation might have provided strong disincentives for innovators because they could not expect to reap the fruits of their intellectual investment. In fact, this variable turns out significant in the regressions in column 4 an 5. More secure general property rights thus stimulated not only growth, but also innovativeness – or perhaps via innovativeness also growth.

[Insert Table 5]

4.2. Comparison with foreign patenting in the U.S.

In order to countercheck our results on the determinants of international patenting with another country, we compare our data with similar data for the U.S. compiled by Cantwell. However, those patents are not importance-weighted.[40] In the late 19th century, the U.S. was already an important host for foreign patents.[41] Cantwell compiled the number of U.S. patents granted to U.S. and Non-U.S. residents in 1890-92 and 1910-12 for the 16 most important patenting countries, but without distinguishing between important and unimportant patents. The share of foreign patents rose from 8.4% in 1890-92 to 11.4% in 1910-12. The United Kingdom was the leading nation in holding patents in the U.S., followed by Germany. Germany almost tripled its total number and doubled its share of foreign patents over the two periods under consideration. Canada was the third-strongest patenting nation, partly because of the short distance to the U.S. (whereas in Germany, Canada ranked 15th in 1910-14). In addition, France and Austria were ahead of Australia. Ireland had astonishingly high patenting rates in the U.S., given its low values in Germany.[42]

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[39] Acemoglu et al., "Rise of Europe."
[40] Cantwell, *Technological Innovation*.
[41] The US Index of Patents registered all patents granted in alphabetical order with the following information: state or country of the patentee, brief description of the patent, patent number.
[42] Ireland was at this time a part of the UK.

In the following, we apply our regression model to Cantwell's data.[43] In Table 6, we regress the number of foreign patents in the U.S. in 1890-92 and 1910-12 on primary schooling rates in the preceding decade, as well as cultural proximity represented by an English language dummy, the existence of patent protection in the host country at the time, and distance to the U.S. Again, the most important feature is the significant and positive (5%-level) impact of schooling on the propensity to patent abroad, which is even stronger in the first period under consideration. The size of the coefficient for English language in 1890-92 is respectable, as reported in Table 5. For the variable "patent protection", statistical significance is not given, which might be caused by the small number of cases. The coefficient is positive and of similar size as the corresponding one in regressions with German patents.

[Insert Table 6]

5. CONCLUSION

Many economists have pointed out the relevancy of patent rates as a valuable indicator of innovativeness, although it is very important to distinguish important and unimportant patents. This study has introduced a new dataset on important patents from around the globe that were patented in Germany and prolonged for at least ten years. For example, countries that today are Uruguay, Vietnam, Guatemala, Argentina, China and many others could be documented for the first time with this dataset, for the questions addressed here.

In this period, globalization boomed, markets developed and integrated, and the electrotechnical and chemical industries were important driving forces behind the second industrial revolution. For example, we identified many Norwegian, Italian, Austrian and Dutch

[43] Cantwell, *Technological Innovation*.

innovations in those industries – in addition to inventions from those countries usually mentioned in this context. This paper has examined the impact of education, patent laws, institutional quality, distance, and economic structure on the number of high value patents per capita that were granted to foreigners in Germany between 1880 and 1914.

Lagged primary and secondary schooling rates had a significantly positive effect on per capita patents after controlling for imports, economic structure, distance and common language. Therefore, our initial hypothesis 2 is confirmed. We interpret this finding based on the fact that schooling is driven by the general commitment a society feels towards education and knowledge creation. If the society spends a lot of resources on primary and secondary schooling, it will also produce good universities and technical schools from which innovators will emerge. Human capital externalities could also be large for primary schooling, as many studies on today's less developed countries have demonstrated.

The existence of a patent law in the country of origin affected the propensity to patent in a modestly positive way, an effect which was not always statistically significant for the late 19th and early 20th century. Hypothesis 1 is thus weakly confirmed. We also found that institutional quality, especially protection against expropriation, was important for innovative behavior, so that hypothesis 3 is confirmed. Finally, we checked the robustness of our model in a variety of specifications. Furthermore, we compared the results to those obtained when taking foreign patents in the U.S. as the basis of analysis.

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Tables

Table 1: Important patents by Patentees from Foreign Countries (today's boundaries) in the German Empire

Country	1880-84	1885-89	1890-94	1895-99	1900-04	1905-09	1910-14
USA	78	109	162	252	502	584	958
United Kingdom	109	122	183	203	248	313	444
France	88	81	95	133	193	276	486
Switzerland	26	32	46	46	114	196	422
Austria	38	37	63	65	116	181	261
Belgium	24	23	27	25	29	68	160
Sweden	11	10	21	17	34	66	154
Czech	11	15	22	22	19	38	66
Italy	3	2	10	13	29	53	62
Denmark	4	5	9	11	29	31	71
Russia	5	5	4	10	17	33	46
The Netherlands	3	7	3	15	12	23	43
Hungary	4	3	3	3	12	21	57
Norway	0	1	5	6	4	17	30
Poland	3	2	8	3	5	3	5
Ireland	2	0	7	1	7	3	8
Canada	0	1	2	1	6	3	13
Spain	1	1	2	4	0	3	10
Luxemburg	4	1	2	1	0	3	7
Australia	0	2	1	2	0	2	3
Brazil	0	0	0	1	0	0	7
Croatia	0	0	0	0	0	4	4
Finland	0	0	0	0	2	1	4
Romania	0	0	0	1	1	1	2
Japan	0	0	0	0	0	0	4
China	0	0	0	0	0	0	3
Guatemala	0	1	0	0	0	0	2
Uruguay	0	0	0	3	0	0	0
Argentina	0	0	0	0	2	0	0
Slovenia	0	0	0	0	0	1	1
New Zealand	0	0	0	0	0	0	2
Indonesia	0	0	0	0	0	0	1
Bosnia	0	0	0	0	0	0	1
Vietnam	0	0	0	0	0	0	1
Turkey	0	0	0	0	0	0	1
Total Foreign Patents	416	460	675	838	1381	1930	3340
Total German Patents	1134	1171	1995	1998	2550	4940	10197
Total Patents	1550	1631	2670	2836	3931	6870	13537

Note: Important Patents are defined here as those prolonged for 10-years

TABLE 2: DESCRIPTIVE STATISTICS

Variable	Obs	Mean	Std. Dev.	Min	Max
PATENTS	137	65.59854	131.0853	1	958
LOG PATENTS	137	5.018705	1.76651	1.305037	9.310396
SEC SCHOOLING ENROLLMENTS	137	2.483024	.1244662	2.061188	2.622656
PRIM SCHOOLING ENROLLMENTS	137	6.180789	.5899319	4.248495	6.878326
PATENT PROTECTION	137	.8905109	.3133977	0	1
CONSTRAINTS ON EXECUTIVE	111	1.885135	6.325129	-10	10
LAND-LABOR RATIO	137	1.531028	.2408061	1.253903	2.30376
IMPORTS	137	-2.751642	1.299922	-6.965798	-.0779886
DISTANCE TO GERMANY	137	6.982989	1.110671	5.274255	9.832161
GERMAN LANGUAGE	137	.2043796	.4047273	0	1

Data sources:

High Value Patents per year and five-year priod: see Table 1 and text;

Schooling Rates, primary and secondary: Lindert, *Growing Public Vol.1*.

Patent Potection: Lerner (2002); Constraints on Executive: Polity2 (http://www.systemicpeace.org/polity/polity4.htm);

Land = Land in sqm: CIA 2005. The World Factbook (www.odci.gov/cia/publications/factbook);

Labor in 1880, 1890, 1900, and 1910 = Economically Active Population by Major Activities (in thousands): Mitchell (1980, 1993, 1998) - International Historical Statistics (The Americas, Europe and Africa, Asia, Oceania), female and male employees over all industries have been added up;

Land-labor ratio = Log (Land / Labor)

Imports per GDP (in logs): Statistical Yearbook, Deutsches Reich, various issues;

Distance: describes the distance between Germany and the respective country in logs (http://www.macalester.edu/research/economics/PAGE/HAVEMAN/Trade.Resources/Data/Gravity/dist.txt) ;

German language: Countries in which a majority of the elite spoke German)

TABLE 3: BIVARIATE CORRELATIONS

	LPCN	LAGLSPX	LAGSSPR	PPROT	CONSTR	LNLANLAB	LNIMPP
LPCN	1.0000						
LAGLSPX	0.6016	1.0000					
LAGSSPR	0.5889	0.9991	1.0000				
PPROT	0.1457	0.2637	0.2490	1.0000			
CONSTR	0.2958	0.6028	0.5975	0.2296	1.0000		
LNLANLAB	-0.2607	0.0557	0.0472	0.1706	0.2209	1.0000	
LNIMPP	0.3102	0.0284	0.0219	0.1519	0.0121	-0.3162	1.0000
LNDISTGE	-0.6368	-0.4429	-0.4499	0.0382	-0.0974	0.6143	-0.3754
GERMAN	0.3219	0.2495	0.2565	0.0816	0.0139	-0.2396	0.1219
DIST*PPROT	-0.0859	0.1107	0.0985	0.9262	0.1993	0.4322	-0.0013

	LNDISTGE	GERMAN	DIST*PPROT
LNDISTGE	1.0000		
GERMAN	-0.3937	1.0000	
DIST*PPROT	0.3807	-0.0711	1.0000

ABBREVIATIONS:

LPCN	LOG PATENTS
LAGLSPX	PRIMARY SCHOOL ENR. (LAG)
LAGSSPR	SECONDARY SCHOOL ENR. (LAG)
PPROT	PATENT PROTECTION
CONSTR	CONSTRAINTS ON EX.
LNLANLAB	LOG LAND-LABOR RATIO
LNIMPP	LOG IMPORTS TO GERMANY
LNDISTGE	LOG DISTANCE TO GERMANY
GERMAN	GERMAN LANGUAGE

TABLE 4: NEGBIN ESTIMATES OF PATENT DETERMINANTS

YEAR	1880	1885	1890	1895
DISTANCE TO GERMANY	-0.244	-0.173	-0.341	-0.167
	(0.540)	(0.668)	(0.384)	(0.538)
SCHOOLING	2.127***	2.565***	2.305***	1.605***
	(0.000)	(0.000)	(0.000)	(0.000)
PATENT PROTECTION	0.811	-0.022	0.318	-0.034
	(0.190)	(0.970)	(0.614)	(0.939)
LAND-LABOR-RATIO	1.775	-1.029	-1.405	-1.448
	(0.370)	(0.514)	(0.359)	(0.224)
POPULATION	0.020	0.033***	0.023*	0.013
	(0.124)	(0.006)	(0.072)	(0.196)
IMPORTS TO GERMANY	6.490***	4.815***	3.006**	3.575***
	(0.000)	(0.001)	(0.013)	(0.003)
CONSTANT	-13.650***	-12.399***	-8.555**	-4.809**
	(0.000)	(0.000)	(0.014)	(0.042)
LOGLIKELIHOOD	-41.583	-46.533	-54.270	-56.549
N	12	14	14	16

YEAR	1900	1905	1910
DISTANCE TO GERMANY	-0.294	-0.533	-0.583
	(0.353)	(0.147)	(0.058)
SCHOOLING	1.949***	2.114***	1.024***
	(0.000)	(0.001)	(0.006)
PATENT PROTECTION	0.033	1.733**	1.975**
	(0.945)	(0.031)	(0.016)
LAND-LABOR-RATIO	-2.145	-2.195	-1.238
	(0.143)	(0.159)	(0.423)
POPULATION	0.021**	0.016	-0.013
	(0.019)	(0.261)	(0.458)
IMPORTS TO GERMANY	1.691*	1.588	3.583**
	(0.060)	(0.201)	(0.014)
CONSTANT	-4.479	-5.044	1.101
	(0.102)	(0.197)	(0.711)
LOGLIKELIHOOD	-64.740	-74.513	-98.072
N	16	16	20

Notes: p-values in parentheses. ***, **, * indicate significance at 1, 5, and 10% levels.

TABLE 5: PANEL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914 IN GERMANY

	(1)	(2)	(3)	(4)	(5)
INCLUDED	All	All	All	> 5 Patents	> 5 Patents
WHICH SCHOOLING	Primary	Secondary	Primary	Primary	Secondary
SCHOOLING	0.70***	3.38***	0.71**	1.10***	4.86***
	(0.0099)	(0.009)	(0.010)	(0.004)	(0.007)
PATENT PROTECTION	0.70**	0.70**	3.19**	-4.88	-5.22
	(0.034)	(0.034)	(0.037)	(0.26)	(0.23)
CONSTRAINTS ON EX.				0.06*	0.07**
				(0.052)	(0.044)
LAND-LABOR RATIO	3.20***	3.27***	3.33***	2.20	2.28
	(0.001)	(0.001)	(0.001)	(0.14)	(0.13)
IMPORTS TO GERMANY	-0.06	-0.05	-0.87*	0.36**	0.35**
	(0.55)	(0.57)	(0.078)	(0.023)	(0.026)
DISTANCE TO GERMANY	-1.15***	-1.16***	-1.17***	-2.07***	-2.14***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.002)
GERMAN LANGUAGE	1.33**	1.33*	1.34*	1.97***	2.00***
	(0.049)	(0.051)	(0.056)	(0.0058)	(0.0058)
PATENT PROT*IMPORTS			0.84*		
			(0.094)		
PATENT PROT.*DISTANCE				0.98	1.04
				(0.15)	(0.13)
TIME DUMMIES INCL.?	YES	YES	YES	YES	YES
CONSTANT	1.91	-2.2	-0.61	7.38	2.85
	-0.42	-0.55	-0.83	-0.18	-0.69
OBSERVATIONS	1.91	-2.2	-0.61	7.38	2.85
R-SQUARED (WITHIN)	0.71	0.71	0.72	0.56	0.56
R-SQUARED (OVERALL)	0.57	0.60	0.56	0.76	0.75

Notes: p-values in parentheses. ***, **, * indicate significance at 1, 5, and 10% levels. Today's boundaries .Random Effects Estimates.

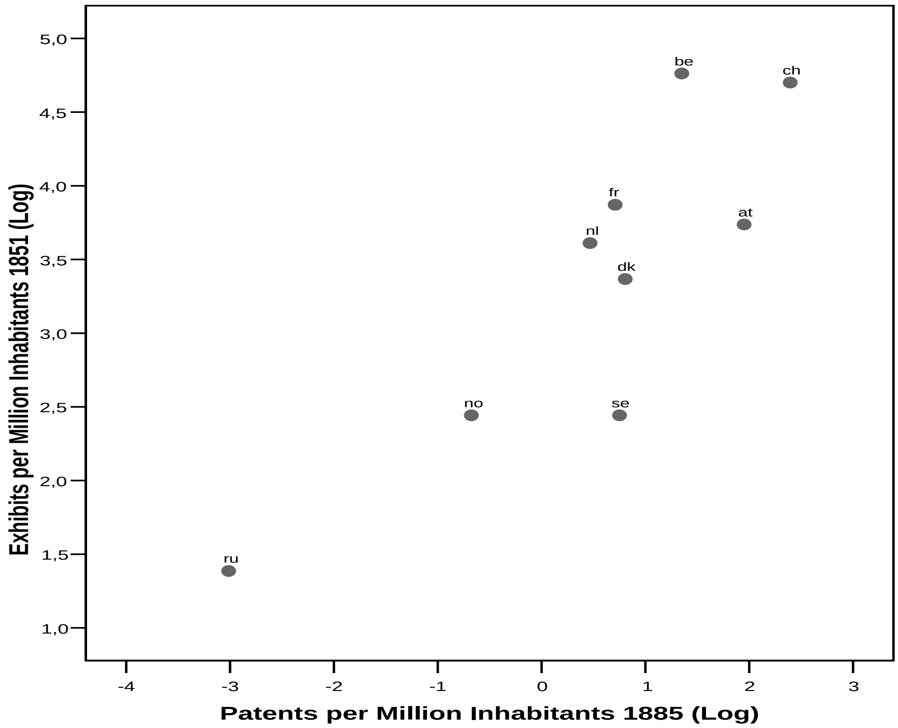
TABLE 6: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG PATENTS PER CAPITA IN THE USA 1890-92 AND 1910-12

	1890-92	1910-12
SCHOOLING	1.598**	1.334**
	(0.027)	(0.049)
ENGLISH LANGUAGE	1.656*	0.958
	(0.093)	(0.288)
PATENT PROTECTION	0.478	0.521
	(0.631)	(0.725)
DISTANCE TO US (LOGARITHM)	-0.672	-0.659
	(0.299)	(0.297)
CONSTANT	-9.794	-7.581
	(0.194)	(0.301)
ADJ. R^2	0.466	0.280
N	15	15

Notes: P-values in parentheses. Data sources: see Text. ***, **, * indicate significance at 1, 5, and 10% levels. Schooling is primary, in logarithms, preceding decade

FIGURE

FIGURE 1: EXHIBITS IN 1851 AND PATENTS PER CAPITA 1885.



Data Sources: Exhibits per Million Inhabitants: Moser, Patent Laws 2003; Patents per Million Inhabitants: see Table 1. Note: For country abbreviations, see appendix B.