Essays on High-Value Patenting in Germany in an International Perspective 1880-1932

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SYMBOLS AND ABBREVIATIONS

CIA….	Central Intelligence Agency
DFG….	Deutsche Forschungsgemeinschaft
EU….	European Union
FDI….	Foreign Direct Investment
GPD….	Gross Domestic Product
GDP/c….	Gross Domestic Product per capita
GNP/c….	Gross National Product per capita
IP….	Intellectual Property
KC-model….	Knowledge-capital model
Ln….	Logarithm
Log….	Logarithm
Max….	Maximum
MCMC….	Markov-Chain Monte Carlo
Min….	Minimum
MNE….	Multinational Enterprise
N….	Number of Observations
OLS….	Ordinary Least Square
p….	Probability
PC….	Patent Class
PPP….	Purchasing Power Parity
Qual VAR…	Qualitative Vector Autoregression
R&D….	Research and Development
ROC-Analysis….	Receiver operating characteristic Analysis
ROE….	Return on equity

Sic2 code….	Standard Industrial Classification (SIC) Code with two-digits
Std. Dev. ….	Standard Deviation
SU….	Sowjet Union
t….	Time
2SLS….	Two Stage Least Square
UK….	United Kingdom
U.S. ….	United States
VAR…	Vector Autoregression
VDMA….	Verein Deutscher Maschinenbau-Anstalten
WWI….	World War I
WWII….	World War II
WLS….	Weighted Least Square

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1 INTRODUCTION

"The patent system
added the fuel of interest
to the fire of genius!"
Abraham Lincoln 1859

1.1 The aim of this dissertation project

The aim of this doctoral thesis is to look at the worldwide relevance of high-value patents granted in Germany between the enactment of the first nationwide German patent law in 1877 and 1932. This patent act enabled both, national and foreign patentees to reap the fruits of their intellectual investment by restraining competitors to adapt the patented invention. Much research is done on patents and their economic effects within national borders at macro and micro levels. But the cross-border importance of patent protection for domestic and foreign inventors and economies is still underrepresented in the literature especially for pre- and post-WWI Germany. Accordingly, this thesis is an attempt to close the gap in the literature by analysing the determinants of foreign high-value patents in Germany for the period 1880-1932. In addition, we explore the impact of a newly developed human capital measure based on adjusted patents and primary school enrolment rates, on long-run economic growth in the respective counties. Furthermore, we explore the relationship between the growing international competitiveness of German mechanical engineering and technological creativity. Finally, we look at FDI of German joint stock companies to establish whether human capital partly based on high-value patents was a determinant on country-level.

1.2 The history and relevance of the first German patent law 1877

The first nationwide patent law in Germany came into force in 1877 (see for example Machlup and Penrose, 1950; Gispen, 1999). It was fundamental for the success of the German patent market during the period under consideration of this thesis (1880-1932). The first harmonised German patent law was not only a quantum leap for inventors and inventing firms in Germany to protect their inventions nationwide, but also opened up new perspectives to expand their economic activity across national borders. Furthermore, inventing individuals and firms from all over the world also benefited from its statutory framework. Without the first nationwide patent law, the German patent market wouldn't have reached its national and international importance. Because of the significance of the first Germany-wide patent law, also for the research questions of this thesis, we look at its evolution and relevance in detail.

While Great Britain, France, and the U.S. had already passed extensive and nationwide patent laws at the beginning of the 19th century, the German Empire struggled with twenty-nine different vague privileges and patent policies. Bernhardt and Krasser (1986) and Khan (2002) emphasise that some states and Hanseatic cities in Northern Germany such as Mecklenburg, Hamburg, and Bremen did not offer any protection of inventions at that time.

Worth mentioning is the Prussian patent system (*Publikandum*) established in October 1814. Fischer (1922) and Seckelmann (2006) note that Prussian inventors did not have a legal protection of their inventions; the coverage was rather a reward of the inventor's effort (*Ermunterung und Belohnung des Kunstfleißes*). The patent granting procedure was extremely bureaucratic and time consuming. The local government forwarded the patent application to the ministry of internal affairs that again sent it to the ministry of trade, commerce and public affairs for a final decision (Heggen, 1975). Nirk

(1977) points at the consequences of the poor Prussian patent protection: Prussia granted only approximately fifteen patents per annum 1820-1830 and fifty to seventy per year in the 1840s.

Under the leadership of Prussia, the German Customs Union (*Deutscher Zollverein*) ratified the first supra-regional convention in 1842[1]. The patent and privileges regulations in each of the states were still in force, but the members agreed on common principles. Even though free trade protection stood in the foreground of this convention, the members introduced the novelty principle for inventions. Patent protection was only granted for inventions that were new and peculiar. As soon as an invention was already published or implemented or generally known, the patent application was rejected (Nirk, 1977).

All subsequent efforts to establish a nationwide patent law before 1877 failed. In general, an anti-patent movement swept Europe during the mid 19th century and the length of patent protection was reduced in some European countries such as France or the Netherlands (Schiff, 1971). In Germany, a well-organised anti-patent lobby successfully influenced the debate about the protection of intellectual property by mid 19th century. Naumann (1999) emphasises the role of the free-trade arguments that viewed patent laws as harmful to a competitive and free economy. Trade associations and the chamber of commerce furthermore pursued the abolition of all patent laws (Machlup and Penrose, 1950). According to Heggen (1975), public interest in the patent protection debate declined by mid 1860s due to several political and economic events, such as the foundation of the North German Confederation (*Norddeutscher Bund*)[2] and

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[1] Territories within the German Custom Union: Prussia, Bavaria, Württemberg, Thuringian States, Saxony, Baden, Grand Duchy of Hesse, Hesse-Cassel, Hesse-Darmstadt, Nassau, Brunswick, Hanover, Oldenburg, Frankfurt.

[2] The North German Federation was a military alliance of twenty-two North German states and Prussia (leading state). The Constitution was founded in April 1867.

the rising economic cooperation between members. But public interest in this topic arose again at the end of the decade. The Prussian chancellor Otto von Bismarck followed the principles of the Association of German Economists (*Verein deutscher Volkswirte*) and tried to persuade the members of the North German Confederation to abandon patent protection.

The Association of German Engineers (*Verein Deutscher Ingenieure*) founded in 1867 emphatically lobbied for a unique and strong patent protection throughout Germany and opposed Bismarck's attempt (Nirk, 1977). Also, the constitution of 1871 did not immediately solve the fragmentation of patent protection in the former sovereign states. Under the leadership of Werner Siemens, the German Association for patent protection (*Deutscher Patenschutzverein*)[3] produced two draft patent laws and sent them to the German Federal Council (*Deutscher Bundesrat*) in 1875 and 1876.[4] Feldenkirchen (1994) and Fischer (1922) hint at the great success of the second draft: the chancellery of the German empire established a patent commission to further develop the initial draft. A first patent law draft was made public the very same year. The final version of the patent law was approved by the Parliament in May 1877 and enacted on 1st July 1877.[5]

The German patent act of 1877 was the first uniform patent law for the German Empire. From this moment on, inventors had the legal entitlement to protect original inventions suitable for industrial use and that do not offend against good manners (Fleischer, 1984; Heggen, 1975; Nirk, 1977). Patents could not be obtained for pharmaceuticals, chemical, and food products, although production processes for such products were under patent protection (Khan, 2002). Experts working at the centralised Administration in Berlin (Imperial Patent Office) were responsible to examine patent

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[3] The Association of German Engineers joined the German Association for patent protection in 1874.
[4] The wording of this draft can be read in Deutscher Patent-Schutz-Verein (1875 and 1876).
[5] See Patentgesetz vom 25. Mai 1877, *Reichsgesetzblatt 1877*, pp. 501-510.

applications and to verify the novelty of the respective invention. In addition, there was an 8-week window for the general public to object the patent before it was granted. Thus, the public had the chance to deny the originality and therefore the validity of the patent.

The maximum life span of a patent was fifteen years. Patent protection could be obtained for one year, and an annual extension was necessary to keep the patent in force. The patent fees increased annually: fifty Marks for the first and second year, from the third year onwards the fee increased by another fifty Marks every year up to 700 Marks at the beginning of the fifteenth year. Streb and Baten (2007) add that fifty Marks was the average gross wage of an industrial worker at that time. Lerner (2002) found that Germany had the highest patent fees among a group of sixty countries between 1850 and 1999. According to Khan (2002) and Seckelmann (2006) patent fees were set high to avoid patent applications for trivial inventions.

Metz and Watteler (2002) or Nirk (1977) mentioned that the patent code followed the first-to-file principle instead of the first-to-invent principle. The first-to-file principle was due to the patent law draft of Werner Siemens who was rather industry-orientated. This principle was in general disadvantageous for employed inventors: the company was the legal patentee and an employed inventor had no chance to benefit directly from the revenues of the implemented invention. Grupp (2005) however sees the first-to-file principle to be one factor of success for the boom of the chemical, engineering, and machinery industries before WWI.

Due to the equality of foreigners and residents as well as of natural and juridical persons, the emerging German patent market also offered further possibilities for foreigners to minimise the risk of imitation of inventions in Germany. As soon as the patent law was enacted in July 1877, the number of national and international patent applications and granted patents increased strongly. The patent office in Berlin received

3,212[6] patent applications in 1877 and granted 190 patents in the same year. Those figures quickly increased to 21,925 applications and 8,784 grants by 1900 (see Fleischer, 1984; and Heggen, 1975).

The German patent system built the legal basis for patent laws not only in many Northern and Central European countries (Boch, 1991), but also in some Latin American countries such as Argentina or Brazil (Khan, 2002).

1.3 How to measure important patents

1.3.1 Measuring innovative activity

The term ‘invention’ should not be confused with ‘innovation’. Ruttan (1959) was amongst the first who brought the terms invention, innovation, and technical change in a logical order: invention is antecedent to innovation and the latter again antecedent to technical change. Acs and Audretsch (1989) and Kennedy and Thirlwall (1972) define inventions as inputs into the development of innovations. The keyword in connection with the term invention is creation. If an invention can be used in practice and commercialised, it becomes according to Acs et al. (1992) or Plasmans et al. (1999) an innovation. An innovation is the process whereby an invention moves into a usable form.

At the empirical frontier, it is difficult to find an appropriate proxy for innovation. One empirical problem is the difficulty of selecting an appropriate proxy for innovation. The most popular proxies used are patents and Research and Development (R&D) (see for example Archibugi, 1992; Acs and Adretsch, 1989; Griliches, 1990). It is important to note that different aspects are connected with both proxies: R&D is an input into the

[6] Total patents, including economically unimportant patents.

innovative process (R&D), whereas patents measure innovative output (patented inventions) (Crosby, 2000; Acs and Audretsch, 1989; Lanjouw and Schankerman, 2004). Acs and Audretsch (1988), Mansfield (2002) and Scherer (1965) found a strong positive correlation between company R&D expenditure, patents, and actual innovations arguing consequently that both measures in general are appropriate proxies for innovation.

Various studies such as Coe and Helpman (1995), Bosworth and Rogers (2001), Hall (1993) or Vossen and Noteboom (1996) used R&D expenditures to proxy innovations in their analysis. They argue that R&D efforts are required to generate inventions as they represent those resources that inventors or inventing firms budget to produce innovative output. Criscuolo et al. (2005) see the strength of R&D in its capacity to exploit and / or augment technological competence. Technological performance of inventing firms does not only depend on own R&D efforts, but also on the ability to utilise complementary resources that are relevant for the local innovation system. Choosing R&D as an innovation indicator has also the advantage that all inputs into the innovative process are included.

1.3.2 Advantages and limitations of patents as a proxy for innovation

Patents are widely used as a measure of innovative output. A number of studies have shown that they are a reliable proxy for innovative activities (see for example the discussion in Hall et al., 2001; Pavitt, 1988; Patel and Pavitt, 1995). Sanyal (2003) claims that patents are often the best available proxy for the use in empirical studies. Amongst many others, Acs and Audretsch (1987) and Griliches (1990) see the superiority of patents as follows: compared to R&D expenditures, they represent the result of an R&D program and not its investment level. To be more precise, inventors try to patent those inventions that are expected to have commercial impact and high future returns. Archibugi and Pianta (1996) stress that patent statistics are also broken down by technological fields and hence do not only mirror the rate of inventive activities but also its direction. In addition, patent statistics are available for rather long periods; they are easily analysable due to their systematics that if at all changes slowly. Patents provide a detailed technical description of the invention and gives relevant information on previous patents, inventors and / or inventing firms (Criscuolo et al., 2005). Markman et al. (2004) base their analysis on patents and argue that they are valuable, rare, and costly to imitate and substitute.

As mentioned above, the use of patents as an indicator for innovation in empirical studies is not undisputed in the literature (for a detailed discussion see Crosby, 2000; or Kennedy and Thirlwall, 1972) and suffers from several limitations. Most criticised in the literature is the fact that some inventions are never patented[7] and not all patented inventions proved to be important innovations (MacLeod et al., 2003; Pavitt, 1985; Scherer, 1983). In addition, not all inventions are patentable by law. For example, Nirk (1977) reports that according to the current law in Germany, patents cannot be obtained for pharmaceuticals, chemical, and food products. Furthermore, patent systems may differ significantly between countries, e.g. in terms of patent scope, maximum years of protection. Consequently, cross country comparisons might be difficult. Nowadays, patents are often used for strategic reasons to secure the own future inventions against rivals and to block competitors (Blind et al., 2007). Lanjouw and Schankerman (2004) see difficulties in estimating the average value of an innovation, as the average value of a patented innovation might decrease or increase due to multiple reasons. Schibany and Dachs (2003) add to the criticism above that product innovations are overrepresented in

[7] See also section 1.3.3 for alternative protection strategies.

patent statistics in comparison to process innovations as seen in higher share of products in all patented inventions.

1.3.3 Secrecy or patent protection? Alternatives to appropriate returns from innovation

Inventors seek to appropriate returns to make the development of the innovations worthwhile (Anton and Yao, 2004; Helpman, 1993). The appropriation of the benefits of an innovation requires its exposure to business partners or the public to some extent. The protection of intellectual property (IP) is desirable in order to provide incentives to invent in the first place. If IP is inadequately protected, the disclosure of the invention is threatened by imitation. Competitors will attempt to free ride by copying innovations and appropriating its benefits (Arundel and Kabla, 1998; Cohen et al., 2000; Scotchmer and Green, 1990; Takalo, 1998). Arrow (1962) and Mansfield et al. (1981) argue that incentives to innovate are also influenced by the accruing imitation costs of an innovation. Inventors might have no or less incentives to carry innovations if the imitation costs are considerably lower than the development expenses for inventions. Since the seminal studies on different strategies to protect IP by Horstman et al. (1985) and Levin et al. (1987), there has been extensive research on this issue.[8] The authors distinguish between two prominent alternatives to seize the returns of innovations: secrecy and patent protection. Other issues such as copyrights, trademarks, first-mover-advantages play a minor role in the empirical literature, but nevertheless were studied by Dam (1994), Harabi (1997), and von Hippel and Krogh (2006).

Gay et al. (2005) define patents as a legal contract between the inventor (or the inventing company) that gives the patent holder exclusive rights to exploit his invention commercially within a limited geographic area for a given period. Hence, patent

[8] An excellent survey of the literature is provided by Arundel (2001), and Carlaw et al. (2006).

protection enables inventors to obtain monopoly profits by restraining competitors to adapt the innovation (Basberg, 1987; Bessen, 2005; Kultti et al., 2006).

Nordhaus pointed in several publications (Griliches et al., 1989; Nordhaus, 1969a; Nordhaus, 1972) to the trade-off between incentives to invention and the inefficient monopoly position generated by the patent law. They argue that patents provide innovators with a temporary monopoly position that offers incentives for them to invest in R&D. Larger quantities or improvements of a given innovation are subsumed by dynamic efficiency. On the other hand, the monopoly position causes static losses due to inefficient monopoly pricing or a restricted use of innovations. Hussinger (2006) refers to the side-effects of patents: due to the required publication of the patent description, competitors might be encouraged and enabled to invent around the patented innovation. To avoid similar inventions, inventors thus may choose secrecy as a proper protection mechanism of IP. Keeping an innovation secret may also be a strategy to protect inventions that are explicitly excluded from patent protection by law (Basberg 1987). Mansfield et al. (1982) emphasises that inventors may also prefer secrecy due to the time-consuming patent granting procedure that delays the market launch of the invention. According to Moser (2003), an inventor might obtain similar conditions to patent protection when choosing secrecy. To be more precise, those inventors could reach similar conditions with massive effort by driving competitors out of the market or by keeping control over assets that are complementary to the innovation. But, in the case of secrecy, the inventor or inventing firm risks the imitation of the respective product or process without any legal consequences for imitators.

Cohen et al. (2000) and Levin et al. (1987) found patents to be more suitable for product innovation than for process innovations. Arundel (2001) shows that secrecy is popular in low-technology sectors such as basic metals: technologies often based on nonpatentable general engineering principles. Analysing the preferences IP protection of 100 U.S. manufacturing companies, Mansfield (1986) also found substantial differences among industries. In some industries such as the chemical or pharmaceutical industry patent protection is considered to be more effective, whereas in other industries such as the vehicle industry patents play a minor role and the share of patented inventions is much lower. He concludes that inventors do not prefer secrecy if patent protection is possible in some degree. Moser (2005a) analysed in her paper 4,688 innovations presented at the Crystal Palace Fair in London and found that secrecy is popular in selected industries that are geographically concentrated. Industries that protected their innovations mostly by patents after the Crystal Palace Fair, tended to be more geographically diffused in the period 1851-1901.

Recently, strategic patenting has gained more importance. Research by Arundel et al. (1995), Cohen et al. (2002), and Hall and Ziedonis (2001) are frequently cited on this subject. Noel and Schankerman (2006) define strategic patenting as follows: in contrast to the traditional patent motive where patents should be protected from imitation by competitors for a certain time horizon, strategic patenting goes beyond this scope. The motive of strategic patenting is to block competitors offensively. Thus, as Blind et al. (2006, 2007) argue, patents are used to secure future inventions against rivals and restrict future technological opportunities. Bessen and Hunt (2007) add that inventors may patent more frequent than necessary to block competitors, even though they do not have a direct interest in using the content of such patents.

1.3.4 How to distinguish between important and unimportant patents

The use of patent counts as an indicator for innovation has been recognised as problematic in the literature[9] (Griliches, 1990). The main point of criticism is the fact that not all patented inventions are economically significant. Simple patent counts do not consider differences in the quality of patents and the fact that some patents are not held to appropriate returns from the invention but for strategic reasons (Levin et al., 1997). In order to overcome this problem, many researchers developed methods to filter important patents from those of little or no value.

The most prominent methods to estimate the quality of patents are patent citation and patent renewal methods.[10] The patent citation approach has been used in a series of papers (for example see Jaffe et al., 1993; Jaffe and Trajtenberg, 1999; Lanjouw and Schankerman, 1999). Patents citations specify how often a patent is cited in following patent descriptions. Thus, they indicate the extent to which innovations are important and presumably more valuable to an inventor (Carpenter et al., 1981; Hall et al., 2001). The underlying principle is that a patent with a higher value generates a stream of new inventions that all cite the initial patent (Gay et al., 2005).

Since the seminal studies on the patent renewal approach by Pakes and Schankerman (1984), Schankerman and Pakes (1986), and Pakes (1986) there has been extensive research on this topic. The idea behind this approach is the requirement to renew the patent protection annually in most countries to keep the patent in force beyond its statutory limit. The patent continues to be renewed if the current value of the remaining expected future returns is greater or equal to the present value of remaining

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[9] See also section 1.3.2.

[10] A further method to discriminate unimportant patents is used by Townsend (1980): He uses experts evaluation of the quality of patents related to coal mining on a 1-4 scale. For a detailed description of alternative approaches to measure the quality of patents see Archibugi and Pianta (1996) and Bosworth et al. (2003).

future costs. Also Lanjouw (1998) and Lanjouw et al. (1998), Pakes and Simpson (1989), and Sullivan (1994) hypothesise that patents renewed for shorter periods have a lower economic value than patents that are renewed for longer periods. The advantage of this method is the possibility to estimate the average value of the invention that may differ among various groups of patent holders, technological fields, and over time. Bosworth and Jobome (2001) emphasise that the value of the invention can be calculated for different patent ages in a given cohort based on the renewal activity and accruing costs. Streb et al. (2006a) also identified the patent renewal approach to be most suitable for the patent database of our DFG research project.[11]

1.3.5 The relevance of foreign patents

A country's patent law is also relevant for foreign inventors. According to the first German patent act in 1877, not only natural and juridical persons were equally entitled to protect their inventions by law, but residents and foreigners as well. The Paris Convention ratified in 1883 was an additional milestone towards the equal treatment of foreign and domestic intellectual property, as foreign patent applicants had been previously discriminated in many countries (Patel, 1974). Each contracting State was obliged to grant the same protection to inventors disregarding the country of origin[12].

Sláma (1981) was a pioneer in analysing the determinants of 'active' and 'passive'[13] patent applications of twenty-seven countries beyond national boundaries using regression analysis for the period 1967-78. In several gravitation models, he found that the number of patent applications is sensitive to changes of GNP/c in the inventor's

[11] See also section 1.4 for a detailed description of the high-value patent database.
[12] Inventors of non-contracting countries were also entitled to get patent protection according to the convention if they resided there or had a commercial or industrial establishment in a contracting country.
[13] Sláma (1981) defines 'active' / 'passive' as export / import of patent applications.

country. Countries with lower GNP/c had comparatively fewer numbers of active and passive patent applications than countries with a higher GNP/c. In addition, countries with higher GNP/c tend to have a surplus of active patent applications over passive patent applications.

The number of studies on international patents has increased during the last years, reflecting the growing importance and worldwide integration of patent rights (see for example Chan et al., 2004; Deng, 2003; Marinova, 2001; Porter and Stern, 2000). Because holding and renewing a patent is very costly, the inventor has to select the country very carefully where patent protection should be given (Eaton et al., 2004). The decision to patent in a given country also depends on how rigorously the country of destination protects IP. For example, the German patent authorities charged a high patent fee but offered rigorous protection in return during the period under consideration of this thesis. Foreign patent applications are only profitable for inventors that anticipate high commercial returns when holding a patent abroad (McCalman, 2001).

As pointed out by Eaton and Kortum (1996) and Eaton et al. (2004), patent protection in other countries is desirable for several reasons: patents beyond the border enhance the value of the invention and sets the foundation for future exports. Generally, inventors seek patent rights in countries with extensive markets where competitors would probably imitate the technology without an existing patent protection. International patenting prevents competitors from imitating the respective good outside the country of origin. It is argued that foreign patents are a proxy for a nation's competitiveness because they have on average a higher value than domestic patents (Basberg, 1987; Kotabe, 1992).

1.3.6 Further economic relevance of patents in an international context

From an international perspective, protection of intellectual property rights through patents has further implications. Patent rights enable patentees to exploit their innovations and provide incentives to broaden their economic activity respectively competitiveness across national borders. In the following, we only look at those global connections that are relevant for this doctoral thesis.

One possibility to extend the appropriation of returns from granted patents is to establish commercial relationships abroad and to export the patented product. The literature on trade performance identifies innovation as a key determinant of trade flows between countries (see for example Freeman et al., 1991; Greenhalgh et al., 1994). An increasing GDP in the target country motivates more inventors or inventing firms to extend their success and to sell the promising innovation abroad. Conversely, foreign inventors may benefit from an increasing domestic demand. Greenhalgh (1990) analysed in her paper the determinants of UK net exports. She found evidence that net exports are influenced by various technology variables and concludes that innovation has explanatory power for both, the relative trade performance of countries across sectors and the trade performance of single countries.

As recalled by Mansfield (1994) Foreign Direct Investment (FDI) is an important channel to transfer technology to other countries. In addition, the weakness or strength of a country's IP protection system has a substantial impact on the type of technology that is transferred to that country. Maskus (1998a) provided econometric evidence that FDI of American companies was sensitive to changes of the patent systems in the country of investment. Lai (1998) adds that FDI also bears the potential for technology spill-overs into local economies.

1.4 The high-value patent database[14]

All chapters presented in this doctoral thesis have one common base: the unique patent database compiled in our DFG-project. To be more precise, we can distinguish between the primary high-value dataset for the period 1877-1918 and its extension for the period 1919-32.

The primary data source is the directory of the previous year's patents (*Verzeichnis der im Vorjahre erteilten Patente*), published by the German Patent Office in Berlin annually. The directory allocated each granted patent to one of the 89 patent classes and from 1900 onwards also to 472 subclasses. These patent classes did often not correspond to the industry in which they were developed but rather to the industry that was supposed to use the respective invention. The result of this system was that specific patents such as the mechanical engineering patents are not only spread logically over several classes but can also be found in less obvious classes. Which information do we get from the patent register precisely? The patent register provides the name of the patent holder, the patentee's status (firm or person), the patentee's place of residence, the corresponding region, the patent class (plus subclass from 1900 onwards), the patent number, and a short description of the patented invention.

Following Streb et al. (2006a), we use the patent renewal approach[15] by Pakes and Schankerman (1984) and Schankerman and Pakes (1986) in this dissertation to obtain economically important patents. Those filtered patents in the remaining part of the thesis are called high-value patents. High-value patents in that sense are those patents profitable enough to be extended for at least ten years. Applying the renewal approach, we have 39,343 (27,157) high-value patents out of 311,019 (258,516) granted patents

[14] The following publications were based on the pre-WWI dataset: Baten (2003), Yin (2005), Streb et al. (2006a), Streb et al. (2006b), Streb and Baten (2007), Spoerer et al. (2007).
[15] For a detailed description of the renewal approach, see section 1.3.4.

between 1877 and 1918 (1919 and 1932) in our datasets. Furthermore, 9,165 (6,255) high-value patents were held by foreigners during the period 1880-1914 (1919-32).

1.5 Empirical findings and publications due to the high-value patent database

The richness of the high-value patent data base kick-started this thesis and generated many other interesting studies. Baten (2003) asked which factors encouraged 4,036 entrepreneurs in Baden around 1900 to set up their own business and to engage employees, and what prevented others from doing it. He came to the conclusion, that not only agglomeration effects and an earlier firm creation stimulated current firm creation, but also the number of per capita patents and the per capita number of students at industrial schools had a positive impact on firm creation rate.

Analysing the survival rate of German patents, Streb et al. (2006a) demonstrated that approximately seventy per cent of all German patents granted between 1891 and 1907 were not extended after five years and also emphasised the validity of the renewal approach for the jointly used high-value patent database. They also identified four different waves of technological progress between 1877 and 1918. The railway industry had its boom in 1877-86, the dye industry 1887-96, the chemical industry 1897-1902, and finally electrical engineering 1903-18. Furthermore, they found evidence that innovative activities during German industrialisation were driven by inter-industry knowledge spill-overs between geographically and technologically related industries.

The aim of Streb et al. (2006b) was to analyse knowledge spill-overs between the synthetic dye and textile industries in Germany between 1878 and 1913. Their empirical analysis led to the following result: the flourishing textile companies demanded more and more synthetic dyes to colour their cloths during the second industrial revolution.

Consequently, chemical firms invested more in R&D projects to further develop their products and increasingly were granted more patents. In the end, inter-industry knowledge spill-overs between textile and chemical firms resulted in a virtuous circle of endogenous growth.

Baten et al. (2007b) analysed innovative activity of companies located in the state of Baden 1895-1913. They came to the conclusion that the innovation activities of large and small firms were positively influenced by inter-industry and intra-industry externalities. More precisely intra-industry externalities were more important for the entire sample, whereas inter-industry externalities were more important for small firms. The presence of firms in other sectors and regional human capital was more beneficial to innovative activities of small firms.

More research on spill-over effects was carried out by Yin (2005). He also analysed spill-over effects of human capital proxied by the number of students in technical and commercial schools on patents across thirty-seven Prussian regions between 1877 and 1914. Human capital exerted a significant influence on innovation (proxied by high-value patents) within the same region. Additionally, human capital had remarkable spill-over effects on innovation in other regions even though the impact of human capital spill-over decreased over distance.

1.6 The structure of this dissertation

The aim of this doctoral thesis is to look at the worldwide relevance of high-value patents that were granted in Germany between the enactment of the first nationwide German patent law in 1877 and 1932. Therefore, we investigate high-value patents that were granted in Germany to inventors and inventing firms around the globe in the periods 1880-1914 and 1919-32 before we draw our attention to the further relevance of high-value patents in an international perspective. Because the structure of this thesis follows those research topics, time periods may alternate.

To be more precise, this dissertation is structured as follows: Chapter two explores the determinants of international high-value patents in Germany for fifty-one countries around the globe in the 1880-1914 period. We study the impact of patent laws in the native country, institutional quality, geographical and cultural proximity, as well as primary schooling among other exogenous variables on foreign high-value patents in various OLS, WLS, and panel regressions. In addition, we check our results with data on foreign patents granted in the U.S. 1890-1912.

Chapter three should give a better understanding of how and why international patenting in Germany has changed in the interwar period, and draws a comparison to the pre-WWI phase. We particularly consider the differences in the patenting behaviour of WWI Allies as well as the German confederates and neutral states.

In chapter four, we explore the impact of a newly developed human capital measure based on foreign patents in Germany, primary schooling on long-run economic growth in the respective counties. We consider whether the stock of human capital has only short-run or also long-run effects on GDP/c levels and growth rates.

From an international perspective, the protection of intellectual property rights through patents is not only important for foreign inventors, but offers various possibilities for native inventors to expand their economic activity and competitiveness across national borders as well. Patentees may seek to extend the appropriation of returns from granted patents and export the patented product. Accordingly, chapter five sheds light on the factors that caused the growing international competitiveness of German mechanical engineering industry in the pre-World War I period. We explain the reasons behind the international market success of machine builders in the German Empire: technological creativity and the availability of a comparatively cheap labour.

Growing competition on the world markets at the end of the 19th and the beginning of the 20th century required diversification. FDI is an important channel to transfer technology across borders and gained in importance at that time. Based on firm-specific data of German joint stock companies, we analyse 948 individual FDI transactions of 377 joint stock companies, as well as a control group of 556 joint stock companies without FDI from 1873 to 1927 in chapter six. We discover firm characteristics that caused FDI, preferred host countries, and whether FDI was successful in terms of enhancing corporate profitability.

Finally, chapter seven summarises the main findings of the preceding chapters.

2 Foreign patenting in Germany and its determinants: A study on 51 countries, 1880-1914

2.1 Abstract

This chapter explores the determinants of the number of important patents in Germany for fifty-one countries around the globe. We study the potential influence of patent laws, institutional quality, and primary and secondary schooling. Controls for distance and industrial structure are included. Investment in primary schooling did in fact decide about innovative success as measured by patent rates adjusted for distance and German language. Moreover, patent laws and institutions that protected other property rights had a promoting effect in the period 1880-1914. Scandinavia ranks higher, and the Mediterranean and Balkan countries lower than we would expect from their respective schooling levels.

Chapter is based on a working paper, see Labuske and Baten (2006). The concept for the paper was developed jointly, the analyses and writing was equally shared.

2.2 Introduction

How innovative were economies around the world between 1880 and 1914, and what determined their innovative 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 (see for example Boldrin and Levine, 2002; Moser, 2003).

Even at first glance, the totalised numbers of high-value patents per country (today's borders) in the German Empire in Table 2.1 provide important insights. Firms and inventors from many countries found it worthwhile to seek patents in Germany: 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, thirty-six nations (today's borders) had important patents in Germany. However, we also included fifteen nations with zero patents for which we had data on the majority of our exogenous variables explained below. One contribution of our study is to extend innovation and human capital studies to a global scale for this period by including a large number of poor countries (earlier studies were often limited to richer countries). Coming back to Table 2.1, 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 colouring, varnish, lacquer, coating, adhesive and chemical processes), whereas the Czech Republic’s patents were distributed across more diversified industries. 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 neighbours, 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 Lerner (2000). It will be important to assess the influence of patent legislation in more detail below.

TABLE 2.1: IMPORTANT (10-YEAR) 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
U.S.	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
Holland	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
Peru	0	0	0	0	1	0	0
Total Foreign Patents	**416**	**460**	**675**	**838**	**1382**	**1930**	**3340**
Total German Patents	1134	1171	1995	1998	2550	4940	10197
Total Patents	1550	1631	2670	2836	3932	6870	13537

Data source: 10-year Patents: Kaiserliches Patentamt (1875-1918).

The main goal of this chapter is to explore the determinants of foreign patents in Germany. 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 distance and same language measures a country's propensity to innovate. This adjustment accounts for the fact that neighbouring countries with a common language and / or cultural background tended to have more patents in Germany. By making this adjustment, a higher propensity to patent due to cultural similarities or geographical proximity is cancelled out. In principal, we test the following hypotheses in this study:

2.2.1 Hypothesis 1: Patent laws had a positive influence on innovativeness

Moreover, investment in schooling could indeed have been a main determinant of innovative 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 (Mokyr 1990, Mitch 1993). For the more recent period, Pritchett (2001) has discussed the phenomenon that additional schooling did not increase GDP per capita in recent decades. The late 19th and early 20th century, in contrast, has been described as a period of transformation to schooling-based innovativeness by Mokyr (1990). Khan and Sokoloff (2004) have emphasised the importance of accumulated human capital for inventors, which makes the activity of inventors a necessary, but not sufficient precondition for innovation, i.e. the process of transforming inventions into economically useful applications. Furthermore, and our study will emphasise this point, a certain level of education is not only necessary for the inventor and innovator himself, but also for the labour 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.

2.2.2 Hypothesis 2: Primary schooling had a positive effect on innovativeness

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:

2.2.3 Hypothesis 3: Constraints on the executive's right to expropriate property had a positive effect on innovativeness

In order to further our understanding of the important human capital growth phase of 1880 - 1914, a number of studies have focused on the economic patent history of the U.S., although it is very difficult to distinguish important and unimportant patents in the U.S. case.[16] (Bailey 1956, p.533). Kenneth Sokoloff and co-authors have also addressed the issue of the limitations of patent counts in several papers (Sokoloff and Khan, 1990; Lamoreaux and Sokoloff, 1997; Khan and Sokoloff. 2004). We hold that it is particularly promising to focus on the German patent market when asking two crucial questions: how innovative were the economies around the world in 1880-1914? And: what determined their innovative success or failure? Germany was not only a country where important new technology was developed, but also an important market for patent rights. No less

[16] The figures of the U.S. include all patents which were granted, and not only high value patents with a life span of at least ten years. The following figures for Germany refer to high value patents which were prolonged for ten years.

than 9,165 important patents that had been granted to foreigners between 1880 and 1914 were prolonged for ten years. Every year, a patent holder had to pay a substantial fee, which he would only do if the expected patent value exceeded the cost.[17] 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 (see for example, Bosworth et al., 2003; or Lamoreaux and Sokoloff, 1997). We will discuss this below.

The rest of the chapter is organised as follows: section 2.3 briefly reviews the literature on renewal data and the German patent system, and data and measurement strategies are described. Section 2.4 provides a simple empirical model and a list of explanatory variables in our basic regression model whose results are reported in section 2.5. This section also includes extensions of the basic model as well as a comparison with foreign patenting in the U.S. Section 2.6 contains additional tests, and section 2.7 summarises our findings.

2.3 Data

2.3.1 Historical overview: The German patent system and the importance of the patent law 1877

Among others, Nirk (1977) has emphasised 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 twenty-five different states and each state had

[17] For a critical account, see McLeod et al. (2003).

its own patent policy, if at all. 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 standardised Germany-wide patent protection system. Khan (2002) 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.

Almost simultaneously, fourteen countries[18] ratified the Paris Convention in 1883 in order to harmonise the protection of intellectual property. The German Empire did not join this convention at first, but became party to the Convention in 1903. 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 (Patel, 1974).

2.3.2 How can we discriminate unimportant patents? The concept of high-value patents

Patent counts that compare different countries with their national patent statistics have been heavily criticised 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 (1986) and others have emphasised that simple patent counts do not mirror the quality of innovations. Various methodologies have thus been adopted to approximate the value of patents. Jaffe and

[18] Belgium, Brazil, Ecuador, El Salvador, France, Great Britain, Guatemala, Italy, the Netherlands, Portugal, Serbia, Spain, Switzerland, and Tunis.

Trajtenberg (2000) measure patent value based on the number of citations from more recent patents, whereas Schankerman and Pakes (1986) and Schankerman (1998) analyse the survival rates of patents. 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 fifty Marks for the first year, and increased annually to up to 700 Marks for the fifteenth year, making the maximum total for fifteen years 5,300 Marks. 5,300 Marks were 1,261 U.S. $ in 1900 and correspond to 25,767 U.S. $ in 2005 real terms, using the GDP deflator.[19] This allows us to identify the more profitable patents: while the fee was substantial enough to deter unimportant patents by amateurs, it was not necessarily high compared with the expected profit from individual patents. We define "important patents" as patents that were renewed for ten years, because they must have been profitable enough to rationalise the cost of renewal.

MacLeod et al. (2003) have stated that the above assumptions are only valid for inventors without credit constraints. 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 realise) a decision as to whether

[19] Lerner (2002) estimated that fifteen years would cost $22,694 in 1998 Dollars. He found that Germany in 1900 had a higher patent fee than sixty countries in the entire time period of 1850-1999.

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.

To which degree do important (10-year-prolonged) patents and all patents differ? To shed light on this question, we look at both important and all patents by industry.[20] We observe that more influential and more dynamic industries such as the chemical and electrotechnical industries had a higher share of ten-year-prolonged patents (Table 2.2). Chemicals even had a share of 27 per cent. In contrast, only 6-7 per cent of transport equipment and industrial machinery patents were extended for ten years (this includes, for example, the producers of parts of steam engines etc., who were less innovative in this period). Hence, the differences within our new, importance-based patenting source are substantial: chemical patents were renewed for ten years about four times as often.

[20] We consider industries that obtained more than 250 German patents in 1905.

TABLE 2.2: SHARE OF 10-YEAR-PROLONGED PATENTS IN INDUSTRIES 1905 (WITH > 250 PATENTS)

Industry	Sic2 code	Share (in %)	High-value patents	All patents
Chemicals	28	26.86	152	566
Electronic	36	14.86	147	989
Primary metal	33	14.09	81	575
Printing / Publishing	27	13.36	35	262
Food Products	20	11.50	33	287
Stone/Clay/Glass	32	10.80	35	324
Instruments	38	10.47	40	382
Fabricated metal products	34	10.01	90	899
Misc. manufacturing	39	9.85	65	660
Agricultural production	10	8.61	23	267
Textiles	22	7.53	21	279
Transport equipment	37	7.20	58	805
Industrial machinery	35	5.98	86	1439

Data sources: 10-year Patents: see Table 2.1.
All Patents: Kaiserliches Statistisches Amt (1880-1915).

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.[21] 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.

[21] The sharp decrease of the patent cohorts' mortality rates during war times is reported in Table 3 in Streb et al. (2006a).

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, although McLeod et al.'s (2003) argument might apply that capital constraints could lead to a slight underestimation of innovativeness in poor countries with underdeveloped credit markets.

2.3.3 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 33,953 high-value patents that were granted to residents or foreigners in Germany between 1880 and 1914. For the purpose of this chapter, we filter out those 9,165 patents that were held by patentees from thirty-six countries. Some summary statistics are shown in Table 2.3.

TABLE 2.3: DESCRIPTIVE STATISTICS

Variable	N	Mean	Std. Dev.	Min	Max
Log patents per capita 1880	51	1.559	2.438	0.000	7.547
Log patents per capita 1900	51	2.131	2.766	0.000	8.122
Log primary schooling rate 1880	51	5.502	0.919	3.651	6.809
Log primary schooling rate 1910	51	5.894	0.747	4.078	6.882
Log GDP/c 1880	51	7.189	0.556	6.292	8.439
Log GDP/c 1910	51	7.525	0.627	6.494	8.591
Patents in chemical / electrotechnical industries (%)	51	0.076	0.110	0.000	0.410
Patent laws 1875	51	0.784	0.415	0	1
Patent laws 1900	51	0.882	0.325	0	1
Institutional constraint on exec.	21	2.857	2.351	1	7
Literacy 1880	17	58.941	23.368	10.0	85.0
Literacy 1910	22	79.000	24.085	9.0	99.0

Data sources: High-value Patents: see Table 2.1; GDP/c: Maddison (1995 and 2001), Literacy: Crafts (1997), Schooling Rates: Lindert (2004a).

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, matters are less clear: Brazilian patent holders had names like Mello, Benedetti, or Bandeira. 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 natural logarithm of per capita patents in the quinquennials between 1880 and 1914. We also include countries with zero patents like Bulgaria, Greece, Portugal, Mexico, Bolivia, Chile, etc. to include as much information as possible in the analysis. The criterion for inclusion is whether explanatory variables are available, the critical bottleneck being human capital indicators like schooling or literacy.

This new sample is much more comprehensive than the samples of earlier studies. But to which extent does selectivity play a role in our sample? Which countries are included, and which are excluded? To answer this question, we calculate the share of today's (2004) low, middle, and high-income countries using three different historical measurement strategies of human capital: literacy, Lindert's original schooling figures, and our interpolations based on Lindert's data. First of all, there is a rather strong selectivity towards high-income countries when we consider literacy rates. None of the seventeen countries for which Crafts (1997) reports data on literacy, fall in the bottom or middle third of today's countries. Lindert's schooling data set covers a broader range of cases: he also reports data on two countries that are medium-income countries today (Brazil, Jamaica), and on one country from the bottom third (India). Finally, our data set uses interpolated schooling figures, especially if patent data are also available. Hence, we arrive at an even broader coverage which enables us to include fourteen middle-income countries and three from the poorest third of today's income distribution (India, Vietnam and Nicaragua). However, we have to keep in mind that when using literacy as an explanatory variable, the data set will be more biased towards today's rich countries.

This chapter aims at constructing data using two strategies established by Maddison (1995 and 2001), who created the most renowned worldwide compilations of GDP estimates. 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 chapter. 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. 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.

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.

2.3.4 Comparison with Moser's sample (2003)

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 twenty-two Northern European countries that exhibited in seven industrial categories (making the total number of observations 154 (see also the shorter version, Moser, 2005b). 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.[22] 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.

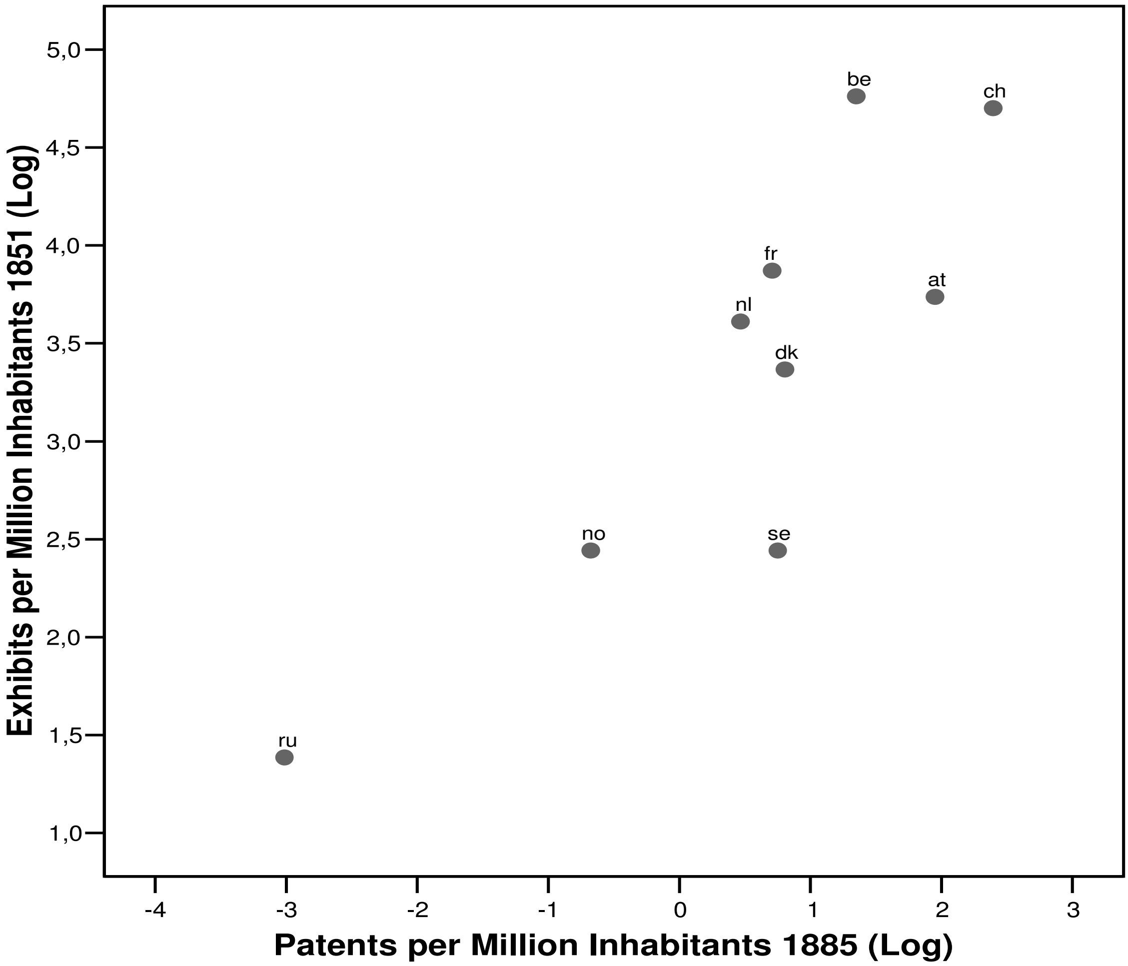
Despite the differences between the sources and our method of distinguishing important from unimportant patents, we can compare our sample with Moser's. After adjusting for distance and industry structure, we find a high correlation between the number of exhibits and per capita patent numbers in Germany. Figure 2.1 shows a comparison of our per 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,

[22] 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.

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 2.1. When plotting Moser's values against our values for 1885 in a scatterplot (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 2.1 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 an underdeveloped country to the centre of Europe, whereas Belgium was already an industrialised 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 patents 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).

FIGURE 2.1: EXHIBITS IN 1851 AND PATENTS PER CAPITA 1885



Note: For country abbreviations, see appendix A.3.
Data Sources: Exhibits per Million Inhabitants: Moser (2003); Patents per Million Inhabitants: see Table 2.1.

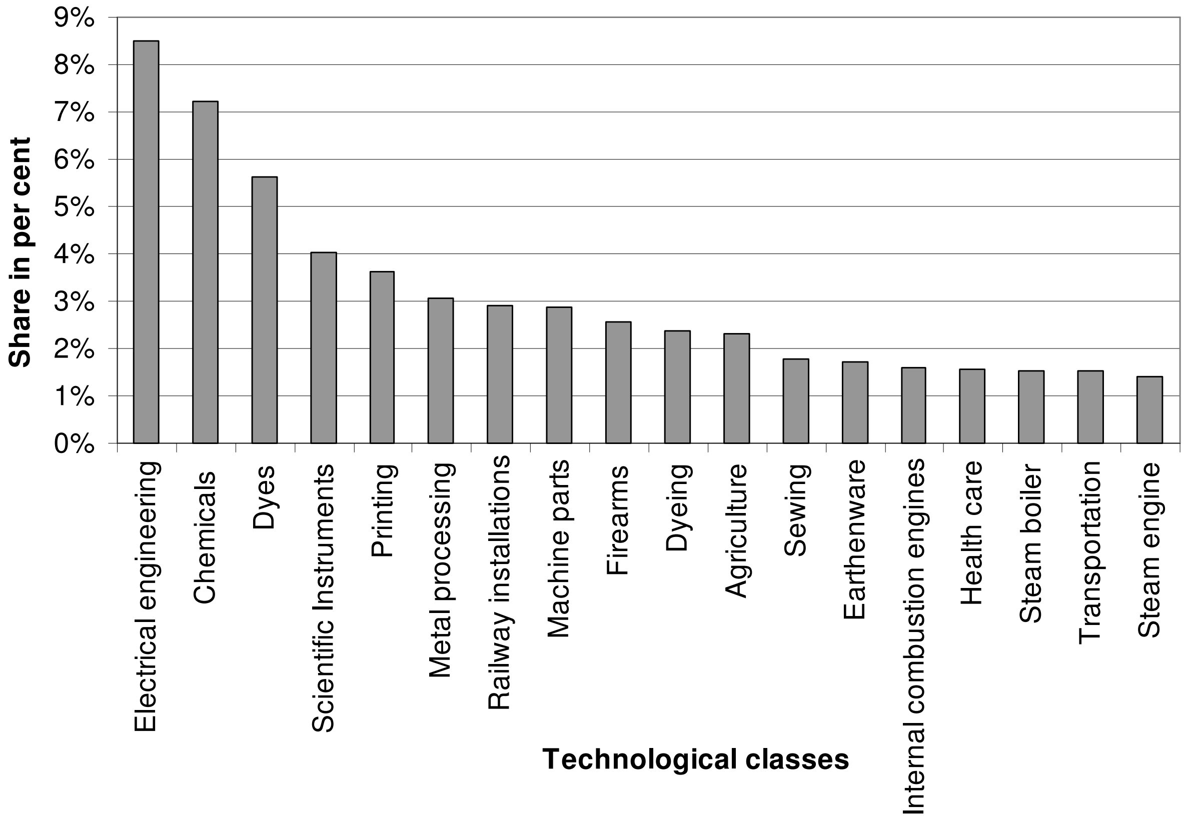
2.4 What determines the number of important patents?

2.4.1 Control variables: geographical and cultural distance, and industrial structure

We distinguish between variables that we want to control – distance is an obvious control variable, for example – and variables that could be determinants of innovativeness (on the latter, see also section 2.4.2 below). We also use a variable that approximates the extent to which the industrial structure of each country was similar to the industrial structure of Germany. Patenting in Germany was more likely for inventions which occurred in similar industries. We proxy this with a patent structure by industry similar to Germany: Germany had a particularly high number of patents in the chemical and electrotechnical industries. With this, we can also somewhat control a potentially higher industrial propensity to patent, because the chemical and electrotechnical industries were prone to this.

All patents granted to citizens and foreigners in Germany were divided into 89 classes. These classes correspond broadly to the industry using the respective invention. For example, inventions in the field of electrical equipment were allocated to class 21, "electrical engineering." As can be seen in Figure 2.2, the latter had a share of 8.51% in all high-value patents in Germany (including those of Germans) between 1877 and 1918, followed by chemicals without dyes (7.22%), dyes (5.61%), scientific instruments (4.03%), printing (3.63%), and metal processing (3.06%) (Streb et al., 2006a).

FIGURE 2.2: SHARE IN ALL HIGH-VALUE PATENTS 1877-1914 (GERMAN PATENTS INCLUDED), ALL YEARS POOLED



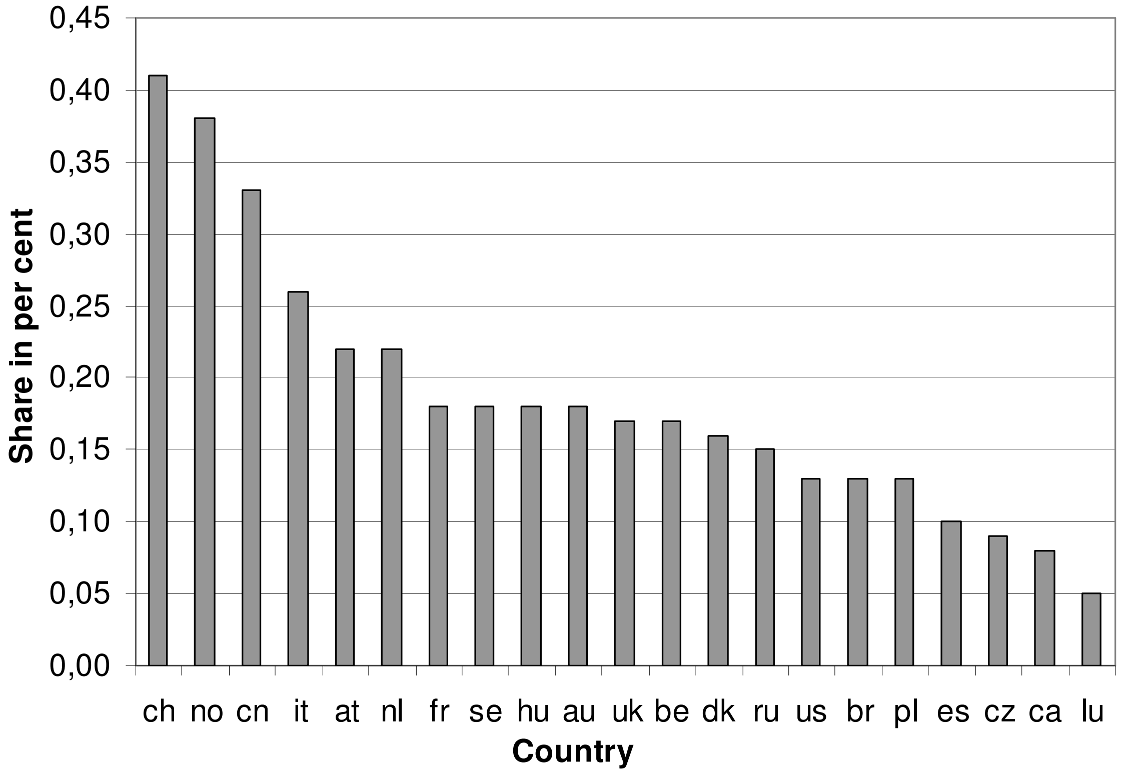
Data source: Streb et al. (2006a).

Because homogenous production data for the countries where the patents originated are not available, we calculate each nation's share of German patents in those two industries (see Figure 2.3).[23] Some countries had no German patents in the electrotechnical and chemical industries (including the dyeing industry), but twenty-one did. We find a particularly high share of patents in electrical engineering, chemicals and dyeing for Switzerland and Norway, but a share of only 13% for the U.S. and 17% for the UK.[24] Nine other countries had 11-20% while four had 1-10%. The Norwegians,

[23] Countries with zero patents are assigned the value of zero because they typically did not produce many chemical and electrotechnical products.
[24] China would be in the top group, but the total number of patents is so low that this observation is not well founded.

Swiss, Italians, Austrians and Dutch participated strongly in those industries which were crucial for the second industrial revolution.

FIGURE 2.3: SHARE OF PATENTS IN CHEMICAL AND ELECTROTECHNICAL INDUSTRIES BY COUNTRY, ALL YEARS POOLED



Note: For country abbreviations, see appendix A.3.
Data source: see Figure 2.2.

Another potential determinant on foreign high-value patents in Germany 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 patent or trade (see Dunlevy, 1999). 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.

2.4.2 Determinants of the technological components of human capital: schooling, literacy, and patent laws

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

During the crucial period of economic development under study, differences in schooling rates were large (see also Table 2.3). While it might be intuitively clear to most economists that primary 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 primary schooling is to be provided to a large share of the population. Lindert (2004a, p. 87) has called primary public education "…the kind of education that involves the greatest shift of resources from upper income groups to the poor." 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 of one's income for the schooling of poor day-labourers 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 labourers 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 democratisation process, attitudes changed in favour of tax-financed mass-schooling. According to Lindert (2004a), 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. Especially at the beginning of mass-schooling, decentralised 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.

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 civilised 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 decentralised decisions were favourable to schooling at an early stage. The decentralised 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 centralised decision-making process was necessary. For Germany, Lindert (2004a) stresses again the importance of decentralised 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'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 not only by the education of the potential inventor and innovator himself, but also by the skills of his potential workers. Only a well-educated labour force could transform innovations into profits and growth in the late 19th and early 20th century. Perhaps even more to the point, a motivated labour force contributes to the profitability of inventions and thus induces entrepreneurs to renew their patents. Hence, primary schooling rates (covering most of the mass-schooling of the time) might have been even more important than secondary and university education.[25] For this reason, we run separate regressions

[25] Moreover, Khan and Sokoloff (2004) also confirm the importance of basic schooling as opposed to university education – even for the great American inventors - at least in an earlier period. For example, about 80% of patents were granted to inventors (born between 1739 and 1794) with only primary or secondary schooling. Higher educated inventors did not hold more patents than those who received only primary or secondary education; thus, the less educated made an important contribution to technological knowledge at that time.

using Lindert's (2004a) primary enrolment rates and secondary schooling rates to consolidate the general impact of schooling on patenting.

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 (Nordhaus 1969b, Klemperer 1990, Gilbert and Shapiro 1990). 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 (Moser 2003). Still others have suggested that many patents are only copies of earlier patents that are sufficiently altered for acceptance by the patent commission (Schäffle, 1867 and 1878). 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. Furthermore, we include Josh Lerner's (2000) figures on the length of patent protection in some regressions.

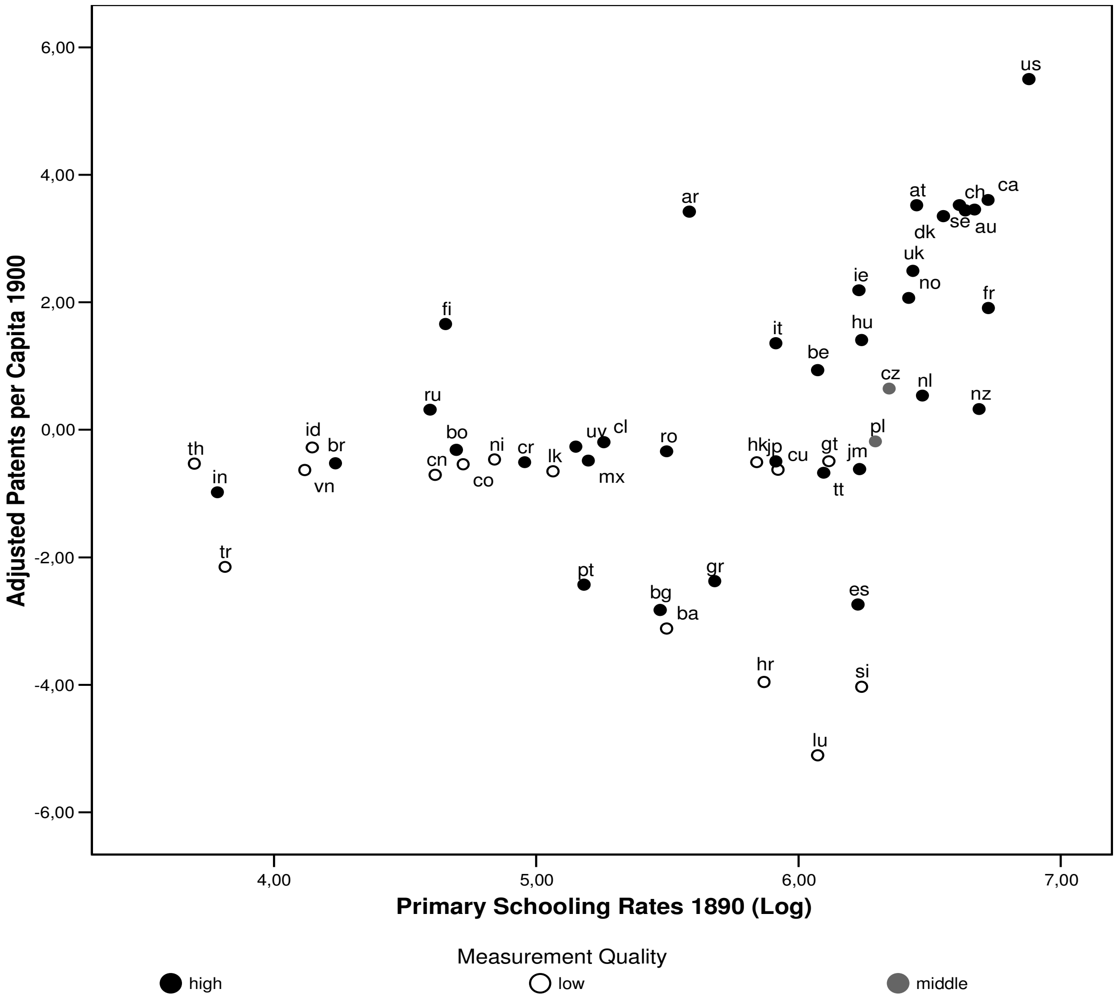
2.5 Results

2.5.1 What determines patenting abroad?

Before interpreting the regression results in Table 2.4, we will compare schooling and adjusted patent rates (adjusted for distance / same language) graphically (Figure 2.4). The adjusted patent rates are constructed as follows: we save the residuals from a regression of the number of patents per capita (logarithm) on distance to Germany (logarithm) and German language. This procedure allows us to remove any higher propensity to patent which is merely due to cultural similarities or geographical proximity.

Black dots mark countries that can be fully weighted because we have real information about schooling rates. Grey and white dots label countries with interpolated schooling rates. Countries with patents in Germany are marked by grey dots, while those without patents in Germany are marked by white dots. Patenting in Germany increased with additional primary school enrolment. There are some interesting deviations from an imagined regression line. The Habsburg and Ottoman Empires, plus Spain, Portugal and Luxembourg had low patent rates in spite of their European location and moderate level of schooling. Finland had an astonishingly high rate of patents in Germany, even though its primary schooling rates ranked comparatively low. The U.S. and Canada had the highest values both for per capita patents and schooling rates. Interestingly, Sweden, Denmark and Austria had almost the same level of schooling rates, and high per capita patent values. It is not agricultural specialisation that reduced patent intensity, because Denmark ranked high whereas the position of the Netherlands was lower. The relatively low value of the Netherlands could have been caused by non-existing patent-laws. This would make it an example of a high-income country with no patent laws, whereas Turkey, which also had fewer patents than expected, would be an example for a low income country without patent laws. The correlation of adjusted patents and primary schooling is particularly strong when we include all cases, including those that had zero or very few patents.

FIGURE 2.4: ADJUSTED PATENTS PER CAPITA 1900 AND PRIMARY SCHOOLING RATES 1890



Note: For country abbreviations, see appendix A.3.
Data Sources: Adjusted Patents: see Table 2.1; Primary Schooling Rates: see Table 2.4.

For our graphical illustration, we first calculate the adjusted patent rates and then plot them against the schooling rates given above. Now, we run regressions for each 5-year-cohort of patents, using five and ten years lagged enrolment rates in log linear specification as a potential explanatory variable (Table 2.4). The lags avoid contemporaneous correlation, although we perform some special tests for the endogeneity structure presented below. Besides Lerner's (2000) data on the length of patent protection, we include the existence of patent laws 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. Note that only a modest number of countries had no patent protection: Switzerland, Holland, China, Romania, Japan, Indonesia, Bosnia, Turkey, Bulgaria, Greece, and Thailand in 1875; and the same group except Bulgaria, Switzerland, Turkey, Bosnia, and Japan in 1900. We control for distance, German language (because the propensity to patent in Germany might be higher for German-speaking inventors/firms), and industrial structure focusing on the chemicals and electrotechnical industries, as these might have caused a higher propensity to patent. In general, the logged enrolment variable has a strong positive effect which is significant for all seven time periods. This result is very important, as it reveals the mechanism by which endogenous growth works: schooling not only augments labour productivity directly, but also stimulates innovativeness.

The length of patent protection in Table 2.4 turns out to have had a positively significant impact on high-value patents in 1895-99, whereas the existence of patent laws has a significantly positive effect (at the 10% level) for the period between 1880 and 1899. Introducing patent laws in the eleven non-patenting countries would have raised patenting activity in the 1880s and 1890s by 1.0-1.2%. This is not a small number. Thereafter, our results are no longer statistically significant. We find two of our main hypotheses supported: a higher level of schooling, as well as the existence of a certain level of patent protection in a country, is crucial for innovativeness (here: as measured by adjusted foreign patents), although the evidence for patent laws is more mixed.

Moreover, our control variable "distance" is always significant (except for 1900-04 at the 1%-level) and negative. On average, a one per cent lower distance to Germany yielded to 0.4-1.0% more high-value patents in Germany. We conclude that geographical distance mattered not only for trade, as many gravity models have demonstrated, but also for "weight-less" innovations. It is clear that geographical distance alone is an imperfect measure, because economic distance was relatively lower for countries that had permanent exchange with Germany (such as the U.S., Argentina etc.). Nevertheless, even this imperfect measure of economic distance indicates that it played an important role, perhaps because of the expected ensuing commodity transport costs. In contrast, the size of the coefficient for German language is not significant at all. Finally, the variable "share of chemical and electrotechnical patents" is significantly positive for all periods.[26]

TABLE 2.4: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914. ALL COUNTRIES IN TODAY'S BOUNDARIES INCLUDED. (UNWEIGHTED)[27]

Variable	1880		1885		1890		1895		1900		1905		1910	
Primary schooling rate (logarithm), preceding decade	**0.473**	*0.084*	**0.864**	*0.003*	**0.872**	*0.001*	**0.680**	*0.026*	**1.054**	*0.003*	**0.950**	*0.001*	**1.006**	*0.008*
Distance to Germany (logarithm)	**-1.049**	*0.000*	**-0.578**	*0.005*	***-0.804***	*0.000*	**-0.753**	*0.001*	**-0.403**	*0.084*	**-0.995**	*0.000*	**-0.986**	*0.000*
German language	0.068	*0.924*	-0.074	*0.912*	*-0.591*	*0.348*	-0.621	*0.398*	-0.264	*0.745*	0.978	*0.127*	0.588	*0.481*
Length of patent protection (logarithm)	-0.074	*0.333*	-0.074	*0.302*	*-0.005*	*0.942*	-0.060	*0.438*	**0.212**	*0.025*	0.055	*0.444*	0.026	*0.787*
Patent protection	**1.161**	*0.080*	**1.032**	*0.097*	**1.082**	*0.062*	**1.222**	*0.073*	-0.799	*0.411*	0.232	*0.764*	0.967	*0.343*
Patents in chemical / electrotechnical industries (%)	**5.139**	*0.034*	**9.454**	*0.000*	**9.625**	*0.000*	**11.38**	*0.000*	**10.127**	*0.000*	**9.079**	*0.000*	**8.487**	*0.003*
Constant	**6.016**	*0.018*	0.088	*0.991*	1.981	*0.373*	2.477	*0.341*	-0.745	*0.793*	**3.899**	*0.098*	3.713	*0.228*
Adj. R^2	0.623		0.669		0.755		0.665		0.636		0.806		0.689	
N	51		51		51		51		51		51		51	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data Sources: High-value Patents: see Table 2.1; Schooling Rates: Lindert (2004a). For interpolation decisions, see appendix A.5; Distance to Germany: http://www.macalester.edu/research/economics/PAGE/HAVEMAN/Trade.Resources/Data/Gravity/dist.txt; Ratio of high patenting industries: see text.
German Language includes Habsburg territories in which a part of the elites spoke German, such as cz, hu, ba, hr, si.

[26] At first, the effect increases gradually from 5% in 1880-84 to 11% in 1895-99, and then decreases somewhat to 8% in 1910-14. This finding corresponds roughly with the patent booms by industry described by Streb et al. (2006a).
[27] For the regressions of log patents per capita 1880-1914 (all countries included), which are weighted by measurement quality, see Appendix A.2.

In addition, we run regressions with historical borders in Table 2.5, as far as this makes sense.[28] We aggregate the European empires by historical boundaries. In comparison to today's boundaries (Table 2.4), we obtain relatively similar regression coefficients and p-values, but for forty-three countries, the R²s are higher in all regressions except for 1910-14.[29] One additional year of patent protection yielded 0.227 more patents in 1900-04.

TABLE 2.5: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914. ALL COUNTRIES IN HISTORICAL BOUNDARIES INCLUDED. (UNWEIGHTED)

Variable	1880		1885		1890		1895		1900		1905		1910	
Primary schooling rate (logarithm), preceding decade	**0.479**	*0.071*	**0.943**	*0.001*	**0.828**	*0.001*	**0.679**	*0.033*	**1.185**	*0.001*	**0.974**	*0.001*	**1.076**	*0.010*
Distance to Germany (logarithm)	**-1.144**	*0.000*	**-0.663**	*0.001*	**-0.866**	*0.000*	**-0.833**	*0.000*	**-0.413**	*0.063*	**-1.036**	*0.000*	**-0.951**	*0.001*
German language	0.852	*0.431*	0.293	*0.772*	-0.072	*0.937*	-0.377	*0.746*	0.119	*0.920*	0.270	*0.786*	0.486	*0.732*
Length of patent protection (logarithm)	-0.028	*0.716*	-0.029	*0.686*	0.035	*0.586*	-0.018	*0.827*	**0.227**	*0.010*	0.061	*0.391*	0.020	*0.843*
Patent protection	0.862	*0.198*	0.759	*0.229*	0.827	*0.145*	0.970	*0.187*	-1.060	*0.233*	0.246	*0.744*	0.925	*0.391*
Patents in chemical / electrotechnical industries (%)	1.632	*0.513*	**6.160**	*0.011*	**7.501**	*0.001*	**9.014**	*0.001*	**8.079**	*0.005*	**9.046**	*0.000*	**8.959**	*0.009*
Constant	**7.289**	*0.004*	0.819	*0.725*	3.130	*0.138*	3.585	*0.184*	-1.073	*0.689*	**4.137**	*0.084*	3.010	*0.369*
Adj. R²	0.661		0.698		0.787		0.671		0.689		0.816		0.674	
N	43		43		43		43		43		43		43	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 2.4.

[28] This was possible and made sense for countries such as the Czech Lands, which were part of Austria-Hungary. It did not make sense for Indonesia and the Netherlands, with the former being a colony of the latter: when calculating per capita values, should we add up many Dutch and a few Indonesian patents and divide them by the two countries' joint population, a large share of which was Indonesian? Similarly, distance to Germany is much more difficult to calculate in the case of historical empires (Poland was added to Russia, given that the largest part of Poland belonged to the Russian Empire).
[29] The impact of the share of chemical and electrotechnical patents on the number of high-value patents is no longer significant for 1880-84, and minor over the whole period.

Furthermore, we estimate a cross-sectional model using secondary schooling rates instead of primary schooling, using the log-linear specification lagged one decade. As becomes clear from Table 2.6, log linear secondary education has a positive effect on patenting 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. The R^2 from the regressions of secondary schooling are lower than in Table 2.4 and confirm our assumption that primary schooling, which covered most of the mass schooling of the time, was more important than secondary schooling for the propensity to invent and patent, as well as for the exploitation of innovations for profit and growth.

TABLE 2.6: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914. ALL COUNTRIES IN TODAY'S BOUNDARIES INCLUDED. (UNWEIGHTED)

Variable	1880		1885		1890		1895		1900		1905		1910	
Secondary schooling rate (logarithm), preceding decade	-0.043	*0.842*	**0.296**	*0.067*	**0.345**	*0.014*	0.306	*0.361*	**0.742**	*0.082*	**0.947**	*0.010*	**0.908**	*0.047*
Distance to Germany (logarithm)	**-1.233**	*0.000*	**-0.580**	*0.048*	**-0.858**	*0.001*	**-0.693**	*0.014*	-0.437	*0.244*	**-1.049**	*0.000*	**-0.840**	*0.001*
German language	-0.088	*0.938*	-0.136	*0.882*	-0.638	*0.497*	-0.708	*0.443*	-0.234	*0.832*	0.619	*0.241*	0.075	*0.887*
Patent protection	**1.073**	*0.088*	**1.306**	*0.033*	**1.703**	*0.005*	**1.497**	*0.025*	1.164	*0.243*	1.179	*0.140*	**2.093**	*0.032*
Patents in chemical / electrotechnical industries (%)	5.625	*0.187*	**10.207**	*0.007*	**10.576**	*0.002*	**10.507**	*0.004*	**10.794**	*0.008*	**7.850**	*0.002*	**4.960**	*0.049*
Constant	**10.176**	*0.000*	**4.214**	*0.092*	**6.196**	*0.003*	**5.435**	*0.027*	2.566	*0.446*	**7.138**	*0.008*	**6.362**	*0.009*
Adj. R^2	0.577		0.558		0.686		0.575		0.514		0.783		0.685	
N	51		51		51		51		51		51		51	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 2.4.

In the following section, we describe several panel data regressions to countercheck our cross-sectional results shown in Table 2.4. In addition to the regression model above, we include time and continent dummy-variables.[30] For the panel regressions in Table 2.7, we use a random-effects model to allow for time-invariant dummy variables in the models. In column 2, we only include countries with patents in Germany, whereas the remaining columns present the panel regression results for all sample countries. In columns 3 to 5, we include some additional variables that might have promoted innovative behaviour:

(1) Institutional constraints on the executive had a strong impact in long-run growth regressions of GDP per capita (Acemoglu et al., 2002). 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 some regressions. More secure general property rights thus stimulated not only growth, but also innovativeness – or perhaps via innovativeness also growth.

(2) We control for the coast-land ratio. This variable accounts for the fact that countries with coastal access (and long shores in particular) might have had a higher export share of commodities, hence holding German patents might have been more attractive for securing future exports to this country. This variable is statistically insignificant.

[30] For details, see the description of Table 2.7.

(3) The land-labour ratio could play a role because on the one hand, countries with a high land-labour ratio might have had higher opportunity costs given their rich endowment with land (New World exporters such as Argentina might have had fewer patents because they specialised in food exports). Moreover, there is a large literature on the "curse of natural resources" which might impact innovative behaviour via institutions, exchange rates, and inequality. On the other hand, countries with a high ratio tend to have high labour costs, and labour-saving innovations in particular might have been profitable there. As a result, these theoretical effects either cancel each other out or are unimportant: at least in our sample, the coefficient for the land-labour ratio is insignificant.

(4) Regressions four and five control for the level of development through the lagged logarithm of GDP per capita. We observe that our results remain robust after the inclusion of GDP, and this control variable turns out to be insignificant. Hence it was not the general level of development that determined innovativeness, but the schooling investment, plus the existence of patent laws and design of general economic institutions which caused differences in innovativeness.

Compared to Table 2.4, the elasticities in the panel regressions are stable and of remarkable size. If we consider only countries with patents in Germany, rising primary schooling rates in the preceding decade caused a rise of 0.46% in high-value patents (Table 2.7, regression 2). By contrast, we obtain 0.17% more patents and a higher level of significance if we include all countries in the same model in regression one.[31] The existence of patent protection in the host country increases the number of high-value patents by about 1.5-1.7% in the regressions in columns 2, 4, and 5. The patent law

[31] A 10% increase in the distance between the patentee's home country and Germany yielded 6-9 % fewer patents per capita. This confirms that countries more remote from Germany tended to have smaller patent counts. The impact of our dummy variable "German language" is significant only once in model 4.

variable has a larger coefficient in the more exclusive club of column 2, but in general, the effect is somewhat limited (not always significant). This corresponds with the notion of Moser (2005b) that patent laws might have been only modestly important in determining the level of innovativeness. Rather, Moser has argued that the industry structure of innovativeness was shaped by the existence of patent laws. The length of patent protection remains insignificant in all regressions.[32]

[32] The modest but noticeable relevance of the impact of intensive patenting industries and the similarity to the German patenting structure shown in Table 2.4 is confirmed by the panel regression. Our regressions in Table 2.4 include countries that had not patented in Germany because we think that these units offer valuable information as well. However, we can examine the impact of our explanatory variables including only those countries with patents in Germany. These results are shown in Table 2.13 in Appendix A.4 where it can be seen that we obtain similar results. The existence of patent laws in the home country of the inventor is highly significant from 1900 until the outbreak of WWI. The impact of primary schooling and distance to Germany on patenting is also similar to the regressions above.

TABLE 2.7: PANEL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914 IN TODAY'S BOUNDARIES. (RANDOM-EFFECTS ESTIMATES)

Variable	All countries		Only countries with patents		All countries		All countries		All countries	
Primary schooling rate (logarithm), preceding decade	**0.624**	*0.033*	**0.455**	*0.087*	**0.549**	*0.059*	**0.898**	*0.000*	**0.809**	*0.000*
Distance to Germany (logarithm)	**-0.938**	*0.001*	**-0.917**	*0.000*	**-0.692**	*0.024*	**-0.848**	*0.000*	**-0.572**	*0.013*
German language	0.089	*0.880*	0.340	*0.467*	0.396	*0.513*	**0.901**	*0.016*	0.467	*0.747*
Coast-land-ratio (logarithm)									1.464	*0.289*
Land-labour-ratio (logarithm)							-0.576	*0.112*	-0.601	*0.170*
Patent protection	0.792	*0.330*	**1.654**	*0.027*	0.890	*0.261*	**1.496**	*0.020*	**1.462**	*0.085*
Length of patent protection (logarithm)	0.006	*0.934*	-0.031	*0.628*	-0.008	*0.912*	-0.071	*0.354*	-0.102	*0.367*
Patents in chemical / electrotechnical industries (%)	**8.185**	*0.000*	**3.002**	*0.073*	**7.386**	*0.000*	**4.049**	*0.001*	**3.764**	*0.008*
Institutional constraint on Executive					**0.210**	*0.100*			0.165	*0.142*
GDP per capita (logarithm)							0.012	*0.957*	-0.063	*0.798*
Dummy 1890-99	**0.453**	*0.091*	**0.365**	*0.052*	**0.463**	*0.084*	**0.606**	*0.041*	**0.715**	*0.040*
Dummy 1900-09	**0.819**	*0.004*	**0.966**	*0.000*	**0.850**	*0.003*	**1.167**	*0.000*	**1.250**	*0.001*
Dummy 1910-19	0.416	*0.157*	**0.867**	*0.000*	0.456	*0.121*	0.521	*0.116*	**0.644**	*0.096*
Dummy Europe	-0.746	*0.576*	**-3.552**	*0.003*	-0.441	*0.736*	1.170	*0.233*	1.718	*0.109*
Dummy Northern America	2.378	*0.147*	-1.251	*0.370*	**2.856**	*0.077*	**3.715**	*0.001*	**4.440**	*0.000*
Dummy Asia	-0.648	*0.588*	**-4.007**	*0.001*	-0.486	*0.676*	0.369	*0.705*	0.275	*0.793*
Dummy Latin America	**-2.558**	*0.072*	-1.019	*0.362*	**-2.817**	*0.042*	**-2.230**	*0.006*	**-2.568**	*0.001*
Constant	4.843	*0.171*	**9.233**	*0.002*	2.753	*0.450*	1.560	*0.565*	-1.130	*0.693*
R^2 (overall)	0.590		0.604		0.603		0.678		0.632	
N	280		169		280		221		188	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see also Table 2.4.
Institutional Constraint on Executive: Acemoglu et al. (2002)
Coast-Land-Ratio (own calculation): CIA (2005). The World Factbook.
Land-Labour-Ratio (own calculation): Land: CIA (2005),
Labour: Mitchell (1980), Mitchell, (1993), Mitchell (1998).

Dummy Variables**:**
Dummy 1880-89 (Reference Category),
Dummy 1890-99,
Dummy 1900-09,
Dummy 1910-19
Dummy Europe: uk, fr, ch, at, se, nl, it, se, ru, dk, hu, cz, ie, es, lu, no, ro, hr, fi, pl, si ba, bg, gr, pt
Dummy Northern America: us, ca
Dummy Asia: hk, cn, in jp, id, vn, tr, lk, th
Dummy Latin America: ar, gt, br, mx, bo, cl, co, cr, cu, jm, ni, tt, pe
Dummy Australia: au, nz (Reference Category)

Finally, we want to check whether literacy can be used as an alternative for schooling in Table 2.8. Literacy has the advantage of being an outcome measure, whereas schooling proxies raw investments. We use literacy even though it is only available for a smaller set of countries. Besides the ability to read, literacy also includes basic writing abilities. Literacy estimates are not available for every decade, only for a cross-section of countries in 1870 (Crafts, 1997). Hence, we run this regression only for 1880-84 and 1885-89. Moreover, literacy rates are only available for seventeen countries (mostly European and former European settlement colonies). All of these countries are rich today. Therefore, we have to be aware that this sample is selected quite differently. We obtain a statistically significant coefficient of 0.671, which indicates a 6.71% increase in the number of patents granted to foreigners for every 10% increase in literacy rates in 1870.[33]

TABLE 2.8: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914. ALL COUNTRIES INCLUDED. (UNWEIGHTED)

Variable	1880		1885	
Literacy 1870	**0.585**	*0.045*	**0.671**	*0.000*
Distance to Germany (logarithm)	**-1.259**	*0.005*	**-0.458**	*0.060*
German language	**4.029**	*0.001*	**2.753**	*0.003*
Patent protection	0.957	*0.222*	**1.273**	*0.015*
Patents in chemical / electrotechnical industries (%)	-8.792	*0.102*	-0.522	*0.814*
Constant	**9.286**	*0.023*	2.252	*0.292*
Adj. R^2	0.788		0.895	
N	17		17	

Note: P-values in italics.
Shading indicates statistical significance at 0.10-level.
Data sources: see Table 2.4; Literacy: Crafts (1997).

[33] The variable "German Language" is positive and statistically significant (0.01-level) in the period 1880-84, but this might be caused by the fact that among the seventeen countries for which we have literacy data, only Austria and Switzerland were German-speaking, and Switzerland had a very large number of patents.

2.5.2 *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 (Cantwell, 1989). In the late 19th century, the U.S. was already an important host for foreign patents.[34] Table 2.9 presents the number of U.S. patents granted to U.S. and Non-U.S. residents in 1890-92 and 1910-12 for the sixteen 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.[35]

[34] The U.S. 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.
[35] Ireland was at this time a part of the UK.

TABLE 2.9: THE TOTAL NUMBER OF U.S. PATENTS GRANTED TO RESIDENTS OF THE MAJOR COUNTRIES OF ORIGIN

Country of origin	**1890-1892 (total)**	**1890-1892 (%)**	**1910-12 (total)**	**1910-1912 (%)**
UK	2145	2.9	2970	2.8
Germany	1378	1.9	3961	3.7
Canada	975	1.3	1673	1.6
France	548	0.8	1031	1.0
Austria (-Hungary)	198	0.3	439	0.4
Australia	147	0.2	284	0.3
Switzerland	139	0.2	310	0.3
Sweden	101	0.1	318	0.3
Belgium and Luxembourg	54	0.1	149	0.1
Ireland	44	0.1	37	0.0
Italy	31	0.0	175	0.2
Denmark	22	0.0	94	0.1
Netherlands	19	0.0	56	0.1
Spain	17	0.0	35	0.0
Japan	6	0.0	34	0.0
Non-US total	6084	8.4	12285	11.4
U.S.	66766	91.6	95022	88.6
Total	72850	100	107307	100

Data Source: Cantwell (1989), p.23.

In the following, we apply our regression model to Cantwell's (1989) data. In Table 2.10, 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. A one per cent higher primary schooling rate in the respective countries yielded to 1.598 per cent more foreign patents in the U.S. in 1890-92 (1.334 per cent in 1910-

12). The size of the coefficient for English language in 1890-92 is respectable and higher than in the German case, as reported in Table 2.4. The existence of a common language was consequently more important in the U.S. than in Germany. 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.

TABLE 2.10: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA IN THE U.S. 1890-92 AND 1910-12. 15 COUNTRIES INCLUDED. (UNWEIGHTED)

Variable	1890-92		1910-12	
Primary schooling rate (logarithm), preceding decade	**1.598**	*0.027*	1.334	*0.049*
English language	**1.656**	*0.093*	0.958	*0.288*
Patent protection	0.478	*0.631*	0.521	*0.725*
Distance to U.S. (logarithm)	-0.672	*0.299*	-0.659	*0.297*
Constant	-9.794	*0.194*	-7.581	*0.301*
Adj. R^2	0.466		0.280	
N	15		15	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 2.4 and 2.9.

2.6 Additional tests: endogeneity specification

Next, we need to address possible endogeneity issues. From a theoretical perspective, the direction of causality from schooling to patenting seems straightforward, whereas the opposite direction is hard to rationalise. Why should many patents per capita lead to increasing schooling efforts? Perhaps because a better-trained workforce is able to cope with more complicated machinery (innovations)? Could it be that patents create technical knowledge and that this knowledge feeds back into education? Or do patents increase innovations, which in turn increase income per capita, which might be correlated with education? While this is plausible, it is probably not the main criterion behind schooling decisions, which Lindert (2004a) has identified as democracy and decentralisation. Lindert has rejected initial GDP per capita as a determinant of schooling investments. We saw above that GDP per capita did not have a significant impact on patenting in our regressions. Nevertheless, in order to reduce the risk of reverse causality problems and to test whether there is an endogeneity problem concerning the schooling variable, we test this explicitly. Endogeneity could create biased estimations if the model errors were correlated with the dependent variable.

One approach to test for endogeneity is the procedure suggested by Hausman (1978). We use lagged schooling rates as instruments for enrolment. First, we run a two-stage least square (2SLS) regression and, after an additional OLS regression, we calculate the Hausman test to analyse if the 2SLS and OLS results are significantly different. The Hausman test with a p-value of 0.352 indicates that differences between coefficients are probably not systematic, and hence the OLS regression is probably a consistent and efficient estimator. We test if the instrumental variables (log linear schooling rates for 1882 and 1870) and the assumedly exogenous variables "distance to Germany," "German language," "patent protection in the countries of origin," and "ratio of high patenting industries" are sufficiently correlated with the potentially endogenous variable "Primary schooling rate 1890," finding this confirmed. It is also important to consider theoretically whether the above variables have a causal relationship with the ultimate dependent variable log patents per capita in 1910 (other than through the potentially endogenous variable), but this is clearly not the case with lagged, potentially endogenous variables because they are merely lagged values of the same variable. In order to ensure that our instruments are valid and uncorrelated with the error term, we also perform the Sargan test. With a value of 0.060 (p-value 0.807), the Sargan test indicates that our instruments are valid. Finally, analogously to Lindert (2004b), we test in Table 2.11 whether lagged patents can explain schooling and find that the reverse impact is always insignificant. In other words, lagged schooling determines innovativeness, but lagged innovation does not cause schooling, if we assume that causes should precede effects.

TABLE 2.11: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. SCHOOLING 1880-1914. ALL COUNTRIES IN TODAY'S BOUNDARIES INCLUDED. (UNWEIGHTED)

Variable	**1880**		**1890**		**1900**		**1910**	
Patents per capita (logarithm), preceding decade	0.005	*0.947*	0.013	*0.852*	0.089	*0.245*	0.030	*0.536*
Distance to Germany (logarithm)	-0.128	*0.239*	-0.077	*0.495*	-0.034	*0.743*	-0.048	*0.516*
German language	0.360	*0.292*	0.370	*0.256*	0.244	*0.414*	0.107	*0.674*
Patent protection	0.364	*0.157*	0.361	*0.143*	0.327	*0.171*	**0.471**	*0.055*
Patents in chemical / electrotechnical industries (%)	1.244	*0.263*	0.711	*0.513*	-0.044	*0.970*	0.248	*0.797*
GDP per capita (logarithm)	**0.744**	*0.004*	**0.810**	*0.001*	**0.590**	*0.010*	**0.693**	*0.000*
Constant	0.806	*0.679*	0.055	*0.976*	1.292	*0.445*	0.726	*0.629*
Adj. R^2	0.423		0.431		0.463		0.507	
N	51		51		51		51	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 2.4.

All of these tests and the insignificance of GDP per capita as an explanatory variable for innovativeness suggest that it was really the schooling investment that caused innovativeness.

2.7 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 innovations from around the globe that were patented in Germany and prolonged for at least ten years. For example, countries that today are Uruguay, Vietnam, Namibia, Guatemala, Argentina, China and many others could be documented for the first time with this dataset, for the questions addressed here.

This chapter has examined the impact of education, patent laws, institutional quality, distance, and industry structure on the number of high-value patents per capita that were granted to foreigners in Germany between 1880 and 1914. Similarity with the German industrial patent structure as proxied by the share of electrotechnical and chemical industry patents had a positive influence on overall patents per capita. In contrast, the control variable “distance” had a consistently negative effect. We considered proximity and similarity as control variables.

Lagged log linear primary schooling rates had a significantly positive effect on per capita patents after controlling for distance and common language. Therefore, our initial hypothesis 2 is confirmed. Secondary schooling had a slightly weaker impact on patenting activities than primary schooling. We interpret this finding based on the fact that an inventor-entrepreneur needs a well-trained labour force which can transform innovations into new and better products or produce at lower costs. Human capital externalities could also be larger 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 19^{th} and early 20^{th} century, and not very large, too. Hypothesis 1 is thus weakly confirmed. In this period, globalisation boomed, markets developed and integrated, and the electrotechnical and chemical industries were important driving forces behind the second industrial revolution. We identified many Norwegian, Italian, Austrian and Dutch innovations in those industries – in addition to inventions from those countries usually mentioned in this context. In addition, we found that institutional quality, especially protection against expropriation, was important for innovative behaviour, so that hypothesis 3 is strongly confirmed. Finally, we checked the robustness of our model in a variety of specifications and the possibility of an endogeneity bias. Furthermore, we compared the results to those obtained when taking foreign patents in the U.S. as the basis of analysis.

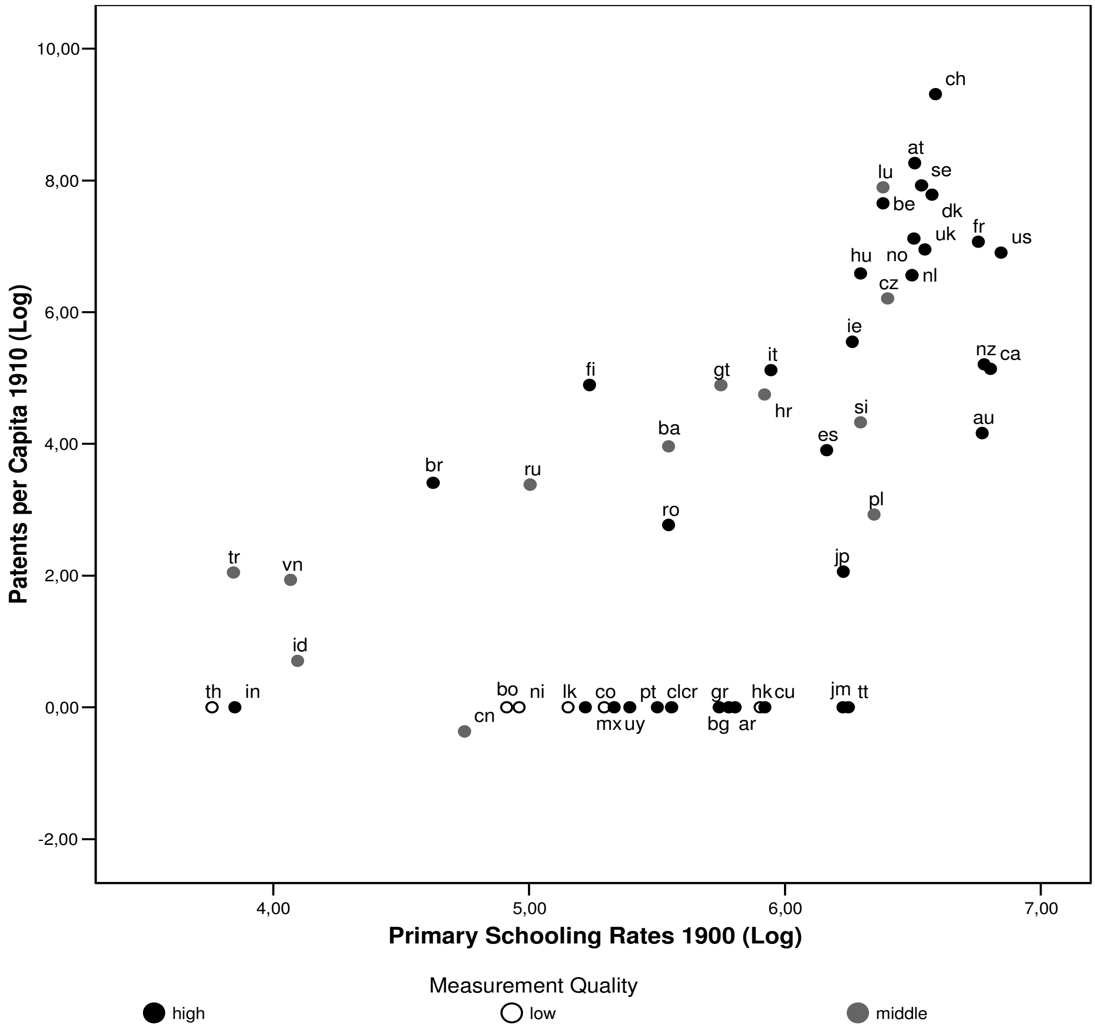
These results are important for economic policy makers even today, because they indicate that governments should invest in primary schooling (if they do not overshoot), well-designed patent laws, and good institutions to stimulate innovative behaviour. This becomes even more evident if one takes a global view, taking into account fifty-one countries as we did in this study. As caveats, we have to mention that there might be more measurement error in the data on poorer countries, although they are still too important to be omitted.

A. Appendix to chapter 2

A.1 Over-adjustment?

One potential criticism has to be answered: is there over-adjustment by the log distance variable? The problem with this variable is that it might be correlated with the level of human capital formation: countries more remote from Germany (and Europe) might have tended to be less educated, with the exception of the U.S. and other European settlements and colonies. Other potential exceptions include (South) Eastern Europe and the Mediterranean. In Figure 2.5, we see the number of patents per capita for 1900 without adjustment for distance, German language, and chemical / electrotechnical industry share. The measurement quality of the schooling rates is indicated in the same way as described for Figure 2.4. Switzerland, Austria, Sweden and Denmark (marked with black dots) had the highest number of high-value patents in 1910, and led in terms of their schooling rates. In contrast, Spain, Australia (with high-quality schooling), Poland and Slovenia (marked in grey) belong to a group with high primary schooling rates, but only average patenting activity. We conclude that the basic relationship between schooling and patenting is robust, even if Germany's neighbours are obviously judged better by adjusted patent rates.

FIGURE 2.5: PATENTS PER CAPITA AND PRIMARY SCHOOLING RATES 1910-14



Note: For country abbreviations, see appendix A.3.
Data sources: see Figure 2.4.

A.2 Determinants of log. patents per capita 1880-1914 (weighted by measurement quality)

In the above regressions, we included the interpolated cases with the same weight. A Weighted Least Square Regression gives less weight to the interpolated schooling rates. In other words, the "importance weight" determines how much each observation in the data set influences the final parameter estimates. We weighted the observations by the quality of our information on primary schooling rates. Cases were fully weighted when we had real measurements, and only weighted by 50% when we had interpolated schooling rates. As a result, we found an impact of the log linear schooling rates on patenting which was strongly similar to the previous regression. Log linear schooling had a significant, positive effect on patents except between 1900-04 (see Table 2.12). The control variable "Distance to Germany" is always significantly negative. The impact of the share of high-patenting industries on granted patents is significantly positive except for 1880-84. Patent protection is rarely significant but always positive and more or less robust in coefficient size.

TABLE 2.12: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914. ALL COUNTRIES INCLUDED. (WEIGHTED BY MEASUREMENT QUALITY)

Variable	1880	1885	1890	1895	1900	1905	1910
Primary schooling rate (logarithm), preceding decade	**0.537** *0.052*	**0.971** *0.000*	**1.018** *0.000*	**0.782** *0.004*	**0.889** *0.010*	**0.969** *0.001*	**1.152** *0.002*
Distance to Germany (logarithm)	**-1.073** *0.000*	**-0.508** *0.007*	**-0.074** *0.000*	**-0.684** *0.000*	**-0.643** *0.008*	**-1.008** *0.000*	**-0.917** *0.000*
German language	0.686 *0.329*	0.167 *0.797*	-0.287 *0.629*	-0.419 *0.533*	0.020 *0.982*	0.847 *0.193*	0.622 *0.460*
Patent protection	0.589 *0.293*	0.586 *0.259*	**1.075** *0.027*	**0.944** *0.064*	0.804 *0.355*	0.763 *0.219*	1.140 *0.159*
Patents in chemical / electrotechnical industries (%)	3.101 *0.189*	**9,127** *0.000*	**8.948** *0.000*	**11.923** *0.000*	**11.272** *0.000*	**10.262** *0.000*	**9.799** *0.000*
Constant	**6.435** *0.010*	-0.716 *0.749*	1.048 *0.609*	1.494 *0.504*	0.747 *0.795*	3.391 *0.136*	2.054 *0.483*
Adj. R^2	0.640	0.702	0.783	0.743	0.630	0.821	0.719
N	51	51	51	51	51	51	51

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 2.4.

A.3 Internet abbreviations for countries.

ar - Argentina	fi - Finland	no - Norway
at - Austria	fr - France	nz - New Zealand
au - Australia	gr - Greece	pe - Peru
ba - Bosnia	gt - Guatemala	pl - Poland
be - Belgium	hk - Hong Kong	pt - Portugal
bg - Bulgaria	hr - Croatia	ro - Romania
bo - Bolivia	hu - Hungary	ru – Russia
br - Brazil	id - Indonesia	se - Sweden
ca - Canada	ie - Ireland	si - Slovenia
ch - Switzerland	in - India	th - Thailand
cl - Chile	it - Italy	tr - Turkey
cn - China	jm - Jamaica	tt - Trinidad and Tobago
co - Columbia	jp - Japan	uk - United Kingdom
cr - Costa Rica	lk - Sri Lanka	us – U.S.
cu - Cuba	lu - Luxemburg	uy - Uruguay
cz - Czech	mx - Mexico	vn - Vietnam
dk - Denmark	ni – Nicaragua	
es - Spain	nl - Holland	

A.4 Additional regression tables

TABLE 2.13: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1914. ONLY COUNTRIES IN TODAY'S BOUNDARIES WITH PATENTS GREATER ZERO. (UNWEIGHTED)

Variable	1880		1885		1890		1895		1900		1905		1910	
Primary schooling rate (logarithm), preceding decade	**1.884**	*0.020*	**1.570**	*0.001*	**1.921**	0.000	**0.946**	0.028	**1.203**	0.006	**1.481**	0.002	**1.239**	0.000
Distance to Germany (logarithm)	**-0.781**	*0.059*	**-0.461**	*0.058*	**-0.810**	0.000	-0.348	0.219	**-0.573**	0.015	**-0.735**	0.001	**-0.670**	0.005
German language	1.056	*0.145*	0.923	*0.204*	0.683	0.360	0.526	0.482	0.538	0.467	0.463	0.318	0.153	0.651
Patent protection	1.340	*0.188*	-0.575	*0.518*	1.288	0.238	0.230	0.703	**1.461**	0.008	**0.987**	0.018	**1.723**	0.002
Patents in chemical / electrotechnical industries (%)	1.786	*0.698*	-1.675	*0.614*	2.698	0.312	3.056	0.273	0.867	0.704	**5.856**	0.000	**3.469**	0.003
Constant	-3.386	*0.528*	-1.502	*0.589*	-3.329	0.239	0.600	0.839	0.228	0.939	-0.764	0.808	0.677	0.604
Adj. R^2	0.659		0.480		0.622		0.434		0.644		0.690		0.754	
N	17		20		20		23		21		24		32	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 2.4.

A.5 Interpolation decisions

Available at http://www.uni-tuebingen.de/uni/wwl/interpolation.pdf

3 WHAT DROVE FOREIGN INVENTORS TO APPLY FOR PATENTS IN WEIMAR GERMANY? AN EMPIRICAL STUDY IN COMPARISON TO THE GERMAN EMPIRE

3.1 Abstract

This chapter shows how and why international patenting in Germany changed in the interwar period comparing it the pre-WWI phase. Weimar Germany had to cope with the aftermath of WWI, internal conflicts, and the 1923 hyperinflation. We ask whether these factors led to a decline in foreign high-value patents. We analyse which factors caused this development and which countries significantly reduced their patenting activities in Germany. We contrast the patenting behaviour of WWI opponents and analyse the differences in relation to Germany's confederates and neutral states. We explain determinants of patenting behaviour with cross-sectional and panel regressions while developing a new method to control for the patent boom caused by the exemption of patent fees during the WWI and the hyperinflation episode.

Chapter is based on a working paper, see Labuske (2007).

3.2 Introduction

The aim of this chapter is to investigate international patenting behaviour during the interwar period and compare it to the pre-WWI phase. Analysing foreign high-value patents in Weimar Germany is promising because they mirror the scale of research activity in the native country at that time. We explore whether inventors from Allied countries were rationalistic and sought patent protection on the same criteria like inventors from confederated countries.

The outbreak of the war in 1914 marked the end of a phase of market integration and ushered a new era of strong cyclical fluctuations and instability. Even though the German economy grew remarkably in the interwar period, the country experienced the devastating effects of war, hyperinflation, currency reform, and global economic crisis. Bessel (1993) argues that in contrast to the decades before the war, when the German economy was developing unquestionable favourably, the world economy was highly sceptical of the economic development chances of post-war Weimar Germany.

In the last decades, economic historians and macroeconomists emphasised the role of innovations as determinants of economic growth (see for example Mokyr, 1990; Romer, 1994; Rosenberg, 1974). This research dates back to Solow's seminal works (1956 and 1957), who already saw technological change as the driving force of economic progress in the mid 1950s. In empirical growth models, innovation is usually proxied by measures such as R&D or patents (Fagerberg, 1988; Kortum 1997; Verspagen, 1991 and 2001). In order to get a first overview of patenting figures and the economic performance of Weimar Germany, we compare the number of high-value patents held by foreigners and inhabitants. Moreover, we compare the latter to the evolution of German GDP per capita in Figure 3.1 We observe a relatively parallel movement of German high-value patents and GDP per capita for the early years and the Golden Twenties but not for the crisis years at the end of the decade. Except for the slump of GDP per capita caused by the hyperinflation in 1923, GDP and patents moved on steadily and quite parallel until the turning point in 1928. Depressed wages and income caused by the hyperinflation led to economic growth in the following years, and the crises years starting in 1929 caused a sharp decline of GDP per capita, yet the number high-value patents held by Germans almost tripled from 1,396 in 1928 to 3,940 in 1932.

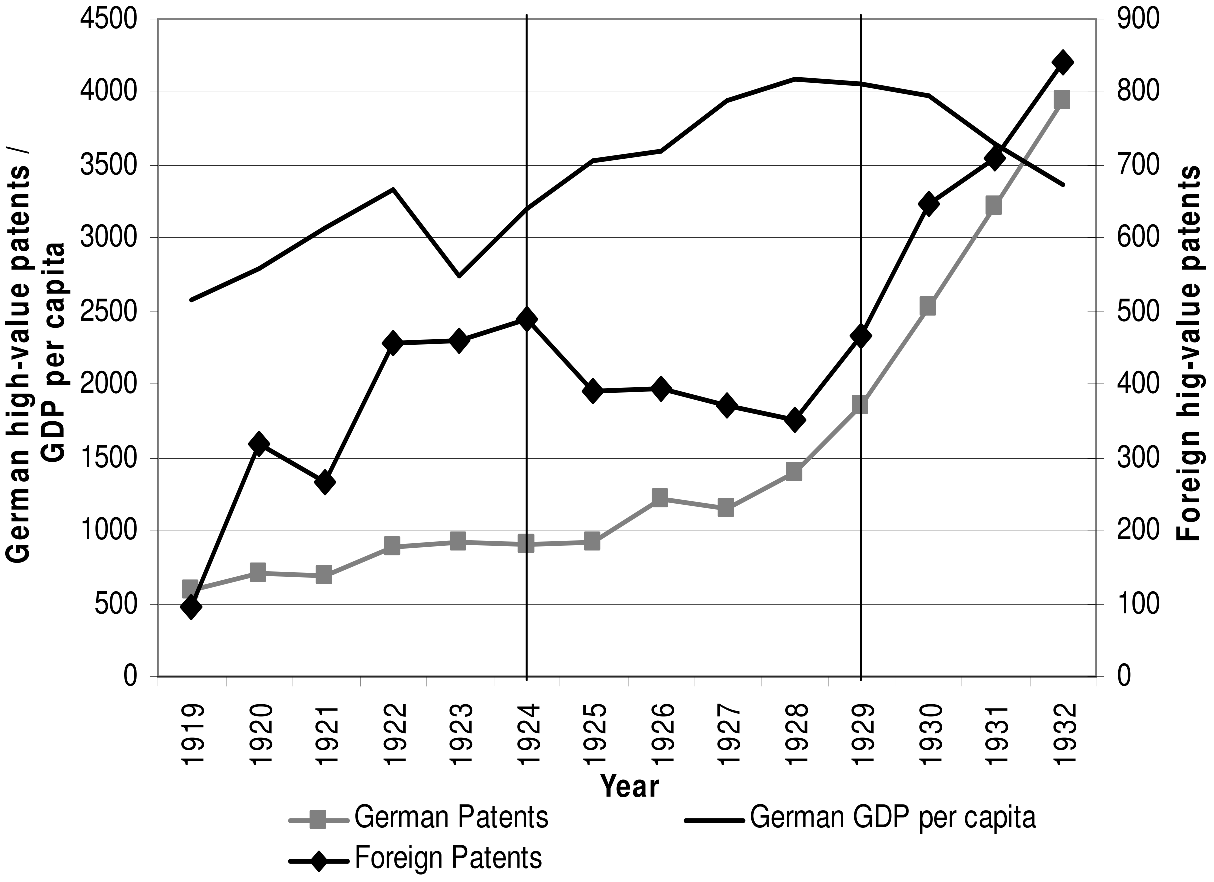
As we are focussing on foreign patenting patterns in this chapter, the relevant question to ask is: how attractive was Germany for foreigners during those turbulent three phases and how did inventors respond? Are there different patenting patterns of Allies and Entente powers of the First World War? According to James (1986) German economic growth was not as closely correlated with growth in other countries during the interwar period as in the nineteenth century, where the similarity between growth phases increased amongst European countries. Hence, different patterns of German and foreign patenting behaviour in various phases are conceivable. Looking at Figure 3.1, we observe a positive trend of both, domestic and external patents during the first period until 1924. The number of international patents almost quintupled from 95 to 461 patents, while German patents developed modestly from 1919-23. The hyperinflation provoked patent holders to hold their patents longer. Due to hyperinflation, national and international patent holders considered more patents to be worth to renew than it would have been the case in a counterfactual situation without inflation.

By mid 1920s, international patenting activity declined strongly, whereas German patents and per capita income continued their upward trend. It is obvious that Stresemann's currency reform and the establishment of the new Rentenmark[36] also changed the profitability of patents and caused a decline in foreign patent application and extension. As can be seen in Figure 3.1, the number of foreign patents moved almost like the German ones and doubled in the last period under consideration (the slump of 1929-32) in the German market. The

[36] According to Southern (1979) the exchange rate of the new currency was 1 Rentenmark = 1 Billion Marks (million million) / 1 US-$ = 4.20 Rentenmark) and circulation was restricted to 3.2 milliards (thousand million). The dollar exchange rate before the reform rose from 630 milliards to 4.2 billions from 12th to 20th November 1923.

banking crises in countries with the highest high-value patent rates (Central and East European states, and the U.S.) did not prevent inventors from filing and extending patents in Germany.

FIGURE 3.1: THE DEVELOPMENT OF FOREIGN AND DOMESTIC HIGH-VALUE PATENTS 1919-32



Data sources: High-value patents: see Table 3.1. GDP per capita: Maddison (2001).

In the following sections, we study how attractive the German market for patent rights was for inventors from all over the world comparing it to the pre-WWI conditions. Were the turbulent historical events of Weimar Germany discouraging inventors abroad? How did patent applicants and holders evaluate their chances of success during the early years (1919-

1923) when the Weimar Republic faced many internal conflicts? How did foreign patenting behaviour change during the Golden Era (1924-1928) and the collapse of Weimar and the raise of Hitler's power (1929-32)[37]? Were war opponents displaying different behavioural patterns than Germany's confederates of the First World War? To be more precise, the aim of the chapter is to examine the following hypothesis:

Hypothesis: Did warfare cause negative externalities for inventors from Allied countries?

Albeit the Treaty of Versailles (July 1919) officially ended the First World War, enormous uncertainty about the future political and economic relationship between Germany and the Allied and Associated Powers remained (Bessel 1993). This might have also influenced the attractiveness of holding a patent in Germany and the expectations of future returns (for Germany vice versa). In particular, war opponents could have reduced their patent activity in Germany as a result to the ongoing political and economic conflicts within Germany and among rival states. At the same time, Germany's wartime allies or neutral states like Switzerland could have enjoyed comparative advantages. They were not inhibited by the aftermath of WWI and might have pursued patenting in Germany without considerable delay. Inventors from neutral and confederated countries had the chance to gain time and first mover advantage by establishing trade relationships with German companies after filing for a patent in Germany.

Conversely, were inventors and firms from the Entente Powers rational and sought patent protection on exactly the same principles like their decision makers from Central Powers or neutral countries? Eaton and Kortum (1999) note that inventors are especially patenting in those countries where they perceive a high risk of imitation. By doing so, they also increase the likelihood that their protected innovations, and not those of their

[37] Definition of phases: see amongst many others Bessel (1993) or Henning (2003).

competitors, are implemented and lead to trade relations in the future. If we believe in this international patent system requirement, we come to the following implication: if inventing companies and individuals from Allied countries had suspected that their products were likely to be imitated by competitors, they would have applied in interwar Germany regardless of the economic and political aftermath of war.

3.3 Historical background and data

In chapter two, we analysed foreign high-value[38] patenting behaviour during the pre-WWI phase and found the German patenting market to be attractive for inventors from a wide array of countries. Noteworthy, firms and individuals from thirty-six countries held 9,165 high-value patents out of 33,953 total patents in Germany between 1880 and 1914 despite the high and even yearly increasing patent fees. Patent holders were attracted by the prospect of commercial operations with successfully industrialising Germany after filing a patent there.

During the period of consideration of this chapter (1919-1932), 6,255 out of 27,157 high-value patents were granted to foreigners of twenty-seven countries. Moreover, we also included twenty-seven countries with no patents in our analysis such as Bulgaria, Greece, Portugal, Mexico, Bolivia, Chile, when additional data were available. It is also important information if inventors decided not to file for German patents. If we look closely at the twenty-seven countries that were patenting in Weimar Germany in Table 3.1, we identify the U.S. with 2,187 total patents again as the unrivalled leading nation followed by Switzerland.

[38] We define economically important patents as those that were prolonged for ten years, because that was a relatively costly business: Every year a fee was demanded from the German patent authorities, and it increased each year. While the fee was substantial enough to deter unimportant patents by amateurs, it was not very high compared with the typical expected profit from an interesting patent. Before prolonging a patent, every patent holder compares the costs and benefits of doing so. A profit-maximizing patent owner will only choose the prolongation if future expected value profits exceed the costs. The patent fees were fifty Marks for the first and second year, and increased from the third year onwards for further fifty marks annually up to 700 Marks for the fifteenth year.

Switzerland climbed from fourth position in the ranking in 1880-1914 to second position in 1919-32. But if we consider high-value patents per capita, instead of the countries total patents in column 7, we observe that confederated and neutral countries are on the top positions with the exception of Hungary and Spain. Switzerland is, with 0.055 patents per capita, the unchallenged leading nation, followed by Luxemburg and Sweden.

Unlike the U.S., the United Kingdom, France, Belgium, Italy, Russia, Romania, and Japan notably war enemies during WWI, Switzerland was neutral during WWI and in the following years. The number of Swiss high-value patents decreased 11% in the years after the hyperinflation in 1923: this decline was stronger than in any other country. A closer look at the development of patents in Table 3.1 during the second period shows, that in addition of the Swiss decline only patents from Sweden and Luxembourg decreased moderately 1924-28 but all other countries had more high-value patents than in 1919-23. The patent rise of remote countries can be explained by possible diversification of patenting countries during the highly uncertain post-war Germany.

As pointed out by Fueter (1928), Bourgeois (2000), and Ochsenbein (1971) the economic relationship between Germany and Switzerland was strengthened continuously since the mid 19th century and particularly due to Swiss neutrality not severely affected during the war years. In that sense, the German chamber of commerce based in Switzerland (DHK 1937, p. 13-20) also stresses the continuous upswing of trade between Germany and Switzerland since the 1890s. This was partly caused by French protectionism policy that lowered trade between Switzerland and France significantly. DHK (1937) describes in detail the ups and downs of Swiss exports before, during, and after the First World War. If we compare this progress of exports with high-value patents, we find a quite consistent behaviour in the first two periods but not in the third: not only the patents rose after the end of the war and decreased in the mid 1920s but also did the Swiss exports to Germany.

Between 1929 and 1932 high-value patents gained 50% but exports decreased dramatically (roughly 60%) as German companies did not honour their debts orderly and as a consequence Swiss banks granted fewer export credit.

Also rather unexpected countries like Algeria held German patents. Some countries like the Czech Republic or Sweden had even more high-value patents in Germany in the interwar-period than in the pre-1914 phase. Also worth mentioning are Sweden, Austria, Netherlands. Those countries roughly doubled their patenting activity from 1924-28 to 1929-32.

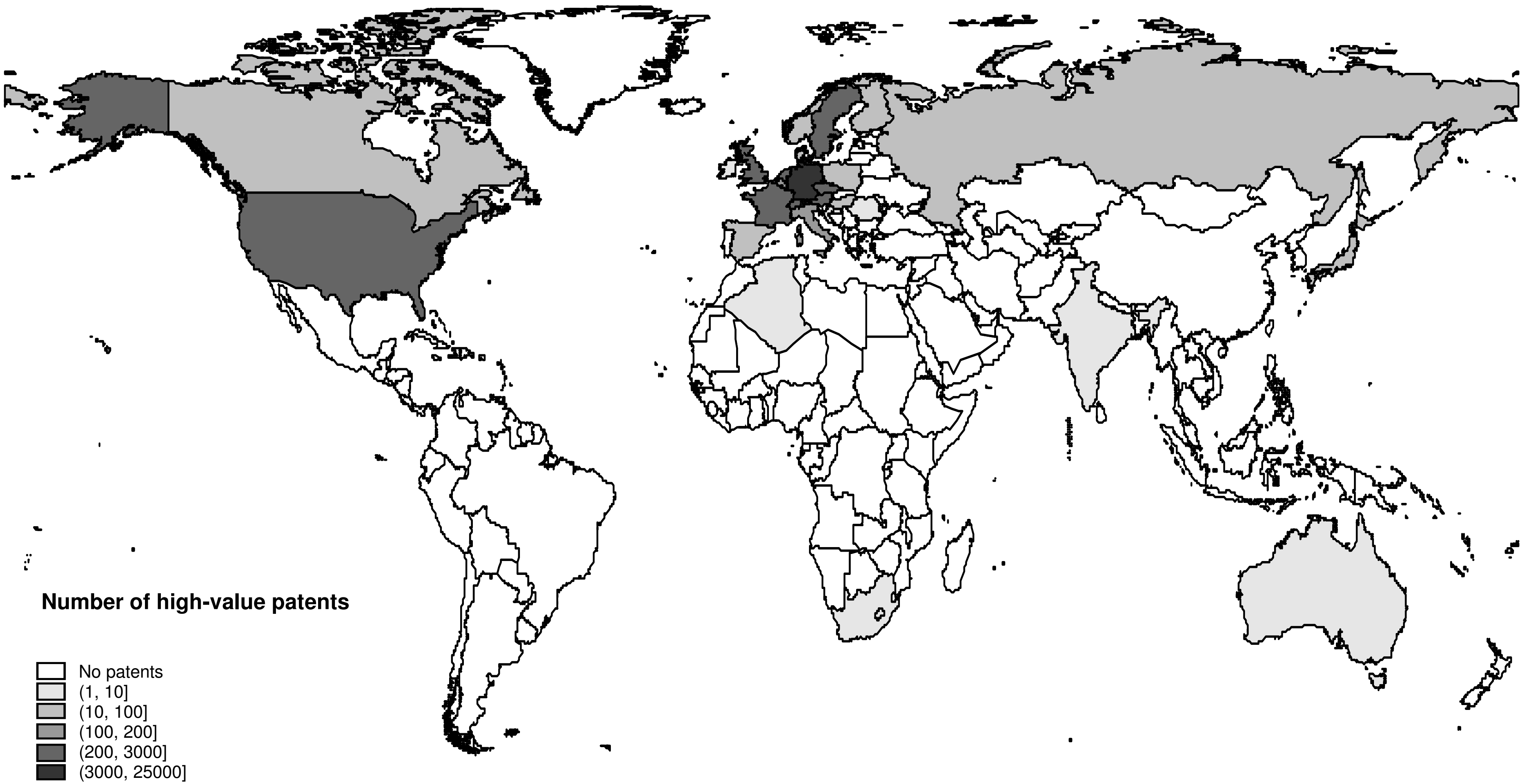
TABLE 3.1: IMPORTANT (10-YEAR) PATENTS BY PATENTEES FROM FOREIGN COUNTRIES (TODAY'S BOUNDARIES) IN THE WEIMAR REPUBLIC

Total patents					Patents per capita	
Country	**1919-23**	**1924-28**	**1929-32**	**1919-32**	**Country**	**1919-32**
U.S.	529	749	909	2187	◈ **Switzerland**	0.054997
Switzerland	302	269	419	990	◈ **Luxembourg**	0.017527
UK	214	230	224	668	◈ **Sweden**	0.013355
France	153	197	234	584	▶ **Austria**	0.009146
Sweden	95	83	182	360	◈ **Holland**	0.007235
Austria	33	85	149	267	◈ **Norway**	0.006332
Holland	42	66	136	244	◈ **Denmark**	0.005675
Czech	42	66	122	230	✦ **Belgium**	0.004097
Italy	27	49	97	173	✦ **U.S.**	0.004063
Belgium	49	54	46	149	▶ **Czech**	0.003782
Denmark	23	36	31	90	✦ **UK**	0.003206
Hungary	20	31	33	84	✦ **France**	0.003146
Norway	28	29	24	81	▶ **Hungary**	0.002183
Canada	7	11	9	27	✦ **Finland**	0.001067
Luxemburg	6	3	13	22	✦ **Italy**	0.000981
Russia	5	6	8	19	✦**Canada**	0.000592
Finland	5	9	3	17	**Croatia**	0.000143
Japan	2	8	6	16	✦ **Romania**	0.000116
Poland	3	4	6	13	◈ **Spain**	0.000112
Spain	7	4	1	12	**Poland**	0.000107
Romania	1	2	4	7	✦ **Australia**	0.000099
Croatia	0	0	5	5	✦ **South Africa**	0.000084
Australia	0	3	0	3	✦ **Ireland**	0.000065
South Africa	1	1	1	3	✦ **Japan**	0.000056
India	1	0	1	2	✦ **Algeria**	0.000034
Ireland	1	0	0	1	✦ **Russia**	0.000025
Algeria	0	1	0	1	✦ **India**	0.000002
Foreign	1596	1996	2663	6255	◈ **Neutral States**	
German	3782	7439	9681	20902	▶ **Central Powers**	
Total Patents	5378	9435	12344	27157	✦ **War opponents (and associated countries)**	

Data source: Reichspatentamt (1919-32). Verzeichnis der vom Reichspatentamt im Jahre [...] erteilten Patente

For a graphical illustration of the country differences, we plotted the number of high-value patents 1919-1932 in a world map in Figure 3.2 and the high-value patents of European countries only in Figure 3.3. On the one hand we observe the dominance of European countries due to the gravity component, but on the other hand the world-wide importance of Weimar Germany as a target for patents becomes clear from the map. We also observe from the map that some less developed countries in Latin America, Africa, and Asia had no high-value patents in Weimar Germany.

FIGURE 3.2: WORLD MAP: HIGH-VALUE PATENTS 1919-32



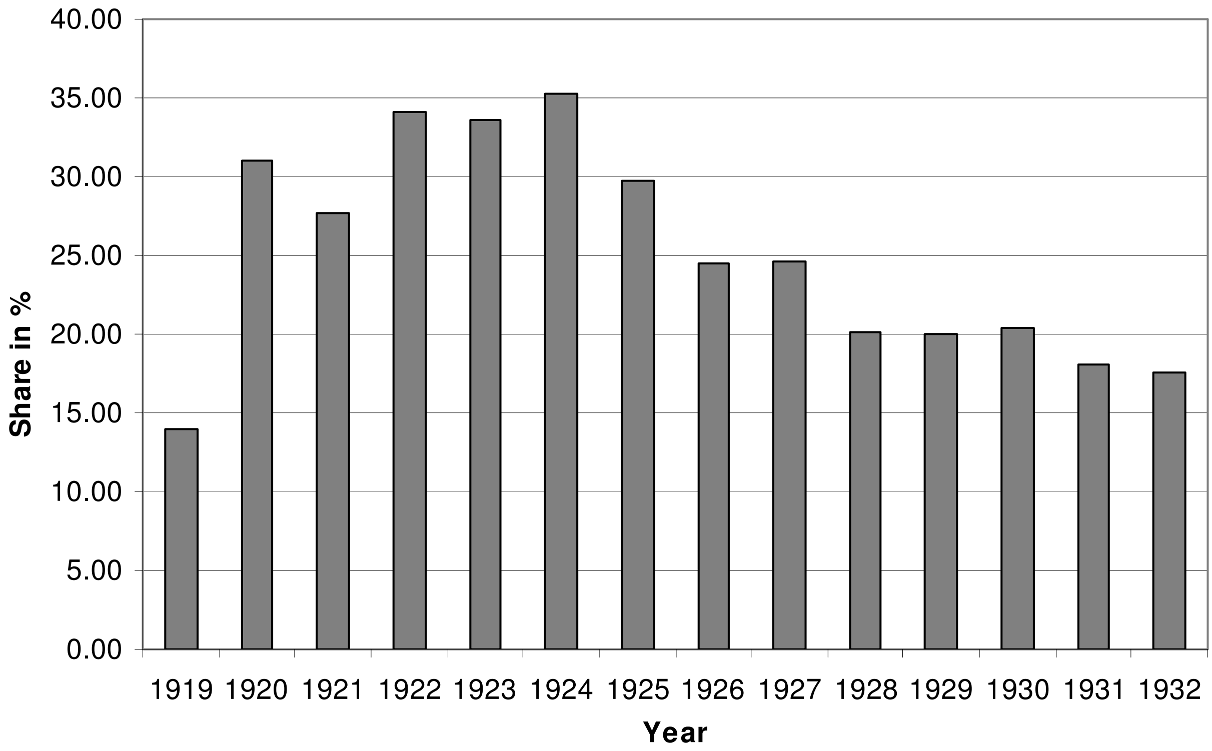
Data source: see Table 3.1.

FIGURE 3.3: EUROPE MAP: HIGH-VALUE PATENTS 1919-32

Data source: see Table 3.1.

Looking at the share of foreign high-value in all high-value patents in Figure 3.4, we observe that the trend increases steadily until mid 1920s and declines afterwards. In 1924, the share of international patents reached its peak as 35.21% of total patents were of foreign origin. If we also look at the absolute number of high-value patents in Figure 3.1, the development of those numbers is becoming quite evident. Due to the sharp increase of international patents and the modest rise of domestic patents in 1919-24, the share of foreign patents in Figure 3.4 grew during that period. In the following years, the German patents quadrupled from 898 to 3,940 patents whereas foreign patents declined noticeable from 1924-28 and grew only 2.5 fold during the last years. Consequently, the share of foreign in all high-value patents sank steadily after 1924.

FIGURE 3.4: SHARE OF FOREIGN IN DOMESTIC HIGH-VALUE PATENTS IN GERMANY 1919-32



Data source: see Table 3.1.

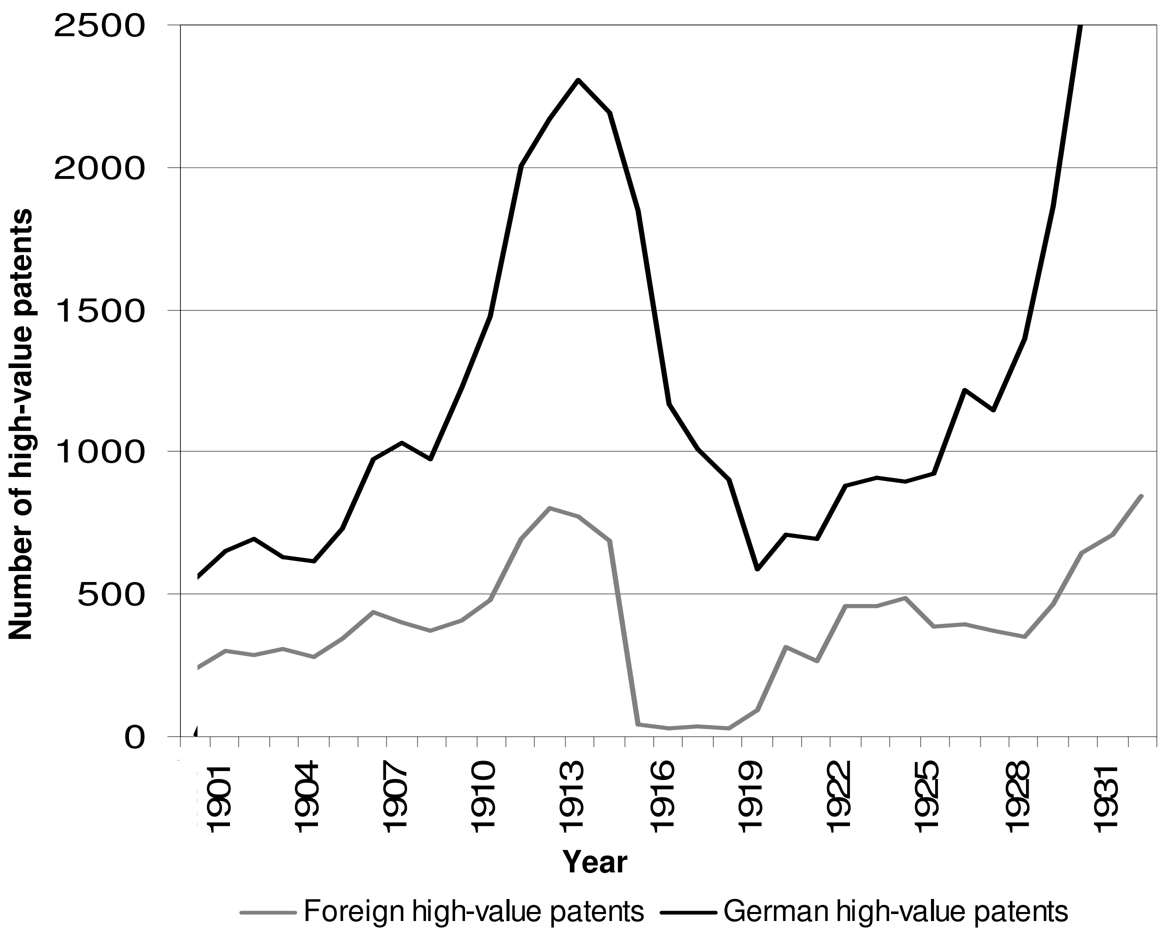
3.4 Controlling for patent booms

In Figure 3.5, we observe that the number of domestic and foreign high-value patents noticeably increased in the decade before WWI. This boom of long-lived patents was probably not caused by a rise in technological progress, but has to be interpreted as an anomaly development due to the substantial decrease of the patent renewal fees between 1914 and 1923. During the First World War, the German government exempted patentees from paying renewal fees. This rule was justified by the assumption that the market conditions of the war economy seriously deteriorated firms' opportunities to sell innovations successfully.[39] As a result, a lot of patentees who would have otherwise decided to give up

[39] See Kaiserliches Patentamt (1914), p. 290 and Kaiserliches Patentamt (1915), p. 118.

inferior patents took the chance to prolong them for free.[40] That is why the suspension of the renewal fee led to a considerable increase in the average life span of the pre-war patents granted since 1905 and therefore also to an upsurge of long-lived patents. The number of international high-value patents decreased due to events in WWI, but nevertheless the exemption of patent fees still led to more foreign patents than in a counterfactual situation where a yearly patent fee was demanded by the German patent authorities.

FIGURE 3.5: THE AUGMENTED INCREASE OF HIGH-VALUE PATENTS IN GERMANY



Data source: see Table 3.1.

[40] The sharp decrease of the patent cohorts' mortality rates during war times is shown in Table 3 in Streb et al. (2006a).

Furthermore, Table 3.2 shows that during post-war inflationary times, wholesale prices increased much faster than the reinstated renewal fees of the patents. The wholesale prices increased 8,598.4 million fold from 217 at the end of WWI to 1,865,850,000,000 by the peak of Germany's hyperinflation in October 1923. During the same time period the renewal fees for patents increased only 61.1 million fold. This uneven development implies that in the period from 1918 to 1923 real patent cost were still considerably lower than before the war. Consequently, more patents were judged to be worth to prolong than it would have been the case in a counterfactual situation without inflation. All other things equal, this exogenous disturbance increased the probability that a patent of the cohorts 1908 to 1913 reached an age of ten years or more.

TABLE 3.2: WHOLESALE PRICES AND RENEWAL FEES DURING THE GERMAN INFLATION 1914-1923, 1913=100

Date	Wholesale prices	Renewal fee for the 10th year
1914	105	100
1915	142	100
1916	152	100
1917	179	100
1918	217	100
1919	415	100
1920	1,486	100
June 1921 / July 6, 1921[a]	1,428	156
June 15, 1922 / June 27, 1922[a]	6,775	667
November 25, 1922	122,919	3,333
March 24, 1923	482,700	46,667
July 10, 1923 / July 9, 1923[a]	4,864,400	222,222
Sept. 4, 1923 / Sept. 2, 1923[a]	298,153,200	11,111,111
Oct. 30, 1923 / Oct. 29, 1923[a]	1,865,850,000,000	69,111,111,111

Note: [a] The first date refers to the wholesale prices, the second to the renewal fee
Data source: Streb et al. (2006a).

In Table 3.2 we have seen the dramatic increase of the renewal fee for the 10th year from 100 Marks in 1918 up to 69,111,111,111 in October 1923. But how much were these amounts in the local currency (U.S.-Dollar and Pound Sterling) at that time? To answer the question, Table 3.3 projects the patent costs for year 1, 5, and ten in US-Dollar and Pound Sterling for eleven points of time between June 1921 and December 1923. An American inventor had to pay 7.10$ for the 10th year of patent protection in June 1921. This price decreased next to almost nothing during hyperinflation. The patent holder was able to lengthen his patent for the 1st year as well for the 10th year for one cent, as the unitization of money did not make it possible to pay 0.000000000001$ as well as 0.00000000011 $ in December 1923. Summing up, patent protection for foreigners was virtually costless during the hyperinflation and consequently the patent fees did not prevent patent holders from extending their patents. It can be assumed that the expected returns of holding any patents at that time were higher than the costs.

TABLE 3.3: YEARLY COSTS OF PATENT PROTECTION IN U.S. DOLLAR AND POUND STERLING DURING THE HYPERINFLATION IN 1923

	Year of patent prolongation	Year 1	Year 5	Year 10
	Patent fee in Mark	**50**	**200**	**450**
Patent fee in U.S.-Dollar	06 / 1921	0.79	3.16	7.10
	12 / 1921	0.26	1.05	2.37
	06 / 1922	0.18	0.73	1.65
	12 / 1922	0.01	0.03	0.06
	06 / 1923	0.001	0.003	0.006
	07 / 1923	0.0003	0.0013	0.0028
	08 / 1923	0.00005	0.00018	0.00041
	09 / 1923	0.000003	0.000010	0.000023
	10 / 1923	0.0000002	0.0000008	0.0000019
	11 / 1923	0.0000000002	0.0000000006	0.0000000014
	12 / 1923	0.00000000001	0.00000000005	0.00000000011
Patent fee in Pound Sterling	06 / 1921	0.20	0.81	1.83
	12 / 1921	0.07	0.27	0.60
	06 / 1922	0.04	0.16	0.37
	12 / 1922	0.001	0.006	0.013
	06 / 1923	0.0001	0.0006	0.0013
	07 / 1923	0.0001	0.0003	0.0006
	08 / 1923	0.00001	0.00004	0.00009
	09 / 1923	0.0000001	0.0000004	0.0000009
	10 / 1923	0.00000001	0.00000004	0.00000008
	11 / 1923	0.00000000004	0.00000000014	0.00000000032
	12 / 1923	0.000000000003	0.000000000011	0.000000000024

Data source: Exchange Rates: Von Schneider et. al (1997).

Because of these considerations it would be misleading to consider every long-lived patent between 1905 and 1923 as valuable as the long-lived patents granted beyond this period. The problem is to differentiate between long-lived patents of this particular period that only reached a high age because of irregular low patent costs from those that would also have lived at least ten years without the suspension of renewal fees and inflation. To solve this problem, we constructed a patent deflator (shown in Table 3.4) for this period under consideration. The deflator estimates the number of real patents granted "under normal conditions".

We first run a regression of total German patents on German GDP per capita and crisis dummies in order to estimate the amount of patents we would expect otherwise[41]. The crisis dummies are inserted following Grabas and Frey (2002) and Klump and Männel (1995) that found that patents by GDP are higher than expected in crisis periods and that firms tried to overcome the crisis by intensified innovative activity. We performed this operation for every possible ten year life-span between 1904 and 1933. In the next step, we used the regression result to forecast the predicted number of patents 1905-1923. We then created the deflator in column five by dividing total actual patents by the forecasted number of patents. Finally, we applied the patent deflator to obtain real patent counts for the 1905-23 period.

[41] GDP data are taken from Maddison (1995 and 2001). Crisis dummies: (1 for 1892, 1901, 1907/08, 1914-18, 1923)

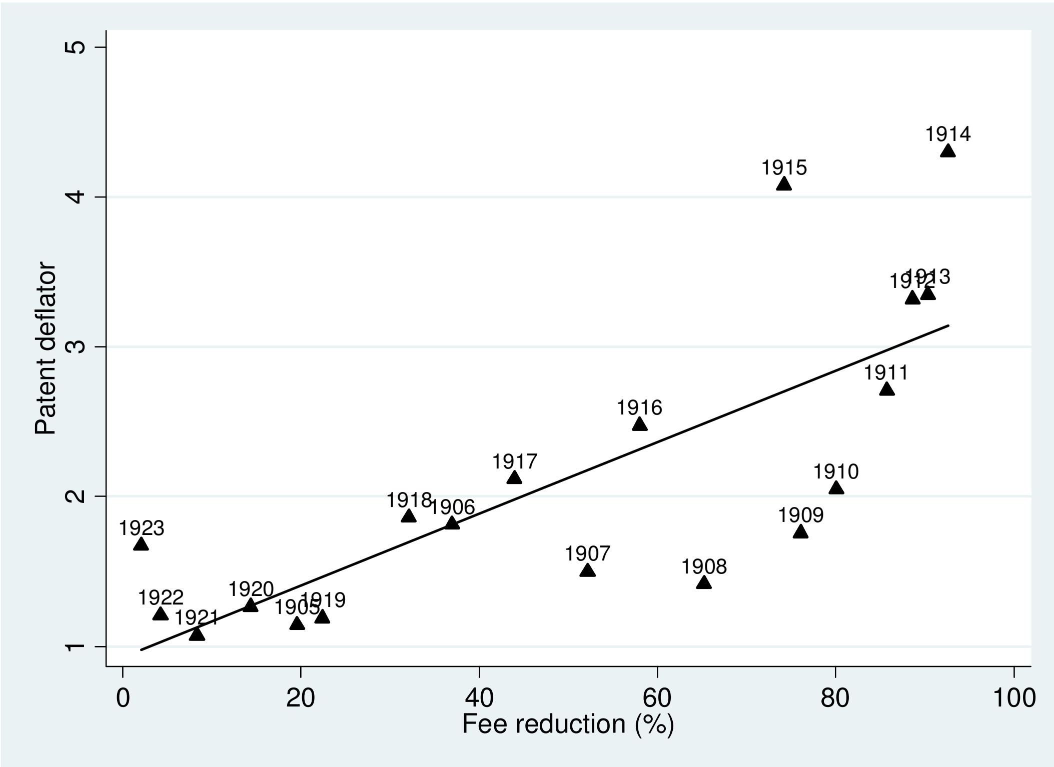
TABLE 3.4: CONSTRUCTION OF THE PATENT DEFLATOR 1905-23

Life span	10 year fee (in Marks)	Fee discount (in Marks)	Fee reduction in %	Patent deflator
1904-13	2300	0	0	-
1905-14	1850.00	450.00	0.20	1.14
1906-15	1450.00	850.00	0.37	1.81
1907-16	1100.00	1200.00	0.52	1.50
1908-17	800.00	1500.00	0.65	1.42
1909-18	550.00	1750.00	0.76	1.76
1910-19	458.00	1842.00	0.80	2.05
1911-20	327.50	1972.50	0.86	2.71
1912-21	261.50	2038.50	0.89	3.32
1913-22	222.00	2078.00	0.90	3.35
1914-23	170.00	2130.00	0.93	4.30
1915-24	593.00	1707.00	0.74	4.08
1916-25	966.00	1334.00	0.58	2.47
1917-26	1289.00	1011.00	0.44	2.12
1918-27	1562.00	738.00	0.32	1.86
1919-28	1785.00	515.00	0.22	1.19
1920-29	1970.00	330.00	0.14	1.27
1921-30	2108.50	191.50	0.08	1.07
1922-31	2202.50	97.50	0.04	1.21
1923-32	2252.50	47.50	0.02	1.67
1924-33	2300	0	0	-

Data source: own calculation.

Based on our knowledge of the annual real renewal fees needed to keep a patent valid for ten years and on the information in Table 3.2, we calculated the yearly relative fee reduction 1905-23 (shown in the 4th column of Table 3.4) in comparison to the patent costs of a ten years living patent in the counterfactual situation without war and inflation. In order to check the validity of this patent deflation approach, we compared the patent deflator with the relative fee reduction in Figure 3.6 and found that the relationship is indeed relatively close and plausible: a further fee reduction caused a deviation between expected and actual numbers of patents.

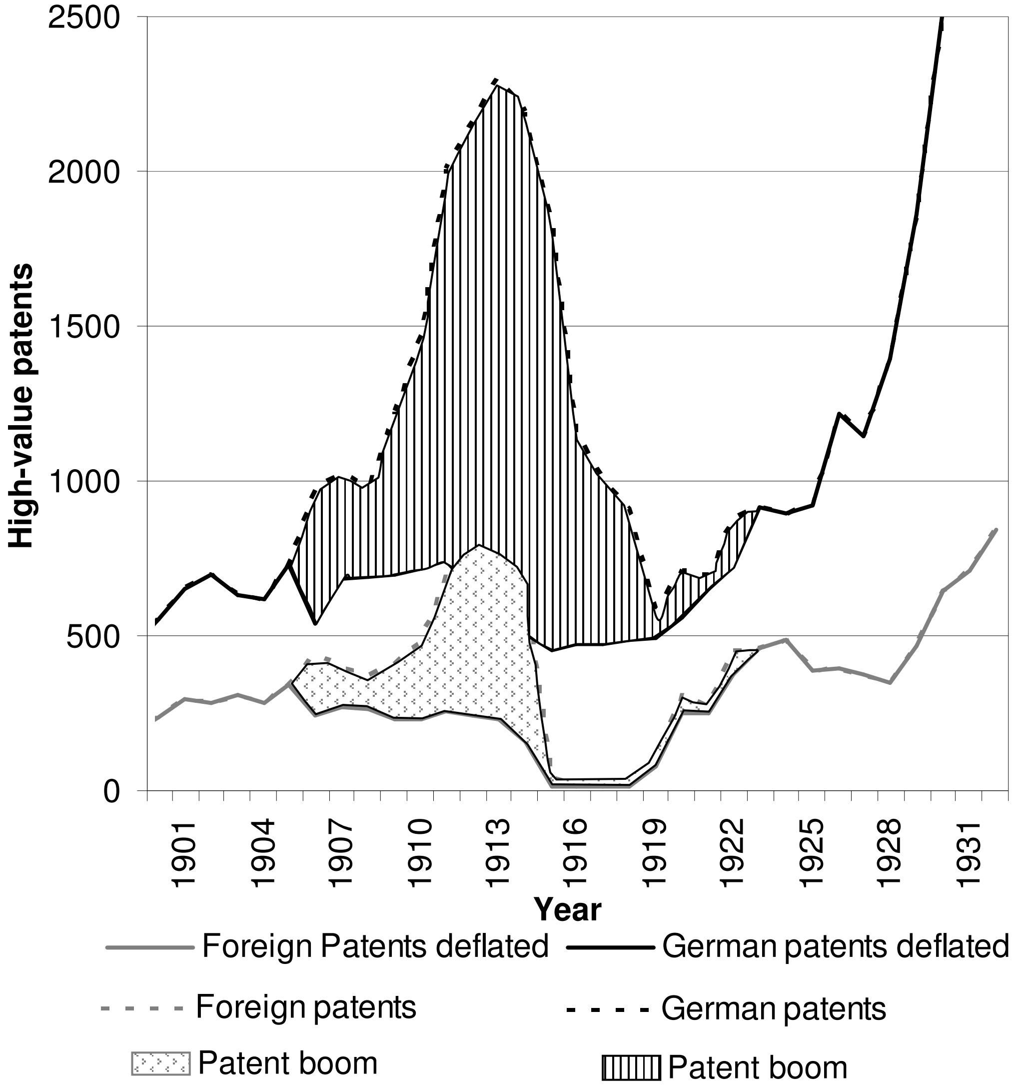
FIGURE 3.6: PATENT DEFLATOR AND FEE REDUCTION 1905-23



Data sources: High-value patents: see Table 3.1. Fee reduction: own calculation.

Figure 3.7 shows the results of this patent deflation for our sample of national and international high-value patents. The continuous black respectively grey line represents the estimated development of "deflated" domestic respectively foreign high value patents between 1900 and 1932 under counterfactual "normal" conditions without war and inflation. After controlling for decreasing renewal fees, the pre-WWI boom of high-value patents completely disappears. The shaded area highlights the discrepancy between nominal and real patents. We will compare the results for both, deflated and non-deflated high-value patents in our regressions.

FIGURE 3.7: DEFLATED FOREIGN AND DOMESTIC HIGH-VALUE PATENTS 1900-32



Data source: see Table 3.1.

3.5 The model

In various regressions, we test the validity of our hypothesis: war opponents were patenting less in Weimar Germany due to economic and political conflicts of the war and ongoing enmities. Furthermore, we highlight differences in the three phases of Weimar Germany 1919-23, 1924-28, and 1929-32. We regress foreign high-value patents per capita in Germany on variables that are not directly related to the WWI: primary schooling in the preceding decade, distance to Germany, common language, the existence of a patent law in the native country, and share of high patenting industries such as chemicals and electrical engineering. In addition, we control for peculiarities of the First World War: Germany's war opponents and casualties of countries that participated the war.

Khan and Sokoloff (2004) found in their study on great inventors in the United States 1790-1930 that 75-80% of the patents at that time were held by inventors with only primary or secondary schooling. Controlling for education in our regressions is not only substantial for the inventors' propensity to invention, patenting and innovation, but also for the skills of the labour force. The labour force also needs a minimum level of education to translate innovations into profits and growth. Controls for distance and a common language (German) are inserted in order to capture the fact that countries more remote to Germany have higher information and transaction costs. In addition, the weight of commodities plays a major role if countries have commercial operations with Germany after filing a patent there. The possibility to interact in a common language could also have an impact on patenting and we thus expect a higher propensity to patent when there are no language barriers. We also control for sufficient patent protection in the native country by inserting a dummy variable for the existence of a patent law there.[42] Eaton and Kortum (1996 and 1999) argue that a patent holder will only apply for a patent abroad if his invention is sufficiently protected in the native country. Generally, inventors seek patent protection in each country where they see a high risk of imitation through competitors. The inventor expands his monopoly position

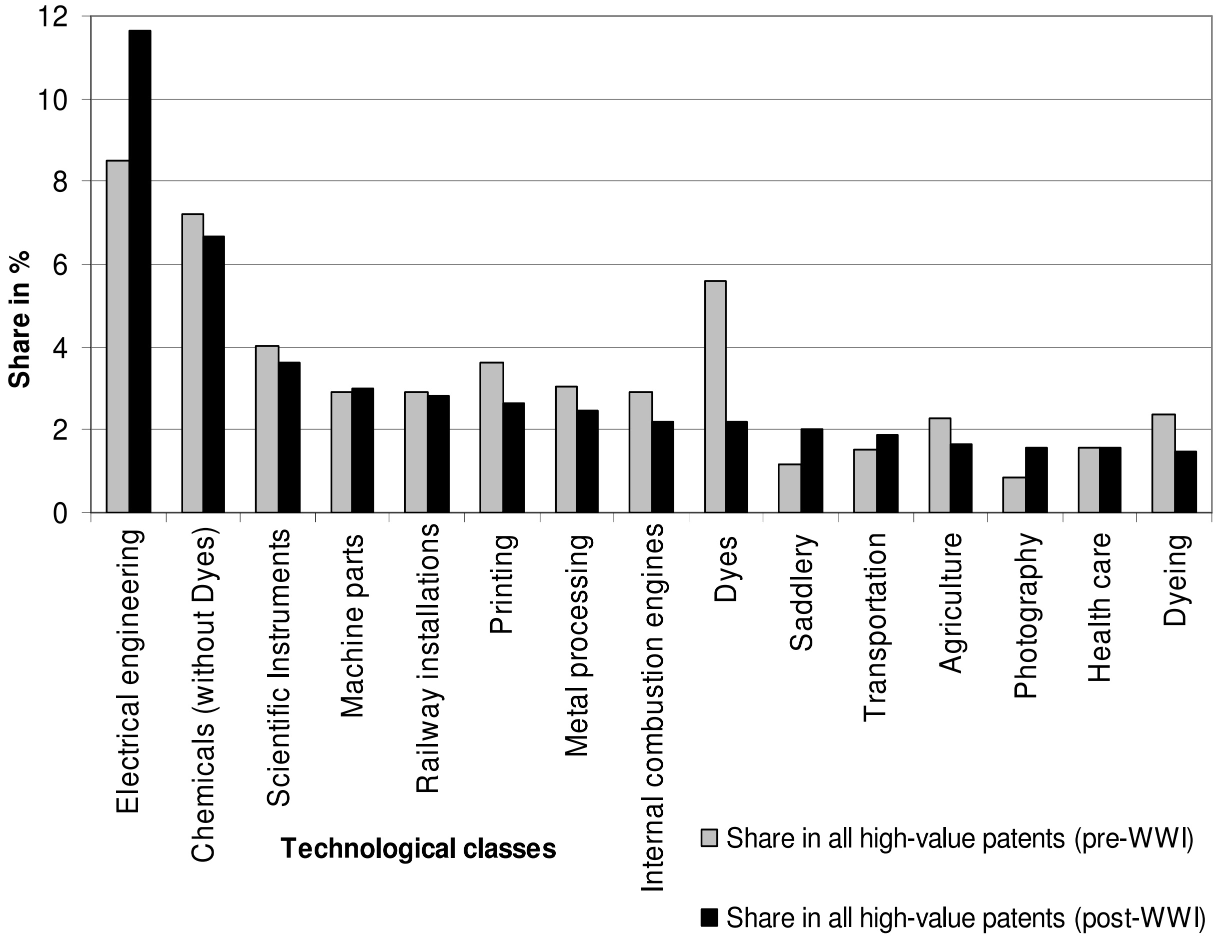
[42] The data stems from Lerner (2000).

abroad to capture high research and development costs and to maximise potential profit. Alternatively, we could also use the exact duration of protection when available.

The relationship between patents and inventive activities of an economy could also be influenced by differences in patenting by industry. The variable "share of high patenting industries" indicates the propensity to patent of different industries. We aggregate all high-value patents by patent classes to show the fifteen most frequented patent classes of the interwar period in comparison with the pre-WWI phase in Figure 3.8. For a detailed illustration of the performance of the industries shown in the Figure, see Table 3.8 in the appendix.

Amongst many others, James (1986) and Ambrosius (2000) mention two groups of industries that attained a particular high level of international competitiveness between World War I and II: first, the chemical industry including dyestuff, and secondly, branches of electrical and instrument industries. It follows that these industries were among high share patent groups. These industries were able to regain their success and competitiveness to a large extent after the war and consequently achieved high shares amongst all patents in the interwar period. Worth mentioning is the performance of dyes, they were on position three with 5.61% in 1880-1914 and drifted towards rank nine (2.17) in 1919-32. The dominance and favourable development of electrical engineering ranking as a leader emerges clearly, whereas chemicals without dyes remained quite comfortably on second position. Due to the sharp decline of dyes we omit this patent class into the construction of the variable "patents in chemical and electrotechnical industries". We considered the patent classes: electrical engineering (11.66%), and chemicals without dyes (6.67%). For our regressions, we calculated in the next step all countries' share in these most popular patent classes 1919-32.

FIGURE 3.8: THE MOST FREQUENTED PATENT CLASSES 1877-1914 AND 1919-32



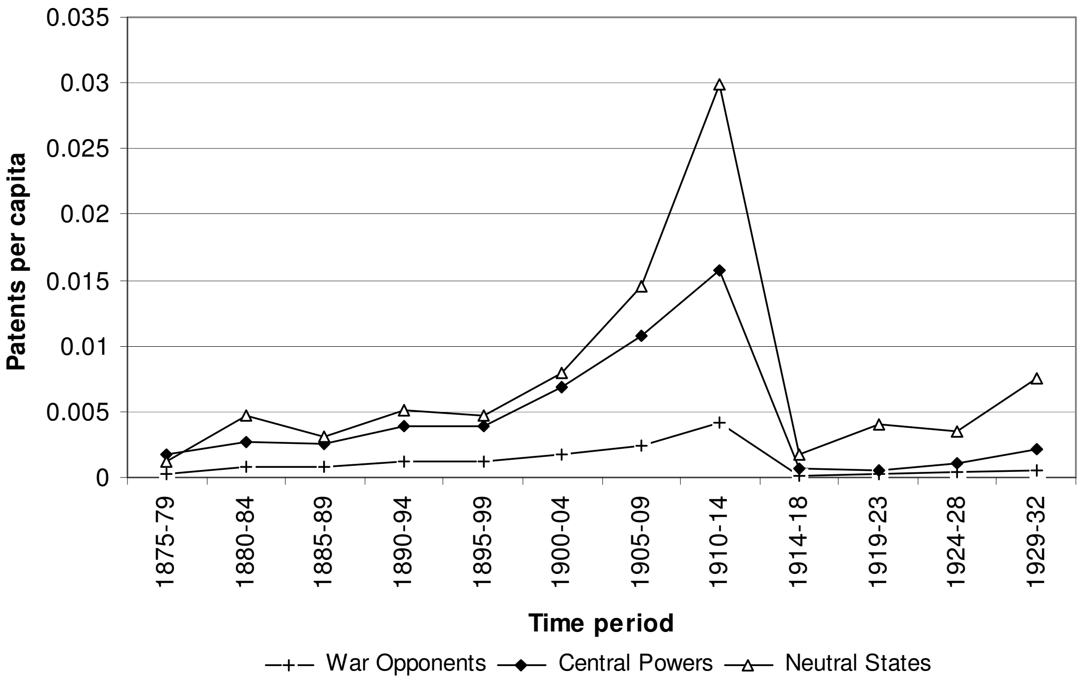
Data source: see Table 3.1.

We control for the patenting behaviour of war opponents and test if inventors from Allied countries behaved in a rational manner as inventors from the Central Powers or neutral countries 1919-32. Hence, we include a dummy variable that is equal to one for the Allies of WWI and their associated countries.[43] To get a first impression of patenting behaviour of the three different groups (Allied versus Central Powers versus neutral countries) we show the average number of high-value patents per capita of each group in Figure 3.9 and 3.10. The

[43] Allies of WWI including associated countries: au, be, bo, br, ca, cn, cr, cu, dz, fi, fr, gr, gt, hk, ie, in, it, jm, jp, lk, ni, nz, pl, pt, ro, ru, th, tt, uk, us, uy, vn, za. Neutral States: ar, ch, cl, co, dk, es, id, lu, mx, nl, no, se. Central Powers: at, ba, bg, cz, hr, hu, tr. For country abbreviations, see appendix B.2.

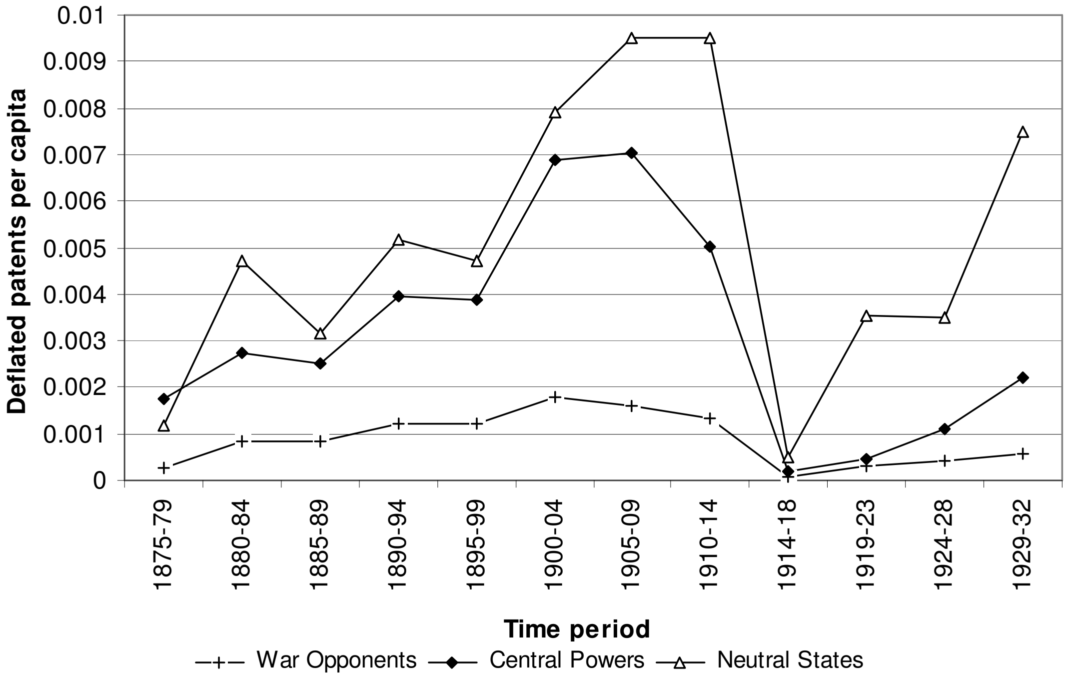
first graph comprises all patents whereas the second controls for the patent inflation caused by the exemption of patent fees during WWI and the hyperinflation. Except for the period 1875-79, neutral countries had most patents per capita, followed by Central Powers and the war opponents. During the war years, patents of all groups collapsed. However, as soon as the war was over, all countries resumed their patenting activity in Weimar Germany, but on a lower level. From the figures, we know that neutral countries re-established their patenting activity more rapidly and in larger amounts than Germany's confederates of war. This fact is even more dramatic if we look at deflated patents in Figure 3.10. Figures 3.11 until 3.14 in appendix B.1 provide detailed information about the performance of those countries with the highest patenting rates.

FIGURE 3.9: AVERAGE NUMBER OF PATENTS PER CAPITA OF WAR OPPONENTS, CENTRAL POWERS, AND NEUTRAL STATES



Data source: see Table 3.1.

FIGURE 3.10: AVERAGE NUMBER OF DEFLATED HIGH-VALUE PATENTS PER CAPITA OF WAR OPPONENTS, CENTRAL POWERS, AND NEUTRAL STATES



Data source: see Table 3.1.

Besides controlling for war opponents, we also include WWI-casualties per capita of war opponents in our regressions.[44] Thereby, we control for psychological factors of the bereaved and the resulting nationwide sentiments. Psychological barriers in the inventor's decision making process could have resulted in reduced patenting rates in the country that is considered responsible for the casualties. Schulze and Wolf (2006) analyse consequences of nationality conflicts in the Habsburg economy before WWI. They investigate whether language, nationality, and regional loyalty had an impact on economic relations within the Habsburg Empire. Accordingly, national and ethnic conflicts within an empire could also lead to emerging borders or its dissolution. Analysing the effects of ethnic and regional borders on grain price dynamics, Schulze and Wolf (2006) found a large and significant

[44] Everett (1980, p. 248) reports casualties figures of WWI for: at, au, be, bg, ca, fr, gr, hu, in, it, jp, nz, pt, ro, ru, tr, uk, us, za.

nationality effect in the Austro-Hungarian Empire from 1895 onwards. On the basis of grain price data, post-1918 borders can be traced back to twenty years before the outbreak of WWI. In a similar manner, losses and casualties of war could also foster nationalism and enmities across countries. Hence, we include those figures in some of our regression models. It is plausible that inventing firms and individuals reduced their patent protection application in those countries where non-quantitative or psychological barriers existed.

3.6 Empirical results

3.6.1 Cross-sectional regression results for the 1919-1932 period

In Table 3.5, we test the influence of the exogenous variables mentioned above, on high-value patents per capita in the three of Weimar Germany 1919-1923, 1924-1928, and 1929-1932. We consider all countries in today's boundaries; hence we include twenty-seven countries without and twenty-seven countries with high-value patents in Weimar Germany in our analysis. When we are controlling for casualties of war in regression 2, 4, and 6 the number of observations decreases strongly due to data limitations. The first two regression columns present determinants of nominal or non-deflated patents 1919-23, the following two regressions those for real or deflated high-value patents. The period 1919-23 is reported frequently because of the applicability of the patent deflator. We calculated the latter for the years 1905-1923 and accordingly, the number of high-value patents in the periods 1924-28 and 1929-32 do not have to be deflated and their determinants are displayed in regression 5 to 7.

In all versions of the model, primary schooling in the preceding decade has a positive impact on high-value patents at least at the five per cent significance level. Rising primary schooling rates in the preceding decade by 1% caused a 0.43-0.96% increase in high value patents. We obtain higher coefficients for primary schooling and most of the other exogenous variables in those regressions where the patent deflator is applied on the number of high-value patents for the 1919-24 period. In addition, the p-values of primary schooling in those regressions show a higher level of significance and higher adjusted R^2s also indicates a better quality of fit. In comparison to the results from chapter two, we detect a higher influence of primary schooling on patens for the pre-WWI phase. The regression coefficients 1919-32 were higher and reached their maximum from 1900 onwards. It seems that during this phase of high industrialisation a certain level of basic education was even more required for innovativeness and for the process of transforming inventions into economically useful applications than in the interwar period.

Consistent to the analysis of high-value patents 1880-1914 in chapter two, the coefficient of distance turns out to be robust and always highly significant and negative, but the magnitude of the coefficients is slightly lower in the interwar period. Distance matters not only for patent applications, but also for commercial operations after holding a patent in another country, as information and transaction costs are lower for adjacent countries.

While Dunlevy (1999) finds that the impact of cultural proximities such as common language or cultural history between countries on the propensity to patent, this cannot be said on the basis of our results. In all specifications of the regression model, the existence of a common language turned out to be insignificant for the period 1919-32, confirming the results of chapter two. The size of the coefficient for German language was significant and of relevant size only in the decade before WWI. This short period of significance could be interpreted as a reorientation of innovative intellectual flow towards the axis powers, which returned after the war.

We also included Lerner's (2000) patent law existence in lagged form: his classification for 1900 for 1919-23 and 1924-28 the classification for 1925 for 1929-32 to

1910-19. Only ten countries had no patent protection in 1900 and eight in 1925[45]. In all our regressions the existence of patent laws in the native country was never significant and showed inconsistent signs (negative prior to 1924 and positive afterwards). During the German Empire this variable was only significantly positive from 1880 until 1899.

The share of chemical and electrotechnical patents was highly significant and positive in all periods in Table 3.5. In those models where we also control for casualties of war, an increase of 1% of patents in those classes led to an 8% rise in high-value patents. In all other specification, the regression coefficient was around 11%. The corresponding regression coefficients for the pre-WWI period showed almost the same size if war opponents were included in the model. But if we look at regressions 2 and 4 without controlling for Entente powers, we find that the impact of chemical and electrotechnical patents is definitely lower than in the reference period. According to the numbers from Figure 3.8, the share of electrical patents in all patents gained more than 3% and chemicals lost only moderately. So those regression results cannot be explained by decreased relevance of those industries.

To test our hypothesis, we are strongly interested in the performance of the variables "war opponent" and "casualties of war" in the three different phases of interwar Germany. Variance Inflation Factors below 1.5 in all regressions indicate that there is no evidence of collinearity in the cross-sectional regressions. The propensity to patent in Germany is visibly lower for war opponents than for countries being not involved in WWI. Shortly after the end of WWI, when the aftermath was most severe (e.g. reconstruction of empires, reparation payments, or psychological trauma), the Allied forces and associated countries patented 1.6 fold less than non-involved or confederate countries. If we also control for military deaths, the impact of the war opponent dummy on high-value patents is a little smaller (coefficient is

[45] Countries without patent protection in 1900: Algeria, Argentina, China, Guatemala, Greece, Indonesia, Netherlands, Romania, South Africa, Vietnam.
Countries without patent protection in 1925: Argentina, Bosnia, China, Guatemala, Indonesia, Ireland, Russia, Vietnam.

about 1.3). The influence of this variable is similar on deflated and non-deflated patents in 1919-24. As expected this effect is reduced in the following years and the regression coefficient declined to -1.32 in 1924-28 and to -1.29 in 1929-32 for the full sample. The impact of the number of casualties per capita in the respective country, involved in WWI, is extremely low and unexpectedly only significant in 1924-28. An increase of one per cent in military deaths resulted in 0.00000107% less patents. This result might be caused by the small number of cases constrained by data availability. This result indicates that psychological factors had only a marginal influence on the inventor's choice of the country where they seek protection for their invention. Furthermore, we obtain slightly higher adjusted R^2 if we control for war casualties. In general, R^2 are satisfactory and always higher than 0.508 – they confirm a good quality of fit. In the following, we will run some random-effects panel regressions to study the behaviour of our variables in the longitudinal format.

TABLE 3.5: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1919-1932. ALL COUNTRIES IN TODAY'S BOUNDARIES INCLUDED

	Non-deflated patents				Deflated patents				Deflation not necessary					
	1919-23		1919-23		1919-23		1919-23		1924-28		1924-28		1929-32	
Primary schooling rate (logarithm), preceding decade	**0.532**	*0.038*	**0.948**	*0.009*	**0.547**	*0.033*	**0.960**	*0.008*	**0.452**	*0.047*	**0.425**	*0.028*	**0.664**	*0.023*
Distance to Germany (logarithm)	**-0.587**	*0.000*	**-0.590**	*0.004*	**-0.609**	*0.000*	**-0.609**	*0.003*	**-0.553**	*0.000*	***-0.654***	*0.000*	***-0.676***	*0.000*
German language	0.022	*0.969*	0.267	*0.742*	0.053	*0.925*	0.262	*0.745*	0.182	*0.695*	*0.944*	*0.516*	*0.291*	*0.626*
Patent protection	-0.298	*0.506*	-0.056	*0.924*	-0.294	*0.508*	-0.052	*0.929*	0.059	*0.872*	0.428	*0.371*	0.093	*0.853*
Patents in chemical / electrotechnical industries (%)	**10.93**	*0.001*	**7.398**	*0.023*	**11.15**	*0.000*	**7.532**	*0.021*	**11.07**	*0.000*	**7.619**	*0.005*	**11.65**	*0.001*
War opponent	**-1.609**	*0.001*	**-1.326**	*0.011*	**-1.604**	*0.001*	**-1.308**	*0.012*	**-1.316**	*0.001*	**-1.294**	*0.039*	**-1.291**	*0.008*
Casualties of WWI (logarithm)			-7e-07	*0.223*			-7e-07	*0.227*			**-1e-06**	*0.026*		
Constant	**-6.912**	*0.002*	**-9.164**	*0.003*	**-6.780**	*0.003*	**-9.030**	*0.003*	**-6.908**	*0.001*	**-5.925**	*0.014*	**-7.156**	*0.005*
Adj. R^2	0.508		0.674		0.524		0.682		0.597		0.716		0.571	
N	54		32		54		32		54		32		54	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data Sources: High-value patents: see Table 3.1; Schooling Rates: Lindert (2004a); Distance to Germany: http://www.macalester.edu/research/economics/PAGE/HAVEMAN/Trade.Resources/Data/Gravity/dist.txt; Ratio of high patenting industries: see text. German Language includes Habsburg territories in which a part of the elites spoke German, such as cz, hu, ba, hr, si.

3.6.2 Panel regression results for the 1919-1932 period

Regressions 1 and 2 in Table 3.6 show the results for total patents and include all countries, whereas the specifications 3 to 6 explain deflated high-value patents. Finally, the last regression shows the performance of deflated patents for the more exclusive club of those twenty-seven countries that were actively patenting during the three analysed periods. In addition to the regressors inserted in the OLS-regressions above, we will also control for the coast-land-ratio, the land-labour-ratio, institutional constraint on executive, and logged GDP per capita.

The coast-land-ratio measures a country's coastline relative to its surface area. The higher the value, the higher is the country's coastline in relation to the land in square kilometres[46] and the better the export possibilities by water. We expect higher patenting rates for countries with coastal access as the establishment of commercial relationships is more attractive due to better export chances after filing for a German patent. Nevertheless, the impact of this variable is insignificant for the period 1919-32 as we also found in chapter two for the pre-WWI period.

We also include a variable (land-labour-ratio) that measures differences in relative endowment of land and labour. Federico (2006) mentions the scarcity of land in South and East Asia and in Europe that was nowhere in the world likewise distinct. He also sees two land-labour-ratio hypotheses: first, countries that are land scarce invest intensively in land saving innovations and second, countries with labour scarcity invest more in labour-saving innovations. Nevertheless, this variable does not show any significance in any of the regressions.

Acemoglu et al. (2002) developed an indicator of institutional quality that measures constraint on the executive powers to expropriate capital. The variable is coded on a 7 point scale, ranging from 1 (there are no regular limitations) until 7 (accountability groups have effective authority equal to or greater than the executive in most activities). Accordingly, higher numbers denote stronger institutions. We include the variable in our regressions; because a high risk of expropriation by a monarch in the native country discourages inventors to establish economic relations and to patent there. Unlike in some models for the pre-WWI period, the variable signs alternate and are not significant.

[46] Data are taken from CIA (2005).

In the following, we are coming back to the variables that were already used in the cross-section analysis and focus our attention on the variables that are strongly related to the First World War. Basic education proxied by primary schooling has a significantly positive effect at all levels of significance on high-value patents. Noteworthy is the last regression model for the twenty-seven patenting countries. Amongst all the models, where we do not control for military deaths per capita, primary schooling seems to have been more important for those countries over time than for the entire sample. A 1% increase in enrolment caused 0.791% more patents, whereas for the fifty-four country sample, the number of patents increased from 0.05 to 0.07%. We can therefore confirm our assumption that primary schooling is crucial for inventors and the labour force in the turbulent interwar period as well. The gravity component distance turns out to be robust and significantly negative as in all previous specifications, whereas cultural proximity measured by the existence of a common language and the dummy for patent protection in the native country are consistently insignificant.

The positive and remarkable influence of patents in chemical and electrotechnical industries does not change the results from the cross-sectional regressions considerably (correlation coefficients vary between 10.3 and 17.7), but it is important to note that higher coefficients and levels of significance are obtained if deflated patents are used instead of nominal patents. GDP per capita as a measure of foreign demand has also a significant positive influence on foreign high-value patents as expected. The higher the income abroad, the more inventors are trying to expand their success and invest in other countries. The elasticities range from 0.7% for the twenty-seven patenting countries to 1% for all countries.

Like in the cross-sections, being a war opponents matters strongly for the patenting behaviour in all models in the longitudinal format. Countries that fought against Germany during the First World War had between 0.9 and 1.4% less high-value patents in the post-war period. This result provides further evidence that inventors from the Allied powers could not free themselves from the impressions of war and were no rationalistic decision makers. The First World War inhibited the patenting behaviour of those countries involved in the war. One possible explanation of this restraint might be that expected future economic relationships and sales potentials at the time of the patent application or prolongation were insecure. Also the number of casualties of war per capita had a marginal but negative impact and supports the latter implication.

TABLE 3.6: PANEL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1919-1932 IN TODAY'S BOUNDARIES. (RANDOM-EFFECTS ESTIMATES)

	Non-deflated patents				**Deflated patents**							
	All countries				*All countries*						*Only countries with patents*	
Primary schooling rate (logarithm), preceding decade	**0.054**	*0.062*	**1.572**	*0.008*	**0.068**	*0.053*	**0.059**	*0.044*	**1.366**	*0.042*	**0.791**	*0.006*
Distance to Germany (logarithm)	**-0.725**	*0.026*	**-1.080**	*0.007*	**-0.731**	*0.025*	**-0.848**	*0.007*	**-1.333**	*0.056*	**-0.471**	*0.040*
German language	0.120	*0.840*	-0.495	*0.898*	0.082	*0.891*	0.419	*0.402*	1.640	*0.705*	-1.074	*0.237*
Coast-land-ratio (Log)	-0.065	*0.288*	-0.053	*0.896*	-0.068	*0.269*			-0.166	*0.715*	-0.086	*0.270*
Land-labour-ratio (Log)	-0.025	*0.350*	0.060	*0.349*	-0.023	*0.394*			0.083	*0.248*	0.048	*0.661*
Patent protection	0.127	*0.575*	0.958	*0.161*	0.136	*0.545*	0.144	*0.522*	0.814	*0.292*	0.566	*0.218*
Patents in chemical / electrotechnical industries (%)	**10.29**	*0.005*	**17.74**	*0.000*	**10.45**	*0.004*	**11.52**	*0.001*	**13.69**	*0.000*	**13.37**	*0.016*
Institutional constraint on executive	0.007	*0.888*	-0.099	*0.608*	0.007	*0.897*	-0.017	*0.729*	-0.092	*0.674*	-0.026	*0.834*
GDP per capita (Log)	**1.096**	*0.005*	**0.869**	*0.004*	**1.053**	*0.007*	**1.059**	*0.003*	**0.662**	*0.057*	**0.679**	*0.036*
War opponent	**-1.009**	*0.012*	**-0.859**	*0.009*	**-1.009**	*0.012*	**-1.123**	*0.004*	**-0.963**	*0.008*	**-1.480**	*0.001*
Casualties of WWI (logarithm)			**-1.54e-06**	*0.057*					**-1.47e-06**	*0.100*		
Dummy 1919-23	-0.170	*0.132*	-0.926	*0.229*	-0.123	*0.273*	-0.125	*0.257*	**-2.181**	*0.013*	**-0.545**	*0.044*
Dummy 1924-28	-0.031	*0.763*	-0.853	*0.270*	-0.032	*0.753*	-0.032	*0.753*	**-2.128**	*0.016*	**-0.400**	*0.004*
Dummy Europe	-0.211	*0.880*	1.710	*0.517*	-0.186	*0.894*	-0.072	*0.959*	0.806	*0.786*	-15.290	*0.122*
Dummy North America	-0.719	*0.485*	1.523	*0.304*	-0.729	*0.479*	-1.143	*0.237*	1.730	*0.298*	**-19.491**	*0.081*
Dummy Asia	0.550	*0.595*	2.237	*0.299*	0.585	*0.571*	0.791	*0.437*	1.149	*0.557*	2.002	*0.331*
Dummy Latin America	0.537	*0.533*	0.838	*0.575*	0.565	*0.512*	0.842	*0.308*	0.374	*0.823*	1.981	*0.337*
Constant	**-11.12**	*0.030*	-18.83	*0.137*	**-10.99**	*0.032*	**-10.06**	*0.043*	-11.98	*0.401*	**-17.86**	*0.001*
R^2 (overall)	0.701		0.663		0.705		0.692		0.647		0.879	
N	162		96		162		162		96		81	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 3.5.
Institutional Constraint on Executive: Acemoglu et al. (2002).
Coast-Land-Ratio (own calculation): CIA (2005).
Land-Labour-Ratio (own calculation): Land: CIA (2005),
Labour: Mitchell (1980), Mitchell, (1993), Mitchell (1998).

Dummy Variables**:**
Dummy 1919-32 (Reference Category)
Dummy Europe: uk, fr, ch, at, se, nl, it, se, ru, dk, hu, cz, ie, es, lu, no, ro, hr, fi, pl, si ba, bg, gr, pt
Dummy Northern America: us, ca
Dummy Asia: hk, cn, in, jp, id, vn, tr, lk, th
Dummy Latin America: ar, gt, br, mx, bo, cl, co, cr, cu, jm, ni, tt, pe
Dummy Australia: au, nz (Reference Category)

3.6.3 Panel regression results for the 1880-1932 period

Having complete information about all high-value patents that were granted between 1880 and 1932, we are able to run panel regression for this long time horizon (1880-1932). By doing so, we can estimate the robustness of our explanatory variables in the long run. The regressions in Table 3.7 are organised like in Table 3.6: regressions 1-5 consider all countries and regression 6 again only countries with patents. In regression 1 and 2, we explain all high-value patents whereas in the remaining regressions, we apply the newly developed patent deflator (see Table 3.4) on patents granted between 1905 and 1923. In each of the regressions, lagged primary schooling has a strong positive and statistically significant impact on high-value patenting (elasticities: 0.815-1.655). During the German Empire, the war years, and in the post 1918 phase, basic educations turns out to be one of the most important basic requirements to originate innovations in the form of high-value patents.

Compared to the regressions for the pre-1914 and post-1919 period, the results for the control variables distance to Germany, German language, and coast-land ratio do not vary much and show the same signs and similar p-values though the regression coefficients for geographical distance are slightly higher. During the period 1880-1914, a statistical significant of the land-labour was not given, but the p-values (0.112 and 0.170) were not far away from significance. If we are exploring the long run, the land-labour-ratio shows significance in all models. Also the existence of patent protection in the native country is significant in those specifications that do not contain controls for the coast-land-ratio and land-labour ratio or for the more exclusive club of only patenting countries. In all other regressions, the impact of patent protection in the home country is not far away from significance like p-values demonstrate. One additional year of patent protection in the home country of the inventor or inventing firm yielded 0.7-1.0 more patents. The share of high-value patents in the booming industries exhibits a remarkable influence on the dependent variable, the elasticity lies between 15.15 and 20.1 at the 1%-level of statistical significance.

In order to test whether war opponents already reduced their patenting behaviour before the outbreak of the First World War or whether this is only a post-war phenomena, we added two interaction terms: post1918*war opponent and pre1914*war opponent. The results for pre1914*war opponent, indicate that belonging to the Allied powers before 1914 did not restrain high-value patents. In contrast, the post1918*war opponent interaction term shows a significantly negative impact. The Allied Powers were definitely patenting with reserve in the post-1918 phase. This close connection is even stronger if we look at the last regression for those countries whose inventing firms and individuals in fact held economically important patents in Germany. Summing up, the initiation of WWI did not hinder the Allied countries to protect their inventions in Germany but the aftermath of war was preventing these countries' inventors to revive their business in Weimar Germany, at least in the early years.

Worth mentioning is the behaviour of the institutional control in regression 6, which includes only patenting countries. The stronger the institutions were in these countries, the higher were the incentives to patent abroad. Once again, we found robust evidence for the patent deflation method. The regressions show mostly higher coefficients for the more important exogenous variables and deliver higher R^2. In addition, p-values are in most cases lower. Together with the findings, shown in Figure 3.9 we are convinced about the validity of our method.

TABLE 3.7: PANEL ESTIMATION RESULTS: DETERMINANTS OF LOG. PATENTS PER CAPITA 1880-1932 IN TODAY'S BOUNDARIES. (RANDOM-EFFECTS ESTIMATES)

	Non-deflated patents				Deflated patents							
	All countries				All countries						Only countries with patents	
Primary schooling rate (logarithm), preceding decade	**1.305**	0.000	**0.815**	0.045	**1.317**	0.001	**1.288**	0.001	**0.985**	0.007	**1.655**	0.001
Distance to Germany (logarithm)	**-1.163**	0.016	**-1.527**	0.005	**-1.118**	0.007	**-1.120**	0.026	**-1.208**	0.013	**-1.403**	0.012
German language	1.127	0.198	-0.724	0.478	0.966	0.319	-0.137	0.873	-0.920	0.313	0.127	0.846
Coast-land-ratio (Log)	0.180	0.251	-0.162	0.114	0.177	0.284			0.170	0.163	0.120	0.106
Land-labour-ratio (Log)	**-0.108**	0.070	**0.115**	0.013	**-0.122**	0.060			**0.103**	0.013	**-0.069**	0.077
Patent Protection	0.775	0.113	0.778	0.174	0.843	0.111	**1.015**	0.064	0.732	0.152	**0.697**	0.001
Patents in chemical / electrotechn. industries (%)	**15.04**	0.000	**20.011**	0.000	**17.71**	0.000	**19.51**	0.000	**16.165**	0.000	**15.15**	0.000
Institutional constraint on executive	0.014	0.854	0.022	0.794	-0.002	0.985	0.034	0.689	0.001	0.995	**0.067**	0.046
GDP per capita (Log)	0.677	0.246	1.049	0.127	0.806	0.201	**1.413**	0.021	0.908	0.139	**1.239**	0.000
War opponent	**-0.405**	0.077	**-0.396**	0.079	**-0.551**	0.083	**-0.782**	0.040	**-0.648**	0.043	**-0.942**	0.039
Post1918 * war opponent			**-1.229**	0.087					**-1.320**	0.034	**-2.093**	0.010
Pre1914 * war opponent			0.478	0.407					0.315	0.540	0.901	0.136
Dummy 1880-84	**4.294**	0.000	**1.440**	0.054	**4.220**	0.000	**4.412**	0.000	**3.020**	0.000	**11.889**	0.000
Dummy 1885-89	**0.751**	0.000	**1.967**	0.007	**4.658**	0.000	**4.826**	0.000	**3.519**	0.000	**11.707**	0.000
Dummy 1890-94	**4.889**	0.000	**2.100**	0.004	**0.801**	0.000	**4.947**	0.000	**3.658**	0.000	**12.052**	0.000
Dummy 1895-99	**5.418**	0.000	**2.674**	0.000	**5.321**	0.000	**5.438**	0.000	**4.217**	0.000	**11.907**	0.000
Dummy 1900-04	**4.930**	0.000	**2.155**	0.002	**4.816**	0.000	**4.867**	0.000	**3.714**	0.000	**12.315**	0.000
Dummy 1905-09	**3.141**	0.000	**2.922**	0.000	**5.540**	0.000	**5.553**	0.000	**1.947**	0.002	**6.966**	0.000
Dummy 1910-13	**4.734**	0.000	**3.168**	0.000	**7.879**	0.000	**7.863**	0.000	**7.472**	0.000	**7.037**	0.000
Dummy 1914-18	**-1.839**	0.000	**-1.434**	0.053	**-1.315**	0.071	**-1.310**	0.074	**-1.344**	0.067	**-2.041**	0.000
Dummy 1919-23	-0.129	0.850	-0.094	0.942	-0.060	0.932	0.021	0.977	**-0.650**	0.825	-0.394	0.207
Dummy 1924-28	-0.042	0.951	-1.403	0.957	-0.038	0.957	-0.023	0.974	**-0.565**	0.391	-0.298	0.328
Dummy Europe	0.308	0.874	-0.203	0.926	0.028	0.990	0.447	0.845	0.233	0.906	-0.510	0.555
Dummy North America	1.444	0.257	1.546	0.271	1.652	0.242	**2.422**	0.097	1.347	0.284	-0.102	0.833
Dummy Asia	1.534	0.314	0.815	0.637	1.297	0.440	1.070	0.547	1.335	0.387	1.318	0.119
Dummy Latin America	0.804	0.512	0.452	0.744	0.540	0.691	0.150	0.916	0.821	0.507	0.226	0.674
Constant	**-13.51**	0.093	**-8.301**	0.365	-12.19	0.166	**-18.97**	0.035	-12.19	0.137	**-17.59**	0.000
R^2 (overall)	0.635		0.564		0.677		0.664		0.575		0.968	
N	594		594		594		594		594		297	

Note: P-values in italics. Shading indicates statistical significance at 0.10-level.
Data sources: see Table 3.5 and 3.6.
Dummy Variables**:**
Dummy 1919-32 (Reference Category).
Dummy Europe: uk, fr, ch, at, se, nl, it, se, ru, dk, hu, cz, ie, es, lu, no, ro, hr, fi, pl, si ba, bg, gr, pt.
Dummy Northern America: us, ca. Dummy Asia: hk, cn, in, jp, id, vn, tr, lk, th.
Dummy Latin America: ar, gt, br, mx, bo, cl, co, cr, cu, jm, ni, tt, pe. Dummy Australia: au, nz (Reference Category)

3.7 Conclusion

Weimar Germany had to cope with the aftermath of WWI that included payment of war reparations to Britain and France imposed by the Treaty of Versailles, internal conflicts, and the hyperinflation in 1923. Consequently, actors on the world markets were highly sceptical about Germany's economic prospects in the post 1918 phase. The market for patent rights was also affected. First, it was extremely difficult for inventors to evaluate the possibilities of establishing commercial operations with German companies after filing a patent directly after the end of WWI. Second, the expected future returns of those commercial relations were highly unpredictable. Nevertheless, interwar Germany attracted firms and individuals from twenty-seven countries who held 27,157 high-value patents between 1919 and 1932. Except for the mid-twenties, international patents grew steadily. Moreover, the foreign participation in all high-value patents amounted less than 15% in 1919 reaching its peak by 1924 with a share of more than 35 per cent.

In our analysis, we tested the patenting behaviour in general and in particular of Germany's war opponents in comparison to its confederates and neutral states during the three turbulent phases 1919-32. We were thus interested if warfare was hindering especially inventors from Allied countries to hold German patents due to economic and political conflicts and ongoing enmities. Was it more likely that inventors from all countries behaved rationalistic and sought protection in those countries where they feared a high risk if imitation of their inventions? Furthermore, we compared our results to the pre-1914 phase and analysed whether first signs of differences in patenting behaviour between the Central and Allied powers were visible already before the outbreak of WWI. Beyond the focus on the performance of war opponents, we were analysing factors such as schooling, the existence of patent protection in the native country, and industrial structure on the endogenous patent variable.

Our cross-sectional and panel regressions led to the following results:

1. Basic education proxied by primary schooling was despite its strong positive influence on the number of high-value patents less substantial for the propensity to patent in Weimar Germany than during the high industrialisation pre-1914 period.
2. Control variables like distance, language, share of chemical and electrotechnical patents showed in most cases their expected signs and sizes and turned out to be quite robust.
3. For the first time, we developed a patent deflation method to control for the exemption of patent fees during WWI and the hyperinflation which definitely caused more patents and further prolongation than in a counterfactual situation. In all our regressions, we obtained higher regression coefficients, lower p-values, and higher overall fits for the most important variables for deflated high-value patents than for nominal patent numbers. Therefore, we are convinced about the validity and application possibilities of the deflator for future use.
4. Allied and their associated countries were patenting less in comparison to countries that were not involved in WWI in the post 1918 period. We showed that the decline in high-value patents was a post-war phenomenon as war opponents did not reduce their patenting activities during the initiation phase of the First World War.
5. We are able to corroborate our hypothesis. Economic, political conflicts and ongoing enmities had a negative impact on the number of high-value patents held in Weimar Germany. In addition, psychological barriers and trauma proxied by casualties of war reduced patenting activities of affected countries marginally. At the same time, Germany’s wartime allies or neutral states were not inhibited and might have pursued

patenting in Germany without considerable delay. Consequently, inventors from those countries had the chance to gain time and exploit first mover advantages.

B. Appendix to chapter 3

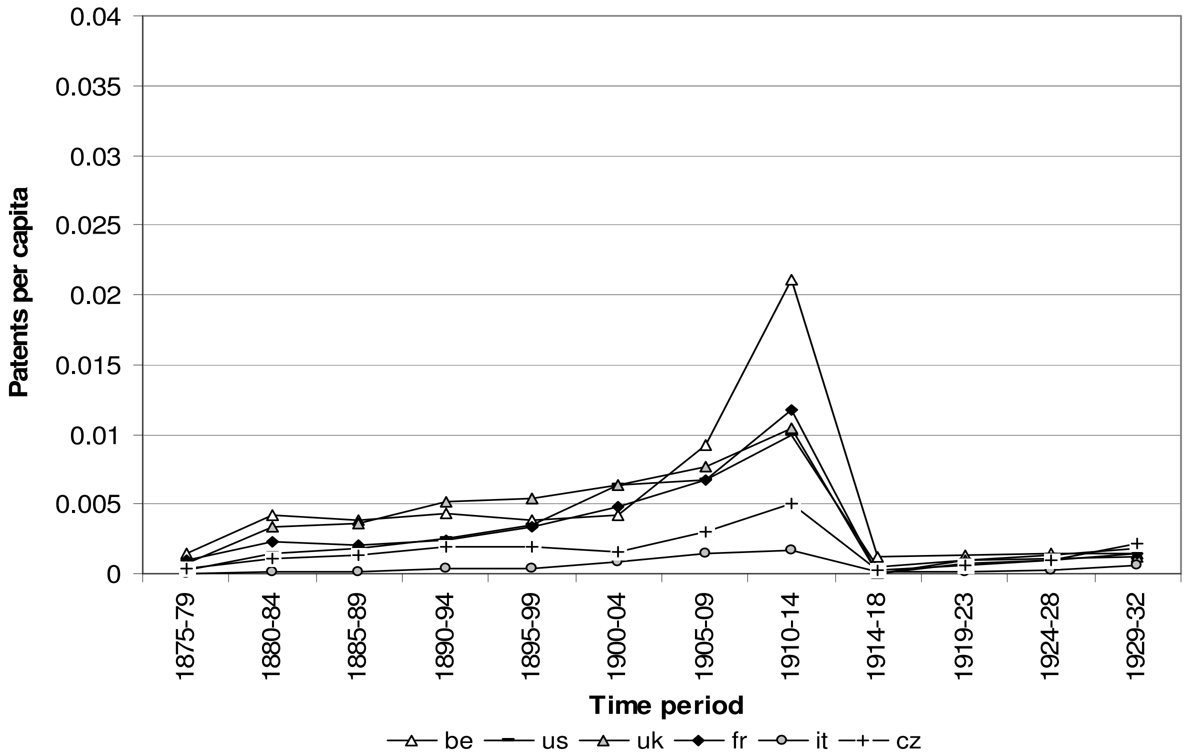
B.1 Tables and figures.

TABLE 3.8: THE MOST FREQUENTED PATENT CLASSES 1919-32

Rank	Class	Number of all high-value patents	Share in all high-value patents	Cumulated shares	Class	Number of foreign high-value patents	Share in foreign high-value patents	Cumulated shares
1	21 Electrical Engineering	3168	11.66	11.66	21 Electrical Engineering	619	9.90	9.90
2	12 Chemicals (without Dyes)	1812	6.67	18.33	12 Chemicals (without Dyes)	285	4.56	14.45
3	42 Scientific instruments	986	3.63	21.96	15 Printing	271	4.33	18.78
4	47 Machine parts	816	3.00	24.96	46 Internal combustion engines	249	3.98	22.77
5	20 Railway installations	766	2.82	27.78	52 Sewing	236	3.77	26.54
6	15 Printing	722	2.66	30.44	42 Scientific instruments	216	3.45	29.99
7	49 Metal processing	665	2.45	32.89	63 Saddlery	199	3.18	33.17
8	46 Internal combustion engines	591	2.18	35.06	47 Machine parts	192	3.07	36.24
9	22 Dyes	590	2.17	37.23	43 Control equipment	188	3.01	39.25
10	63 Saddlery	546	2.01	39.24	20 Railway installations	138	2.21	41.45
11	81 Transportation	508	1.87	41.11	72 Firearms	112	1.79	43.25
12	45 Agriculture	447	1.65	42.76	71 Footwear	109	1.74	44.99
13	57 Photography	430	1.58	44.34	22 Dyes	96	1.53	46.52
14	30 Health care	428	1.58	45.92	14 Steam engines	95	1.52	48.04
15	8 Dyeing	405	1.49	47.41	49 Metal processing	94	1.50	49.54

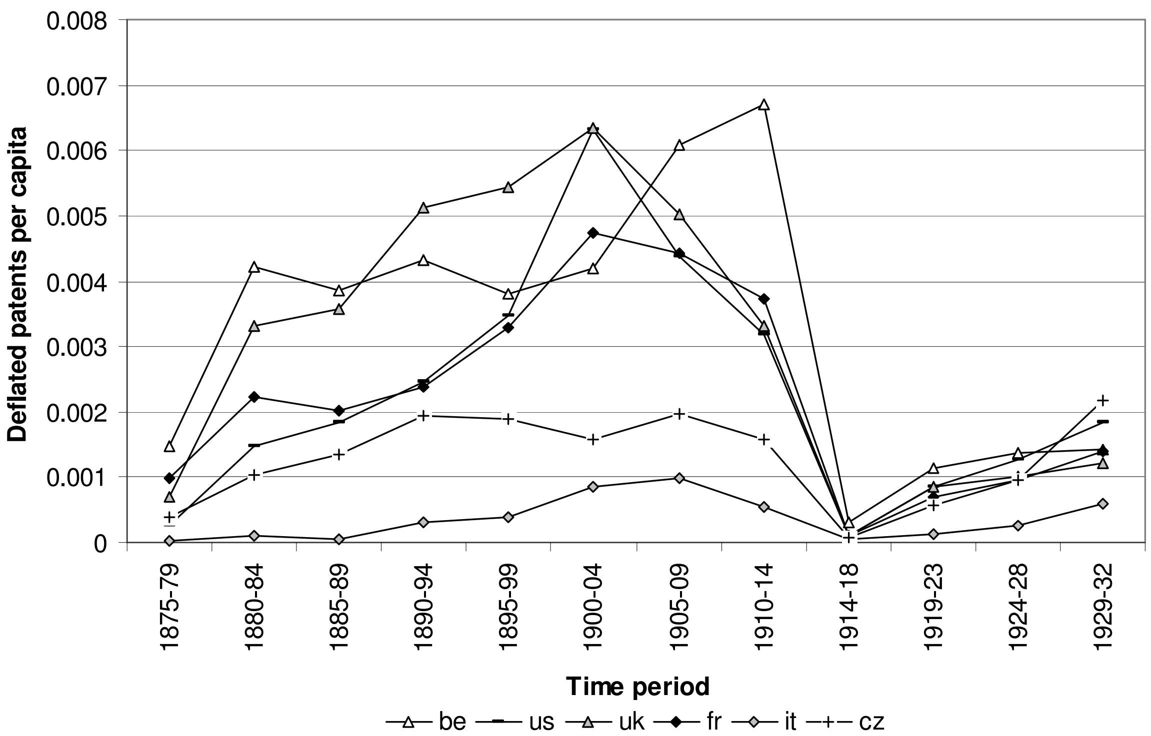
Note: All patents, either national or international, were allocated to 89 patent categories. These categories correspond broadly to the industry that supposedly uses the given invention and not to the industry in which the invention was developed.

FIGURE 3.11: PATENTS PER CAPITA OF WAR OPPONENTS



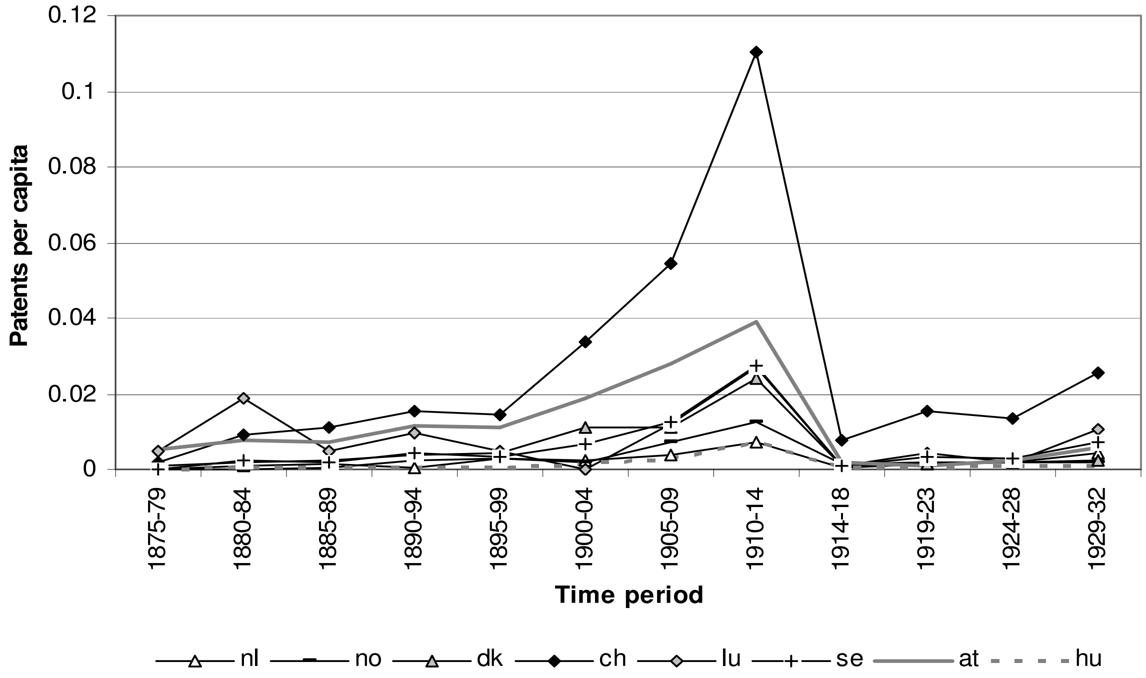
Data source: see Table 3.1.

FIGURE 3.12: DEFLATED PATENTS PER CAPITA OF WAR OPPONENTS



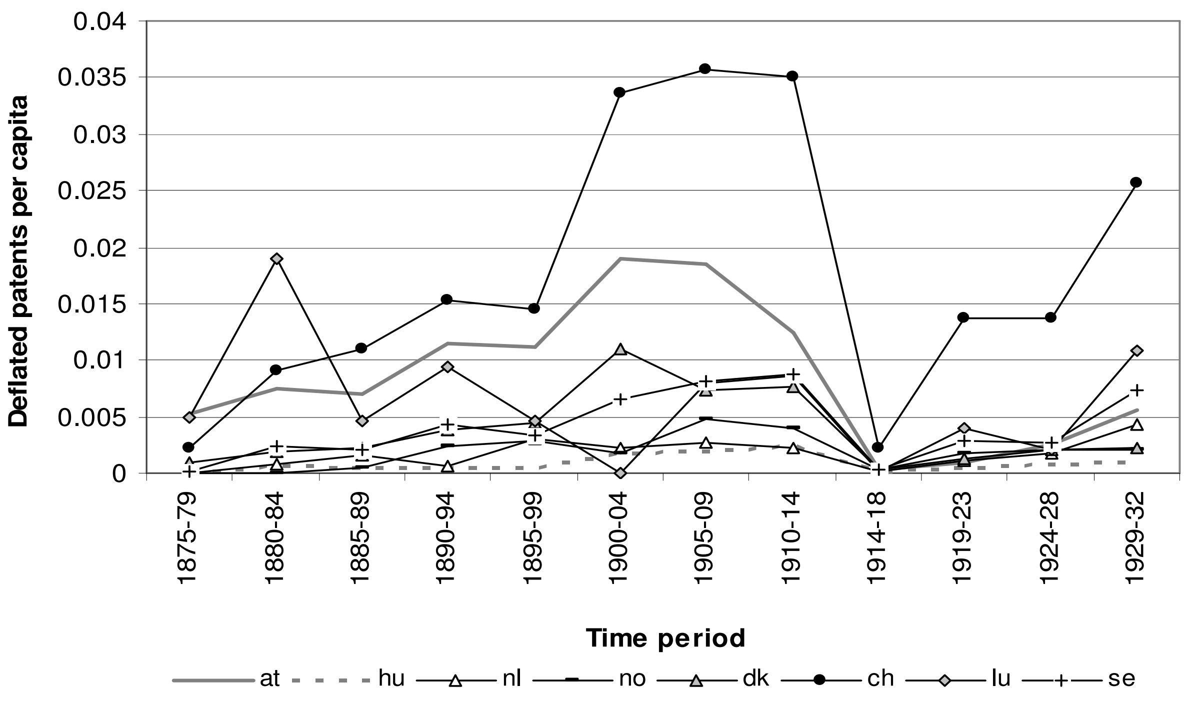
Data source: see Table 3.1.

FIGURE 3.13: PATENTS PER CAPITA OF NEUTRAL STATES AND CENTRAL POWERS



Data source: see Table 3.1.

FIGURE 3.14: DEFLATED PATENTS PER CAPITA OF NEUTRAL STATES



Data source: see Table 3.1.

B.2 Internet abbreviations for countries

ar - Argentina
at - Austria
au - Australia
ba - Bosnia
be - Belgium
bg - Bulgaria
bo - Bolivia
br - Brazil
ca - Canada
ch - Switzerland
cl - Chile
cn - China
co - Columbia
cr - Costa Rica
cu - Cuba
cz - Czech
dk - Denmark
es - Spain
fi - Finland
fr - France
gr - Greece
gt - Guatemala
hk - Hong Kong
hr - Croatia
hu - Hungary
id - Indonesia
ie - Ireland
in - India
it - Italy
jm - Jamaica
jp - Japan
lk - Sri Lanka
lu - Luxemburg
mx - Mexico
ni – Nicaragua
nl - Holland
no - Norway
nz - New Zealand
pe - Peru
pl - Poland
pt - Portugal
ro - Romania
ru – Russia
se - Sweden
si - Slovenia
th - Thailand
tr - Turkey
tt - Trinidad and Tobago
uk - United Kingdom
us – U.S.
uy - Uruguay
vn - Vietnam

4 On the persistence of human capital effects: Human capital in 1910 and welfare levels in the late 20th century

4.1 Abstract

We apply a new measure of human capital, which also takes into account its technical component, to the hypothesis that human capital levels in 1910 had a strong persistent effect on national income until the late 20th century (and perhaps even longer). Controlling for GDP/c in 1910, we find that the impact of human capital on income was mostly significant. Growth successes of the 20th century such as Japan or the Scandinavian countries were also based on their early human capital formation.

Chapter is based on a working paper, see Labuske and Baten (2007). The concept for the paper was developed jointly, the analyses and writing was equally shared.

4.2 Introduction

In this chapter, we suggest new human capital estimates based on two equally weighted measures: the number of foreign high-value patents in Germany adjusted for distance and language, and Lindert's (2004a) primary schooling rates for fifty-one countries for the period 1880-1914. It is clear that we need to control for a number of other factors if our human capital measure serves as a predictor for GDP/c levels and growth rates in our cross-sectional regressions.

In chapter two, we already developed and explained those adjusted patent rates. We argue that the residual after controlling for distance and same language measures a country's propensity to innovate. This adjustment accounts for the fact that neighbouring countries with a common language and / or cultural background tended to have more patents in Germany. By making this adjustment, a higher propensity to patent due to cultural similarities or geographical proximity is cancelled out. There, we also compared the number of patents in detail with other measures of human capital components and proxies, such as schooling-rates and literacy, in order to assess the plausibility of those estimates, which was clearly given.

The aim of this chapter is to investigate whether our newly created human capital measure in 1910 had a strongly persistent effect on national income until the late 20th century (and perhaps even longer). Therefore, we regress annual growth rates of real GDP/c in 1950-55 and 1955-60 as well as levels of real GDP/c in the quinquennials between 1950 and 1989 on various exogenous variables known in the literature from Barro's growth regressions (Barro, 1991).

4.3 Estimation of human capital formation

Our new estimates on human capital formation in fifty-one countries in 10-year-intervals are shown in Table 4.1. As already mentioned above, this data is based both on our patent-based measure for technical human capital and on the Lindert (2004a) figures on enrolment (plus our interpolations, marked with a star).

By now there is a large growth literature showing the relevance of Human Capital in endogenous growth models. Amongst many others, Barro and Sala-i-Martin (2004), Griliches (1997), and Romer (1990) emphasise human capital as a key factor for economic growth. Human capital pushes ideas as well as the development and adaptation of new products that lead to technological change. Thus, economies with a higher initial human capital stock are able to implement new products faster on the markets and as a result show higher growth rates. Barro (1991, 1999, 2001) emphasises the strong financial and provisional involvement of governments in school systems at all levels. Thus, human capital accumulation is influenced by public policies.

We would argue that our patent-based component has the advantage to measure cases in which enrolment rates might not capture the "true" human capital formation because of unusually high or low government expenditure for education. In order to obtain “enrolment equivalents”, we saved the predicted values from a regression of enrolment rates on the adjusted patent rates. Hence, we obtain an adjusted measure for the innovativeness of a country’s industry. In the next step, we calculated the averages between those predicted values and primary school enrolment rates.

In Table 4.1, we observe the U.S., Australia, Canada, Sweden, and Denmark leading regarding our definition of human capital in 1910. Finland had an especially strong improvement in human capital. Its inhabitants were quite active in patenting in Germany, which suggests that technical human capital was quite substantial. But Finland was disadvantaged because the Russian Empire was ruling Finnish education and under-invested in education in the Finnish territory relative to its potential. On the other hand, the Habsburg Empire spent much on education in the Czech, Croatian, Slovenian and Bosnian parts of its Empire. Enrolment rates were probably relatively high, given the state of economic development of the latter three territories. Good (2003) argued that the Habsburg Empire shifted government expenditure to the minority regions in order to constrain political upheaval. In contrast, the latter three territories had very few important patents in Germany; this reflects the human capital formation better than the enrolment rates alone. Hence, we find that our adjusted patent indicator expands our knowledge of this important indicator in a crucial phase of world development.

TABLE 4.1: ESTIMATED HUMAN CAPITAL FORMATION, BASED ON PATENTS IN GERMANY AND ENROLMENT SHARES

Country	**1882**	**1890**	**1900**	**1910**
Us	61.30	96.34	89.66	87.40
Nz	41.29	46.68	47.57	[83.46]+
Au	44.22	75.43	68.04	74.43
Ca	37.39	65.96	70.47	72.11
Se	47.51	64.72	61.02	65.50
Dk	34.47	54.51	61.06	59.72
No	25.65	52.44	50.77	59.66
Fr	43.90	49.58	56.53	58.99
At	42.42	61.52	60.20	55.53
Ch	46.91	64.19	62.22	55.30
uk	37.88	50.95	54.49	54.41
Lu	38.82*	38.14*	20.79*	49.19*
Be	34.15	33.81	41.91	48.18
Nl	32.91	31.94	42.35	47.92
Jp	24.28	27.43	32.85	47.52
Ie	31.72	45.59	45.65	47.25
Gt	24.61*	30.36	25.87*	43.81*
Tt	18.65*	29.11	32.49	42.00
Hu	31.95	35.45	42.36	41.75
Cz	32.74*	41.46*	40.89*	41.06*
It	24.52	29.63	35.35	40.68
Es	29.60	31.44	24.50	39.15
Pl	29.68*	35.81*	36.17*	37.89*
Cl	15.05	20.84	23.65	34.90
Jm	25.03	31.48	32.36	34.09
Ar	16.99	24.26	41.37	33.78
Si	21.70*	18.57*	22.53*	33.33*
Ba	16.01*	14.03*	17.22*	32.73*
Hk	21.83*	26.37*	27.87*	32.25*
Fi	9.96	10.00	25.68	31.87
Hr	18.21*	15.62*	18.84*	31.54*
Ro	16.81*	15.34	23.77	31.16
Cu	26.47*	26.90*	27.75	30.23
Uy	14.00*	19.51*	21.56	28.51
Cr	22.82	16.95	23.44	28.46
Ru	12.84*	12.68	19.57	27.04*
Lk	16.67*	17.45*	18.83*	26.18*
Bg	14.49*	14.59	20.28	25.97
Co	19.92	14.99*	20.47*	24.77*
Gr	18.43	17.53	20.72	24.13
Br	11.58	11.78	14.68	24.08
Mx	19.00	19.22	19.87	22.24
Ni	11.11*	16.12*	17.49*	21.90*
Bo	11.56*	15.39*	17.37	21.58*
Tr	7.68*	7.17*	8.23*	20.32*
Cn	13.09*	13.80*	15.29*	19.38*
Pt	13.24	13.53	17.29	18.57
Vn	10.70*	10.91*	10.98*	14.55*
Id	11.10*	11.77*	11.59*	13.59*
In	8.58	8.68	9.45	12.49
Th	8.58*	8.99*	9.52*	12.47*

Note: Transformed into enrolment share equivalents; For country abbreviations see appendix C.2.
* Interpolated values. For interpolation decisions see appendix C.1.
+ Possibly over-adjustment due to distance.
Data Sources: Patents: Verzeichnis der von dem kaiserlichen Patentamt im Jahre 1875-1918 erteilten Patente.

4.4 Impact on long-run growth: path dependency of human capital?

In this section, we will assess the impact of our new human capital measure on long-run economic growth. We seek to explain the rate of growth of per capita GDP between 1950-55 and 1955-60, as well as the GDP levels per capita between 1950 and 1989 with our variable "human capital formation 1910", which is based on patents in Germany and schooling. Also Barro (1991) found a positive impact of initial human capital (proxied by schooling rates 1960) on the growth rate of real GDP per capita 1960-85. Our question is, however, whether the stock of human capital has only short-run effects or whether a long-run impact can be discovered.

Explaining the relationship between human capital and economic growth requires a model that controls for other potential growth factors. Hence, we included GDP levels per capita 1910 (natural logarithm), Barro's (1991) political instability variables, and his market distortion variable (magnitude of the deviation of PPP value for the investment inflator from the sample mean) in our regression models. Furthermore, we account for institutional constraint on the executive, the land-labour-ratio, and the coast-land-ratio.

There is broad evidence that the GDP per capita growth is inversely related to the initial level of GDP per capita. According to the conditional convergence effect, cited for example in Barro (1999, 2001, 2003), countries or regions with a low level of per capita GDP relative to the long-run or steady state position, are growing faster than those with a higher initial income level. Consequently, former laggards might catch up the level of countries and regions with a higher initial per capita GDP after a certain time.

Barro (1991) also found that growth rates are inversely related to the purchasing-power-parity numbers for investment goods, economies with more extensive market distortions grow slower. He argues that market distortions of market prices are especially considerable if they apply to capital goods due to the direct connection between investments and growth.

The number of assassinations per million population per year and the number of revolutions and coups per year are proxies for political instability. Barro (1991) argues that both variables have a negative impact on property rights and thus also a negative impact on investments and economic growth. The constraint on the executive powers to expropriate capital is an indicator developed by Acemoglu et al. (2002). The institutional quality indicator is coded on a seven point scale, running from one (there are no regular limitations) until seven (accountability groups have effective authority equal to or greater than the executive in most activities). Consequently, lower numbers denote weaker institutions. Knack and Keefer (1995), Acemoglu et al. (2002, 2004), Easterly and Levine (2003) found evidence that political institutions that are hindering the executive powers from expropriation are stimulating economic growth.

The variable land-labour-ratio measures differences of a country's relative endowment of land and labour. Rogowski (1987) emphasises that no country can be rich in both factors. He distinguishes between advanced and backward economies: capital is abundant in advanced economies and scarce in backward economies. A low land-labour ratio in advanced economies implies that land is scarce and capital labour is abundant (high: capital land is abundant and labour poor). Conversely, if capital land is scare and labour abundant, backward economies exhibit a low land-labour ratio (high: land is abundant and capital labour poor).

The coast-land-ratio measures a country's coastline relative to its surface area. The higher the value, the higher is the country's coastline in relation to the land in square kilometres[47] and the better the export possibilities by water. Coastal access matters for internal trade and the bigger the coast, the lower the transport costs. Usually, navigable rivers flow into coasts and simplify trade possibilities further. Also Gallup et al. (1998) found that landlocked countries have lower incomes than countries with larger coasts. Analysing the GNP per capita of all countries with a population above one million in 1995, he found that almost all landlocked countries in the world are poor. Exceptions are some western counties like Switzerland that are well integrated into Europe regarding trade.

Table 4.2 contains regression results for annual growth rates of real per capita GDP 1950-55 and 1955-60 for fifty-one countries. We have chosen 1950-60, because this was the first relatively stable period after WWII. The growth rate of real per capita GDP 1950-55 is negatively related to the initial level of real per capita 1910 and positively related to human capital formation proxied by our patent and schooling based variable. Only in the extensive model in 1950-55, we could not prove a significant impact of our human capital measure on GDP growth. In all of the remaining regressions, we obtain statistically significant (0.05-level) coefficients for human capital. A one per cent increase of human capital formation in 1910 caused a 0.11-0.12% higher growth rate of per capita GDP in 1950-55 and a 0.17-0.18% per capita GDP growth in 1955-60. This result is also interpretable by the convergence hypothesis: if the initial level of GDP per capita is low relative to the base level of our human capital variable, the growth rate of GDP per capita increases. However, Barro (1991) numbers of yearly assassinations per million population had an expected negative, but insignificant impact on per capita growth between 1950-55 and 1955-60. The number of yearly revolutions and coups is assumed to influence property rights and consequently to have an impact (negative) on growth and investment. This could not be proven on the basis of our data. In those regressions where we controlled for institutions, a statistical impact on per

[47] Data are taken from CIA (2005).

capita growth is not demonstrable. We would like to stress the positive impact of a country's relative endowment of land and labour, which was significant in 1955-60 and not far away from significance in 1950-55: The higher the factor land in relation to the factor labour, the higher was the GDP per head growth rate between 1950 and 1960. Nevertheless, as indicated by the size of the regression coefficient (0.002), the impact of the land-labour-ratio on GDP/c growth was rather small.

TABLE 4.2: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF PER CAPITA GROWTH 1950-55 AND 1955-60

	1950-55						1955-60					
GDP per capita 1910 (logarithm)	**-0.018**	*0.093*	**-0.014**	*0.086*	-0.011	*0.165*	**-0.032**	*0.001*	**-0.026**	*0.001*	**-0.024**	*0.001*
Human capital 1910 (logarithm)	0.108	*0.214*	**0.121**	*0.041*	**0.124**	*0.037*	**0.182**	*0.015*	**0.169**	*0.002*	**0.172**	*0.002*
Deviation of PPP	-0.001	*0.987*					-0.006	*0.661*				
Assassinations	-0.002	*0.785*					-0.004	*0.576*				
Revolutions and coups	0.002	*0.880*					0.008	*0.629*				
Institutional constraint on executive	0.001	*0.527*	0.002	*0.202*			0.001	*0.546*	0.002	*0.300*		
Land-labour-ratio (logarithm)	0.001	*0.108*					**0.002**	*0.023*				
Coast-land-ratio (logarithm)	0.001	*0.922*					0.001	*0.608*				
Constant	0.184	*0.107*					0.147	*0.121*				
Adj. R^2	0.179		0.119		0.088		0.400		0.229		0.211	
N	51		51		51		51		51		51	

Notes: P-values in parenthesis. Shading indicates statistical significance at a 0.10-level.
Data sources:
GDP per capita 1910: Maddison (1995)
Human Capital Formation: see Text.
Deviation of PPP, Assassinations, Revolutions and coups: Dataset used in Barro (1991)
Institutional Constraint on Executive: Acemoglu et al. (2002).
Coast-Land-Ratio (own calculation): CIA (2005).
Land-Labour-Ratio (own calculation): Land: CIA (2005), Labour: Mitchell (1980), Mitchell, (1993), Mitchell (1998).

In addition to the regressions of growth rates above, we are also interested in explaining the level of real GDP per capita (logarithm) in the quinquennials between 1950 and 1989 with GDP per capita in 1910 (logarithm) and the variables from the growth regressions above. The most interesting result of Table 4.3 is the strong positive (statistically significant on 5%-level) impact of the patent- and schooling-based human capital variable on GDP per capita between 1960-85 even after controlling for the level of GDP per capita and the other exogenous variables. Of course, GDP per capita in 1910 has a positive effect on later GDP per capita (between 1960-89), which is significant on the 10%-level between 1960 and 1975.

The market distortion variable (magnitude of the deviation of PPP value for the investment inflator from the sample mean) has a significantly positive effect at least at the 5%-level on GDP per capita. The size of the regression coefficients of this market distortion variable was much higher in the quinquennials 1950 and 1955 (4.626 and 5.523) than in the following decades (varies between 1.089 and 1.333). Unlike the growth regressions, we found a significant negative impact of the number of revolutions and coups on the GDP level in 1955. It seems that political instability affected the level of income, at least in this regression. All other exogenous variables had an insignificant influence on the regressand. In general, we obtain a quite high goodness of fit in all the regressions in Table 4.3 ($0.657 < R^2 > 0.995$).

TABLE 4.3: CROSS-SECTIONAL ESTIMATION RESULTS: DETERMINANTS OF LOG. GDP PER CAPITA 1950-85

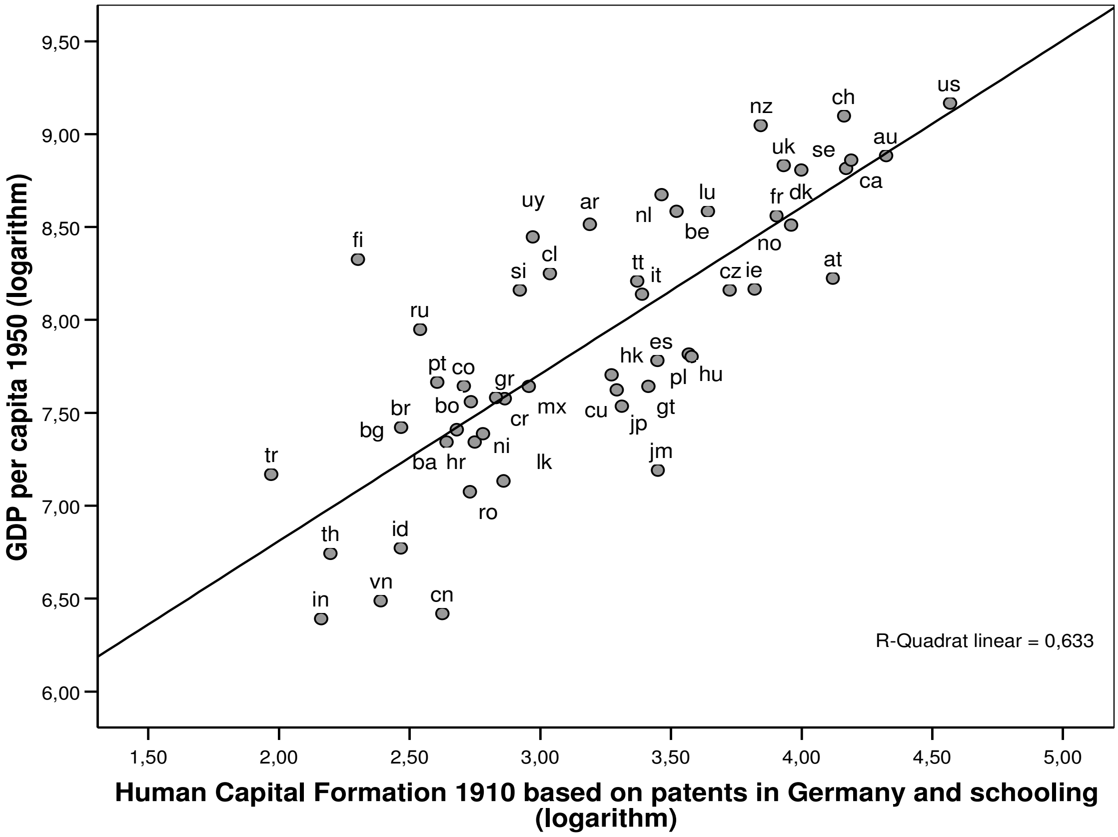
	1950		1955		1960		1965		1970		1975		1980		1985	
GDP per capita 1910 (logarithm)	0.707	*0.563*	0.387	*0.717*	**0.348**	*0.040*	**0.294**	*0.090*	0.237	*0.181*	*0.209*	*0.231*	**0.157**	*0.415*	**0.132**	*0.504*
Human capital 1910 (logarithm)	-5.283	*0.604*	-4.323	*0.627*	**3.839**	*0.008*	**4.205**	*0.005*	**4.258**	*0.005*	***3.822***	*0.011*	**4.082**	*0.014*	**3.718**	*0.028*
Deviation of PPP	**4.626**	*0.019*	**5.523**	*0.002*	**1.089**	*0.000*	**1.107**	*0.000*	**1.115**	*0.000*	**1.171**	*0.000*	**1.140**	*0.000*	**1.333**	*0.000*
Assassinations	-0.255	*0.774*	-0.245	*0.753*	-0.088	*0.465*	-0.118	*0.345*	-0.144	*0.261*	*-0.159*	*0.211*	-0.190	*0.180*	-0.224	*0.123*
Revolutions and coups	-3.330	*0.146*	**-4.161**	*0.040*	0.087	*0.776*	0.117	*0.712*	0.157	*0.629*	*0.132*	*0.680*	0.210	*0.556*	0.060	*0.869*
Institutional constraint on executive	0.187	*0.425*	0.174	*0.394*	0.024	*0.456*	0.029	*0.374*	0.029	*0.389*	*0.033*	*0.320*	0.034	*0.357*	0.038	*0.318*
Land-labour-ratio (logarithm)	0.069	*0.463*	0.033	*0.688*	-0.008	*0.520*	-0.005	*0.721*	0.001	*0.946*	*0.008*	*0.571*	0.007	*0.596*	0.015	*0.340*
Coast-land-ratio (logarithm)	-0.144	*0.306*	-0.156	*0.203*	0.013	*0.479*	0.015	*0.429*	0.015	*0.465*	*0.011*	*0.566*	0.015	*0.490*	0.016	*0.467*
Constant	4.361	*0.741*	5.590	*0.628*	**-8.427**	*0.000*	**-8.485**	*0.000*	**-7.935**	*0.000*	***-6.798***	*0.001*	**-6.730**	*0.002*	**-5.801**	*0.009*
Adj. R^2	0.658		0.738		0.992		0.994		0.992		0.993		0.993		0.990	
N	51		51		51		51		51		51		51		51	

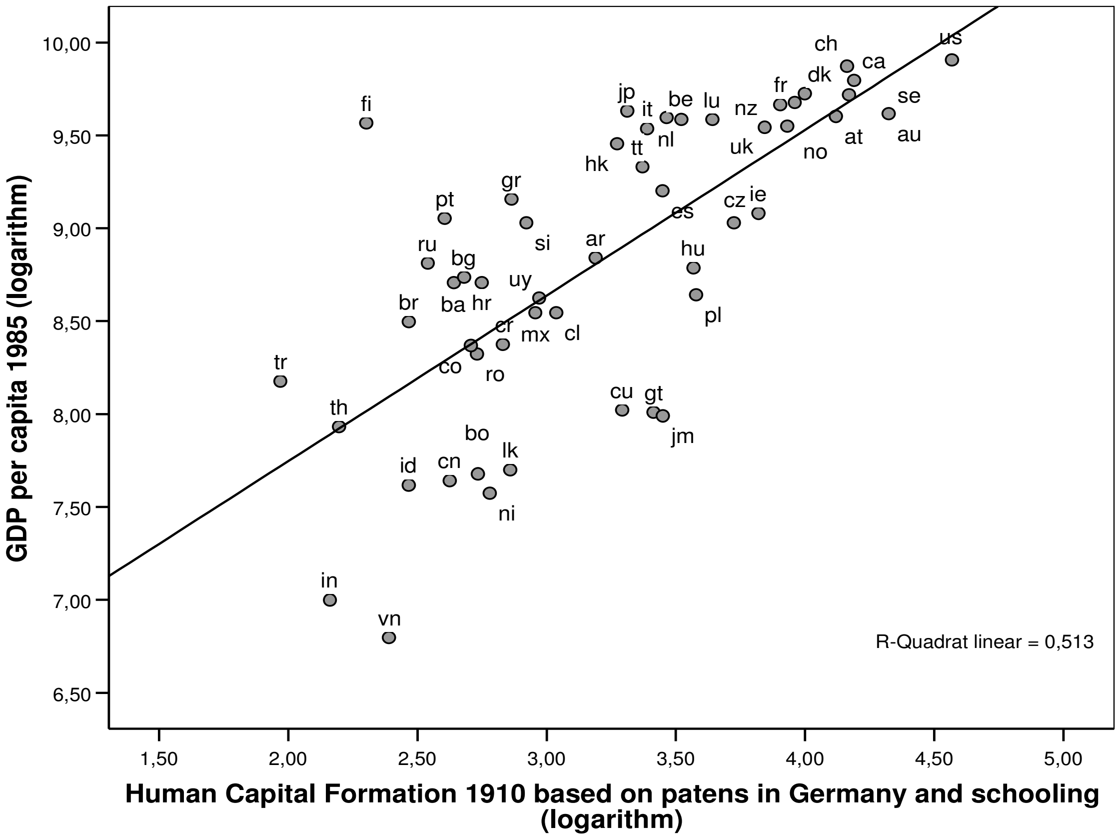
Data sources: see Table 4.2.

In order to explore the impact of our human capital measure on income and to differentiate between countries over time, Figure 4.1 shows the GDP per capita in 1950 (1980) plotted in a scatter gram against our human capital variable (based on patents and schooling) in 1910. We can also see the positive and linear relationship between GDP per capita and human capital formation. The U.S. is at both points the country with the highest GDP per capita and the highest level of human capital in 1910. We stress that they were also leaders in terms of their numbers of adjusted patents per capita as of 1910.

Finland exhibited a relatively high income in 1950 and 1985 despite a relatively low level of Human Capital in 1910. Some European countries, like Spain, Norway or Ireland, remained close to the average over time, whereas India, Vietnam or Thailand were the laggards in respect to their GDP per capita in 1950 and 1980, and their status of human capital in 1910. The GDP per capita rose in all countries in this period, but it is interesting to see which countries were able to use their high level of human capital in 1910 to make substantial progress between 1950 and 1980. Especially Japan, Spain, Italy, and Portugal rose strongly in rank over time. It is fascinating to see that Japan's welfare level in 1985 can be predicted quite well by our measure of human capital that includes its technical component, whereas Japan's development in the 1950s was often termed a growth miracle. The human capital investments during this early period can explain the development quite well, and it similarly does so for the Scandinavian countries. Bolivia, Uruguay, and Nicaragua experienced the lowest growth rates between 1950 and 1985.

FIGURE 4.1: HUMAN CAPITAL FORMATION 1910 AND GDP PER CAPITA 1950 AND 1980





Data sources: GDP per capita: Maddison (1995), Human Capital, see Table 4.1.

4.5 Conclusion

In this chapter, we generated new estimates for human capital formation between 1880 and 1910 based on Lindert's (2004a) primary schooling data and adjusted patents. These, for example, are due to the adjustment less favourable for the Balkans and the Mediterranean regions, and more favourable for Scandinavia, especially Finland compared with earlier schooling-based estimates. We found that our patent and enrolment-based variable "Human Capital Formation" could explain a substantial share of economic growth even half a century later. There is a strong positive effect of the human capital in 1910 on the level of GDP per capita 1950-85.

Of course, this is a reduced model of human capital path dependency that we estimated here. There were a lot of other developments during this period that would suggest a much weaker relationship between human capital 1910, 1950 and 1980. For example, large migrations took place during and between the war periods (although immigration target societies tended to transfer some of their education to immigrants). Political events interfered, such as the Marshall Plan or the Korean War. Given these distorting developments and events, the influence of human capital on income might have been even stronger in real.

C. Appendix to chapter 4

C.1 Interpolation decisions

Available on http://www.uni-tuebingen.de/wwl/interpolation-decisions.pdf

C.2 Internet abbreviations for countries

ar - Argentina
at - Austria
au - Australia
ba - Bosnia
be - Belgium
bg - Bulgaria
bo - Bolivia
br - Brazil
ca - Canada
ch - Switzerland
cl - Chile
cn - China
co - Columbia
cr - Costa Rica
cu - Cuba
cz - Czech
dk - Denmark
es - Spain
fi - Finland
fr - France
gr - Greece
gt - Guatemala
hk - Hong Kong
hr - Croatia
hu - Hungary
id - Indonesia
ie - Ireland
in - India
it - Italy
jm - Jamaica
jp - Japan
lk - Sri Lanka
lu - Luxemburg
mx - Mexico
ni – Nicaragua
nl - Holland
no - Norway
nz - New Zealand
pe - Peru
pl - Poland
pt - Portugal
ro - Romania
ru – Russia
se - Sweden
si - Slovenia
th - Thailand
tr - Turkey
tt - Trinidad and Tobago
uk - United Kingdom
us – U.S.
uy - Uruguay
vn - Vietnam

5 Technological creativity and cheap labour? Explaining the growing international competitiveness of German mechanical engineering before World War I

5.1 Abstract

Which factors caused the growing international competitiveness of German mechanical engineering industry in the pre-World War I period? In this chapter, we want to address this question and elucidate whether or not the international market success of machine builders in the German Empire was determined by technological creativity and the availability of a comparatively cheap labour force. Based on an unbalanced panel, we therefore investigate the influence of demand, labour costs and technological creativity on export performance of thirty-two different machinery types. We find robust evidence that the development of export-import ratios in mechanical engineering was positively influenced by the growth of patent stocks that represent the new knowledge being available for German machine builders. In addition, we present some evidence for the assumption that the growing international competitiveness of German mechanical engineering was also caused by decreasing relative unit labour cost.

Chapter is based on an article forthcoming in the German Economic Review, see Labuske and Streb (2008). The concept for the paper was developed jointly, the analyses were done by the author of this thesis, the major part of the paper was written by Jochen Streb.

5.2 Explaining international competitiveness

Can Germany still be saved? Under this provoking heading Sinn (2003) discusses the reasons for the poor economic performance of the contemporary German economy. One of his most important hypotheses is that, in contrast to the situation in the German Empire, industry now lacks both technological creativity and cheap labour (Sinn, 2003, pp. 19, 22, 26, 58). Sinn (2003, p. 67) concludes that contemporary Germany is apparently transforming itself into a "bazaar economy" exporting goods that were not really "made in Germany" but mostly manufactured in low-wage countries of Eastern Europe. During the globalisation period before World War I, on the contrary, German firms seemed to be able to gain international market share by producing comparatively cheap and high-quality products within the borders of their home country.[48] In this chapter we do not question Sinn's diagnosis with respect to contemporary Germany. Instead, we test whether it is true that the growing international competitiveness of firms in the German Empire can be explained by technological creativity and the availability of a comparatively cheap work force.

We focus on mechanical engineering, which, along with chemicals and electrical engineering, was the fastest growing export industry in the German Empire. Figure 5.1 shows that the share of machinery exports in total German exports rose rather slowly rose from 1.3% in 1880 to 2% in 1893, but then fast increased to about 7% on the eve of World War I.[49] As a result, mechanical engineering steadily climbed up the hierarchy of Germany's most important export industries, improving its position from the ninth place

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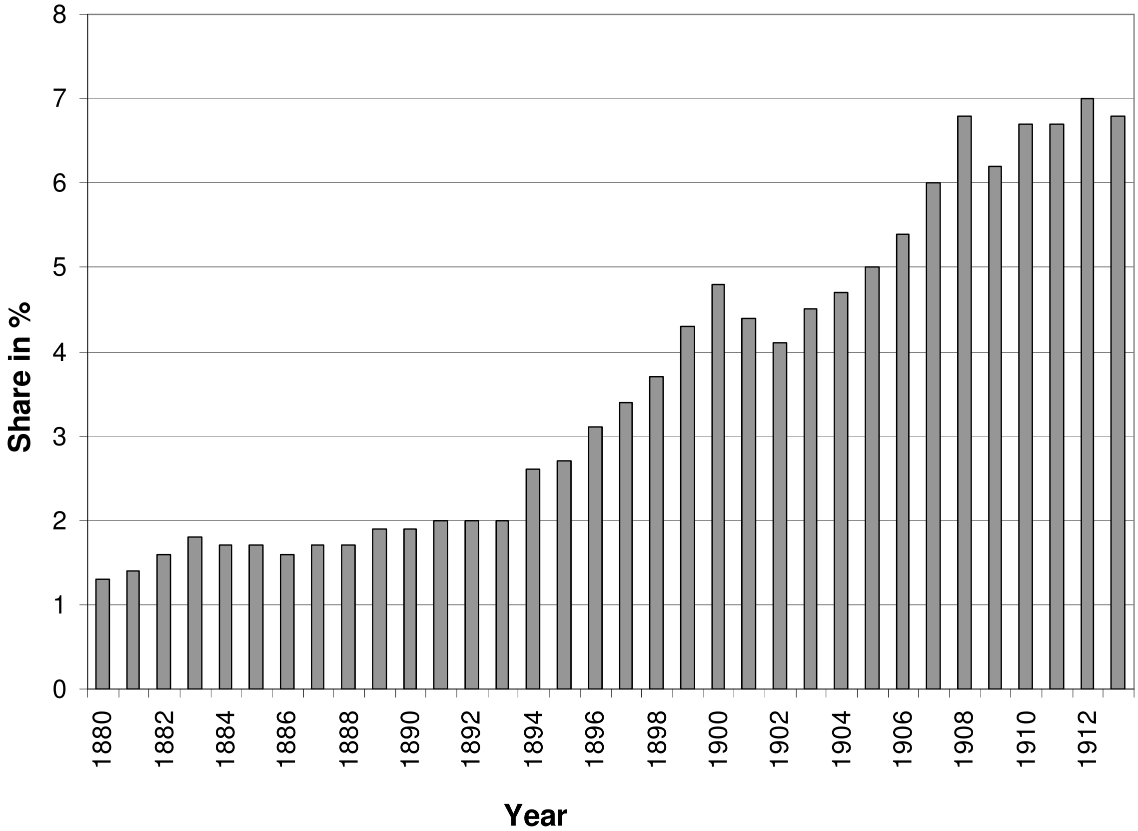
[48] For an overview of the economic history of industrialising Germany see Borchardt (1972), Ogilvie and Scribner (2003), and Tilly (1990).

[49] In Figure 5.1, machinery exports include all types of machines that exceed mere tools except for electrical machines and vehicles. The value of German machinery exports increased fifteen-fold between 1872 and 1911 while total exports tripled in the same period.

in 1891 to the third place in 1905.[50] Between 1906 and 1913, machinery exports were always ranked first in the German export statistic.

FIGURE 5.1: SHARE OF MACHINERY EXPORTS IN TOTAL EXPORTS, GERMANY 1880-1913



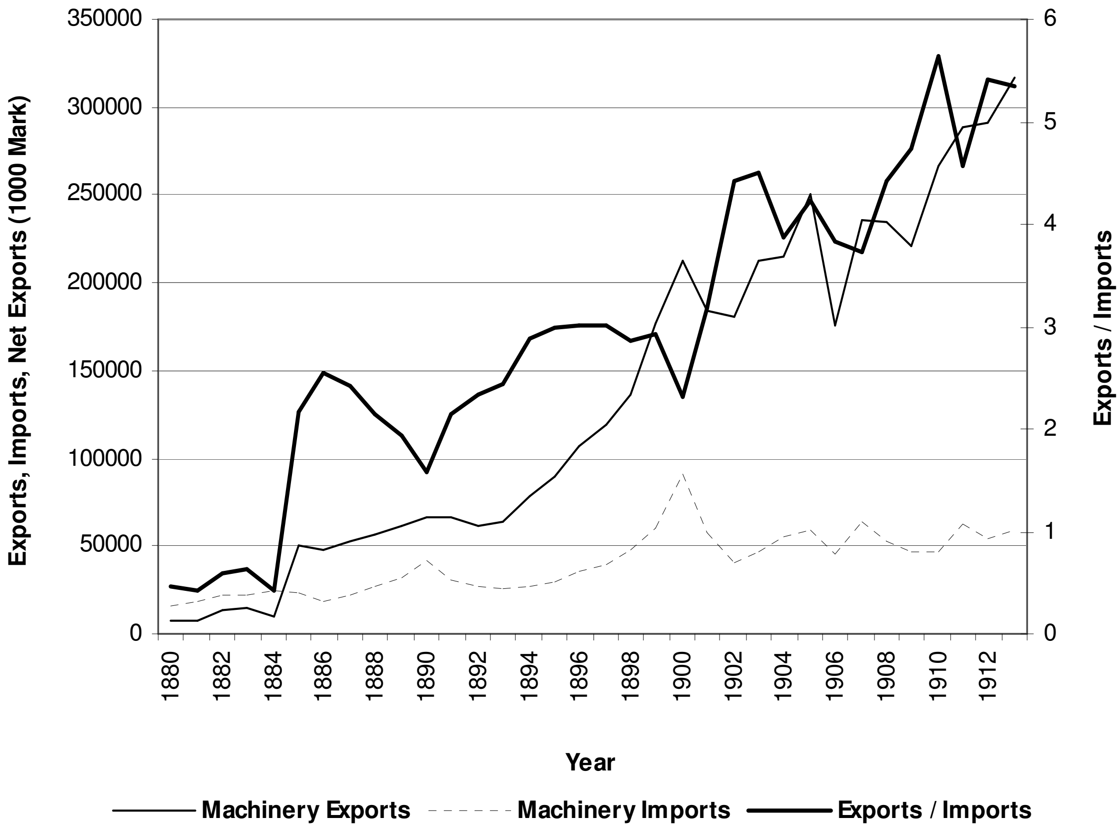
Data sources: Export values measured in current prices. Own calculations, based on: Kaiserliches Statistisches Amt (1881-83), Kaiserliches Statistisches Amt (1884-91, 1908), Kaiserliches Statistisches Amt (1892-1897, 1904, 1906, 1912, 1914).

Figure 5.2 reveals that German machinery exports surpassed imports in 1885. After a two-year-lasting collapse of both quantities during the global economic crisis of 1901/1902, machinery exports returned to their upward trend while machinery imports stagnated on a low level. Consequently, the export-import ratio more than doubled between 1900 and 1913. This development perfectly mirrors the growing international

[50] In 1905, cotton and woollen textiles were ranked first and second with respect to export values.

competitiveness of German mechanical engineering. According to Reitschuler (1963, p. 253), in 1913, Germany was the world's largest exporter in the field of mechanical engineering selling abroad machinery being worth 175.7 million U.S. $ while at the same time the value of machinery export was 162.1 million U.S. $ for the United States and 171.7 million U.S. $ for Great Britain.

FIGURE 5.2: EXPORT-IMPORT RATIO OF GERMAN MECHANICAL ENGINEERING



Data sources: see Figure 5.1.

How can the growing international competitiveness of German mechanical engineering be explained? Analysing the early development in German mechanical engineering between 1800 and 1870 Schröter and Becker (1962, p. 153) conclude that German firms owed their success in international price competition to the comparatively low wages they had to pay for skilled workers. To find out whether this conclusion was still true for the period between 1880 and 1913 we calculated real wage ratios, first, between Germany and its most important trading partner UK, second, between Germany and the U.S. that were Germany's third largest trading partner with an especially flourishing machine tools industry,[51] and, third, between Germany and its remaining major partners in overall foreign trade.[52] The later were Belgium, France, Italy, Netherlands, and Sweden. Annual real wages are taken from Williamson (1995). Real wage data for Austria-Hungary, Germany's second largest trading partner, and Russia are not available.

The development of the three real wage ratios is shown in Figure 5.3. First note that the real wage ratios both between Germany and the UK and between Germany and the U.S. were always smaller than one. This finding seems to support the usual assumption that, before World War I, German firms had labour cost advantages at least in comparison with their British and American competitors. After the mid of the 1890s, however, the wage gap between Germany and the UK was considerably decreasing.[53] The fact that the ratio between the German real wage and the average real wage of the five

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[51] See Atack and Passell (1994) p. 467 f.

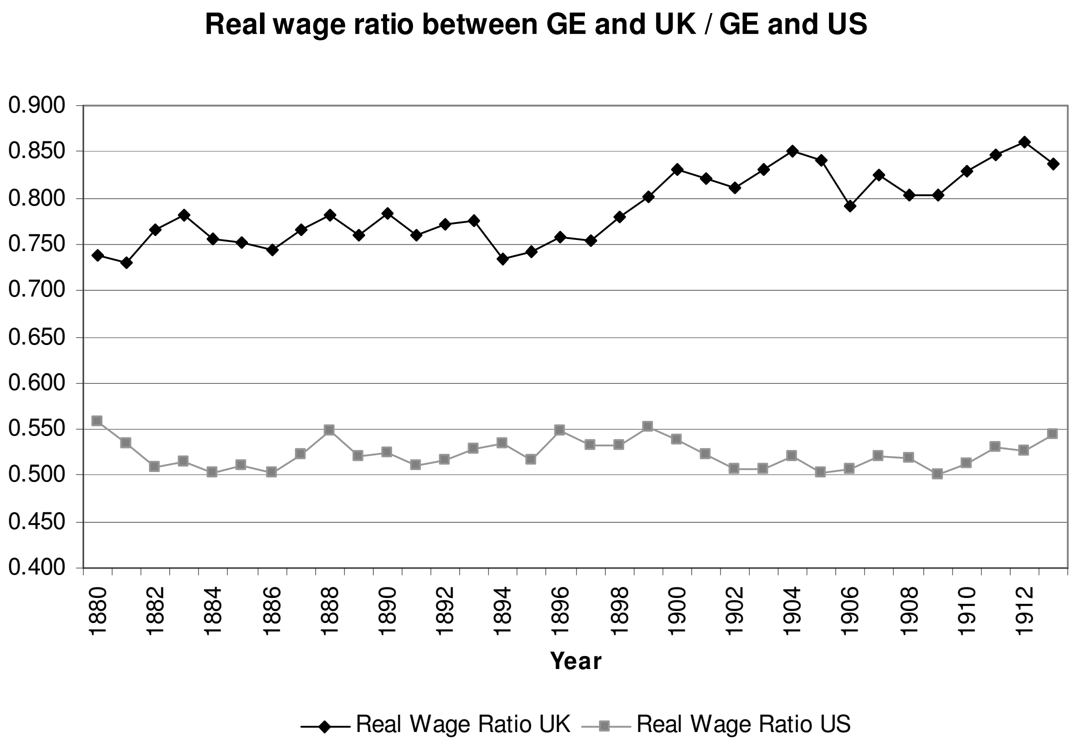
[52] We had to base this comparison on figures about overall foreign trade because both Gothein (1901) and Kaiserliches Statistisches Amt (1880-1915) present detailed export and import data with respect to mechanical engineering only for a limited number of countries and machinery types, and only for short sub periods.

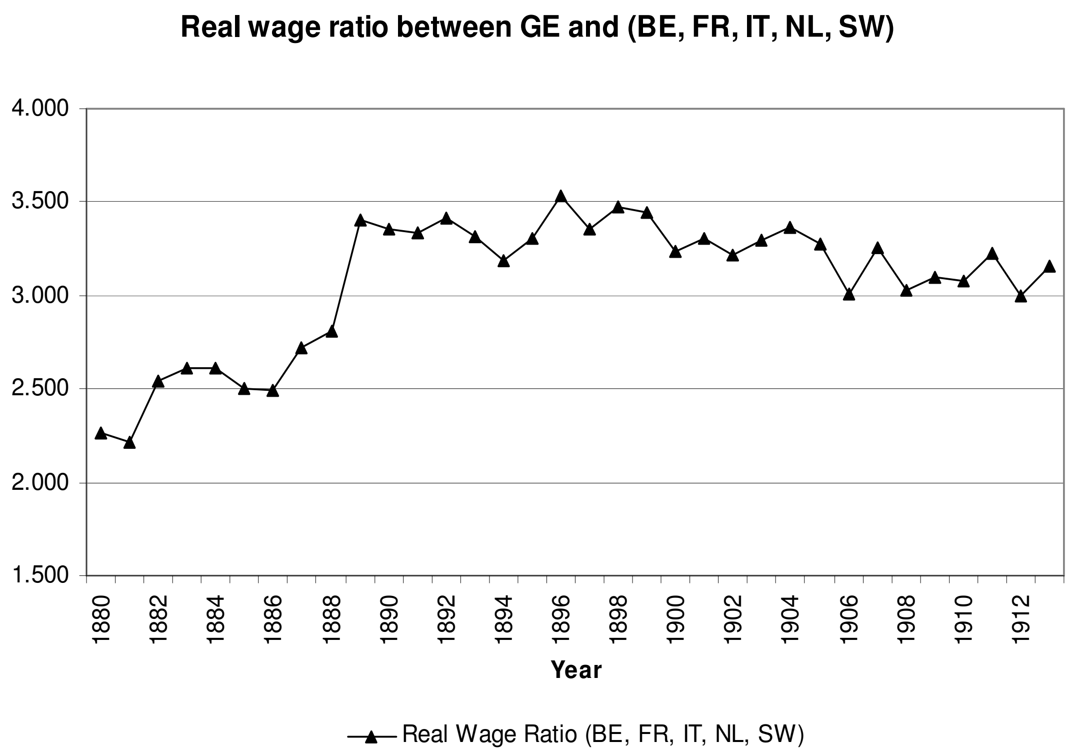
[53] The wage gap between Germany and the U.S. was remaining rather constant. This observation corresponds to the well-known fact that, in the late 19th century, both the U.S. and Germany were catching-up to the UK with respect to productivity. See, for example, Abramovitz (1986). The high real wages in the U.S. perfectly mirror the relative labour scarcity in this country. See O'Rourke and Williamson (1999), especially chapter four.

remaining trading partners, calculated by weighting their national real wages by their shares in German exports[54], was always higher than one also speaks against the assumption that German machine builders owned their success on international markets primarily to cheap labour. In addition, the wage gap between Germany and these countries sharply increased between 1880 and 1890, but only slightly declined afterwards. To conclude, the fact that German mechanical engineering industry gained a leading position in international machinery markets in the two decades before World War I can obviously not be explained by a significant decrease of the real wage ratios in this period.

[54] Export shares were taken from Mitchell (1980).

FIGURE 5.3: REAL WAGE RATIOS BETWEEN GERMANY AND ITS MAJOR TRADING PARTNERS



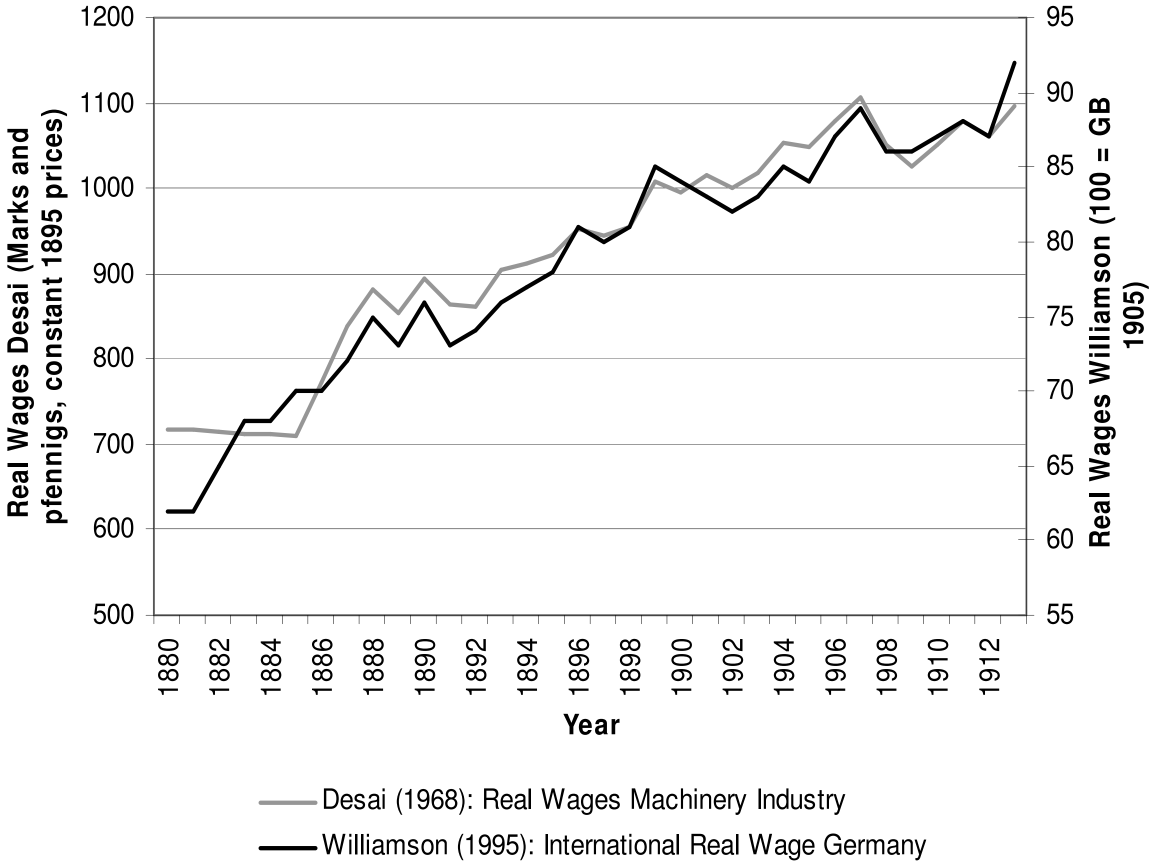


Data sources: Own calculations. Real wages are taken from Williamson (1995, pp. 141-196). Shares in German Exports are calculated based on Mitchell (1980), p.547.

One might argue that Williamson's real wage data which are based on wages of unskilled workers are not the adequate measure to compare the labour costs of mechanical engineering firms that primarily relied on skilled workers. Unfortunately, data about the wages of skilled workers in mechanical engineering are not available for the whole period under consideration for most of the countries of our international comparison. The German case, however, suggests that using Williamson's data instead of wages of skilled workers does not lead to a large bias. Figure 5.4 shows that the development of real wages in the German machinery industry collected by Desai (1968) is very similar to the development of the real wage data presented by Williamson.[55]

[55] Another benchmark is provided by the Verein Deutscher Maschinenbau-Anstalten (1926) who presents nominal weekly wages of skilled workers in mechanical engineering for the year 1913/14 for some countries. The resulting wage ratios between Germany and the UK (88 per cent) and between Germany and the U.S. (59 per cent) are close to the ratios given by Williamson which are 92 per cent and 54 per cent respectively. A large difference occurs in the case of Belgium, where the respective figures are 128 per cent (VDMA) and 97 per cent (Williamson, 1995).

FIGURE 5.4: THE DEVELOPMENT OF GERMAN REAL WAGES IN THE MACHINERY INDUSTRY COLLECTED BY DESAI AND GERMAN REAL WAGES PRESENTED BY WILLIAMSON



Data sources: Own calculations, based on:
Desai (1968), p.125, Williamson (1995), pp. 141-196.

An alternative reason for the growing international competitiveness of German mechanical engineering is presented by Barth (1973, pp. 120-132) who highlights the accelerated diffusion of drawing offices (*Konstruktionsbureaus*) and experimental departments (*Versuchsstationen*) in this industry around 1900. With these organisational innovations both engineering knowledge delivered by the expanding technical universities (Titze, 1987) and the idea of systematic industrial R&D entered the large and medium-sized machine builders. As a result of this deepening of the scientific base of machinery production German firms might have been able to develop a growing number of product innovations that could be successfully sold in international markets. The German Patent statistic confirms this hypothesis of a growing technological creativity of German firms engaged in mechanical engineering. Measured by the number of German patents that were held at least ten years,[56] forty-six per cent of the one hundred most innovative German firms of the German Empire belong to the group of machine builders. Table 5.2 in appendix D lists the twenty most innovative of them. The innovating activities of the German machine builders ranged from rather traditional fields like textile machines and railway installations to printing as well as type-setting, and to new transportation technologies like bicycles and combustion engines. It can easily be seen by the timing of their individual innovation periods that most of these firms produced their long-lived patents around and after 1900. We conclude from this observation that technological creativity might have been an important reason for the growing international competitiveness of German mechanical engineering before World War I. To test this hypothesis we use in the following an econometric model that is mainly inspired by a paper of Greenhalgh et al. (1994).[57]

5.3 The Model

Greenhalgh et al. (1994) explain the development of the export-import ratios of British industries between 1954 and 1985 by the influence of demand, production cost and product quality.[58] Domestic and world income per capita is used to measure the influence of demand. It is reasonable to assume that a growing foreign income led to an increasing demand for British products, thereby raising the export-import ratio, while a growing

[56] We discuss this indicator for innovativeness in great detail below.
[57] For a quantitative analysis of the export performance of British and German textile manufacturers before 1914 that neglects the influence of technology see Brown (1995).
[58] Greenhalgh et al. (1994, p. 105) also use strike incidence to measure the reliability of supply.

domestic income had the opposite effect by causing both a rising import demand in Great Britain and an increasing domestic consumption of goods that would have been otherwise sold abroad. The impact of production costs on foreign trade is indirectly assessed by the ratio of domestic and foreign prices. Greenhalgh et al. (1994, p. 105) suppose that British exporters acted in a imperfectly competitive market and had therefore the possibility to alter their export prices according to changes in exchange rates, capacity utilisation, production costs and innovative output. Consequently, the authors take domestic prices not from price statistics but estimate them independently in a separate model. To evaluate improvements of product quality Greenhalgh et al. (1994) mainly relied on three- and five-year moving averages of annual U.S. patents applied for by the British industries. Their empirical findings vary from industry to industry. With respect to highly innovative industries that operated in a price-competitive international market, and who are therefore comparable to German mechanical engineering in the 19th century, Greenhalgh et al, (1994) find out that the export-import ratio was positively influenced by an increase in innovative activities and negatively affected by rising production costs and growing domestic income.

We will deviate from the model presented by Greenhalgh et al. (1994) in two major aspects. First, we will use the real wage ratio instead of the price ratio to assess the impact of labour costs. Second, we will measure technological creativity not by short-term fluctuations in annual patents but by the long-term development of patent stocks. Greenhalgh et al. (1994) are absolutely right to take into consideration that at least in markets for heterogeneous goods like machinery the terms of trade might not only be determined by international pay differentials but also by different outcomes of national R&D processes that allow the more innovative national industry to sell better products at higher prices. As a result, an increasing difference between domestic and foreign prices can indicate both a decrease in international competitiveness because of growing labour cost disadvantages, or an increase in international competitiveness because of growing productivity advantages caused by superior innovative activities (Streb, 2004, pp. 85, 98-100). In principal, the same argument holds for real wage ratios. To avoid this kind of interpretation problem it is therefore advisable to measure the influence of labour cost directly by unit labour cost that are defined as the quotient between wage and labour productivity. With respect to this indicator international labour cost disadvantages only increase when the relative wage grows faster than relative labour productivity but decrease when the growth of relative labour productivity exceeds the growth of relative wage. Unfortunately, productivity figures for mechanical engineering for most of the countries in the period under consideration are not available.[59] We were therefore not able to calculate unit labour cost ratios but had to rely instead on data about real wages. That is why, when it comes to interpreting the empirical results in section 4, we have to keep in mind that a rising real wage ratio does not necessarily imply an increase in labour cost disadvantages but might indicate growing productivity advantages instead.

Using three- or five-year moving averages of annual patents Greenhalgh et al. (1994) implicitly assume that the invention of a new product or process improves the international competitiveness of a national industry only for a very short time period. This assumption implies that foreign competitors were able to imitate innovations very fast despite the fact that new knowledge was not only protected by patents but often at least partly tacit, e.g. tied to particular persons, firms or regions (Maskell and Malmberg, 1999), and therefore not imitable in the short run. Only looking on short-term fluctuations in annual patents also neglects the idea that technological change is a path-dependent incremental process (Cantwell, 1989, p. 17, Porter and Stern, 2000) in which a particular

[59] Broadberry (1997, pp. 28-31) presents benchmark estimates of comparative labour productivity within mechanical engineering for the UK, U.S. and Germany in 1907.

innovation is usually the starting point for a multitude of related R&D projects. That is why several scholars (Bosworth and Jobome, 2001; Nadiri and Prucha, 1996; Schankerman and Pakes, 1986) interpret new technological knowledge as a kind of capital good that generates competitive advantages for several years and can be accumulated over time like real capital. We follow this approach by estimating the technological creativity of the German machine builders on base of the development of the stock of machinery patents.

For the period from 1880 to 1913 we investigate the influence of demand, labour costs, and technological creativity on the export performance of thirty-two machinery types listed in the German trade statistics and matched with the corresponding technological classes of the German patent statistics. Given the fact that the UK and the U.S. were next to Germany the most important exporters of machinery and also the largest and third largest German trading partner respectively, we test our model both by using data for all major trading partners of Germany and by only employing the data for the UK and the US:[60]

[60] It might be promising to disaggregate analysis and to estimate this model separately for the bilateral machinery trade between Germany and each of its main trading partners. Unfortunately, based on the data available this extension is impossible and might be an issue for future research. Gothein (1901) and Kaiserliches Statistisches Amt (1880-1915) deliver export and very few import data only for a limited number of countries, machinery types, and only for a short sub period.

I. Main trading partners: UK and US:

$$\mathbf{Ln(eiw_{it}) = ß_0 + ß_1\, ln(innoratio_{it}) + ß_2\, ln(gdp\_ukus_t) + ß_3\, ln(gdp\_ge_t) + ß_4\, ln(rw\_geuk_t) + ß_5\, ln(rw\_geus_t) + a_i + u_{it}}$$

II. Main trading partners: Belgium, France, Italy, Netherlands, Sweden, UK, US:

$$\mathbf{Ln(eiw_{it}) = ß_0 + ß_1\, ln(innoratio_{it}) + ß_2\, ln(gdp\_all_t) + ß_3\, ln(gdp\_ge_t) + ß_4\, ln(rw\_geuk_t) + ß_5\, ln(rw\_geus_t) + ß_6\, ln(rw\_gerest_t) + a_i + u_{it}}$$

where,

$ln(eiw_{it})$	LN of $\frac{\text{Exports of machinery type i at time t}}{\text{Imports of machinery type i at time t}}$
$ß_0$	intercept
$ln(innoratio_{it})$	$\frac{\text{depreciated patent stock assigned to machinery type i at time t (inhabitants), Lag3}}{\text{depreciated patent stock assigned to machinery type i at time t (foreigners)}}$
$ln(gdp\_ukus_t)$	LN of (GDP per capita UK + GDP per capita US), equally weighted
$ln(gdp\_all_t)$	LN of Germany's main trading partners' GDPs per capita, weighted by their share in German exports at time t
$ln(gdp\_ge_t)$	LN of German GDP per capita at time t
$ln(rw\_geuk_t)$	LN of real wage ratio between Germany and the UK at time t
$ln(rw\_geus_t)$	LN of real wage ratio between Germany and the U.S. at time t
$ln(rw\_gerest_t)$	LN of real wage ratio between Germany and the remaining main trading partner at time t
$a_i + u_{it}$	disturbance terms.

The export-import ratio (ln(eiw)) is a widely used indicator for assessing a national industry's international competitiveness.[61] This indicator is the more rigorous criterion than, for example, net exports because it only rise when the growth rate of

[61] Note that the export-import ratio always refers to Germany's total foreign trade with respect to machinery goods. Data to calculate the respective figures only for foreign trade between Germany and its main trading partners are not available.

exports is higher than the growth rate of imports while net exports already grow when the additional exports have a higher absolute value than the additional imports. Hence, we will explain in our regression models only the development of export-import ratios. To take into account that the quality of the traded machines changed over time because of technological progress the export and import variables are not measured in volumes but in actual prices (Buchheim, 1982, p. 18). Data are taken from the trade statistics of the Imperial Statistical Bureau (*Kaiserliches Statistisches Amt*) that altered the classification of the machinery types three times in the period under consideration. Before 1900, machines were mainly distinguished by the material of which they consisted. The new classification scheme that was introduced in 1900 differentiated machines for the first time by the intended purpose (Gothein, 1901). In 1906, the classification of machinery types was modified again. Because of these changes it was mostly not possible to construct time series that show the export performance of a particular machinery type for the whole period from 1880 to 1913. Table 5.3 in appendix D lists for each of the thirty-two machinery types the time span for which we have consistent data.

The gross domestic product (GDP) per capita is used to evaluate the impact of domestic and foreign demand on the export performance of German mechanical engineering. We expect a negative influence of a growing German GDP per capita and a positive influence of an increasing average GDP per capita of its main trading partners. The latter is calculated in two different ways, depending on the underlying regression model. Regarding regression model I that uses only data for the UK and the US, we take the natural logarithm of the equally weighted sum of the GDPs per capita of the UK and the US. For the broader model II with seven trading partners, the national GDPs per capita of Belgium, France, Italy, Netherlands, Sweden, UK, and U.S. were weighted by these countries' share in the German exports delivered to them. GDP data are taken from

Maddison (1995). The impact of the real wage ratios is ambivalent. When the unknown German unit labour cost grew faster than the also unknown unit labour cost in the comparative countries, we expect a negative influence of the real wage ratio. When the opposite was true, we expect a positive influence.

To evaluate the development of technological creativity in the German mechanical engineering industry we employ a newly developed ratio of innovativeness (ln(innoratio)) based on machinery type-specific patent stocks. In the following section, we describe in detail the four main methodological steps needed to create this exogenous innovation variable. First, we distinguish patents with a high private economic value from those with a low one by employing information about their individual live span. Second, we assign the technological classes used by the German patent office to the machinery types used in the trade statistics. Third, we construct patent stocks by accumulating and depreciating individual patents granted to German and foreign patentees. Fourth, we define the ratio of innovativeness.

5.4 Measuring technological creativity

Pure patent counts allocate the same weight to every patent, no matter whether it has a high or a low economic value for the patentee or the society. Using the number of patents as an indicator for technological creativity suitable to foster international competitiveness therefore might lead to a potentially very large measurement error (Griliches, 1990, p.1669). To decrease this kind of measurement error it is necessary to distinguish patents with a high economic value from those with a low one. A possibility to do this is to let every single patent be evaluated by experts. Townsend (1980), for example, rated patents related to coal mining according to their importance on a scale from 1 to 4.

Unfortunately, this procedure does not work for large patent populations when the careful evaluation of every single patent would be very time consuming and would require engineering competence in a wide range of technological fields.

That is why Streb et al. (2006a) instead follow the seminal approach of Schankerman and Pakes (1986) and use information about the patents' individual life spans to identify the high-value patents in the sum total of more than 310,000 patents of the German Empire listed in the annual patent directory (*Verzeichnis der im Vorjahre erteilten Patente),* edited by the *Kaiserliches Patentamt* (1875-1918). The patent protection introduced by the German patent law of 1877[62] could last up to fifteen years but was not for free.[63] Rather, the patentee had to pay each year an increasing renewal fee in order to keep his patent in force. This annual renewal fee came to fifty Marks in the first two years, and grew then by fifty Marks each year up to 700 Marks at the beginning of the fifteenth year. Since most of the patent holders obviously decided to renew their patents only if the costs of doing so were lower than the expected future private returns of the patents,[64] this scheme was deliberately designed to get rid of low-value patents as fast as possible. The empirical facts suggest that this mechanism worked as assumed. About seventy per cent of all German patents granted between 1891 and 1907 were already cancelled after just five years.[65] After the fifth year the speed of patent cancellation was decelerating. About ten per cent of all patents were still in force after ten years, 4.7 per cent of all patents reached the maximum age of fifteen years. As a result, the actual life span of a patent can be used as an indicator for its private economic value.

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[62] See „Patentgesetz vom 25. Mai 1877“, *Reichsgesetzblatt*, pp. 501-510.

[63] Lerner (2002) points out that Germany had the highest patent fees among a group of sixty countries between 1850 and 1999.

[64] For a detailed analysis of this renewal decision see Streb et al. (2006a), pp. 351-353.

[65] See Kaiserliches Patentamt (1914, p. 84).

A basic question of the life span approach is how many years a patent had to be in force to be interpreted as a high-value patent. Schankerman and Pakes (1986) came to the result that most of the value of the patent stock built up in the post World War II period in Britain, France and Western Germany was concentrated in the five per cent most long-lasting patents. Given the historical survival rates of the patents granted in the German empire, following this hint would have meant to interpret only those German patents as the high-value ones that reached the maximum life span of fifteen years. Analysing the British and Irish patent statistics of the second half of the 19th century Sullivan (1994), however, finds out that the high-value patents of this sample were represented by the ten per cent most long-lasting patents. Since this later finding refers to the same historical period of time in which the patents of the German Empire were granted, Streb et al. (2006a) decided to include in their data base the ten per cent most long-lasting patents which implied to select all patents that lived at least ten years, and for which the total renewal fees came to at least 2,300 Mark (see chapter two). This approach resulted in a data base of 39,343 so-called high-value patents including information about the technological class of the invention and the name and location of the patent holder. We now use this additional information to identify the high-value machinery patents granted to Germans and foreigners.

The Imperial German patent office allocated each patent to one of 89 patent classes (PC) that had been furthermore subdivided into 472 subclasses in 1900. These patent classes did often not correspond to the industry in which they were developed but rather to the industry that was supposed to use the respective invention. That is why patents with regard to mechanical engineering are not only spread over several classes like PC 47 (machine parts), PC 49 (metal processing), PC 14 (steam engines) or PC 63 (vehicles), but can also be found in less obvious classes like PC 45 (agriculture) or PC 86 (weaving) to name just a few. For the purpose of this chapter we had to identify the subset of those high-value machinery patents that represented the specific innovative knowledge that could be used to produce and sell abroad those machinery types that were explicitly named in the trade statistics. Therefore we constructed the concordance shown in Table 5.3 in appendix D that matches the machinery types (MT) with their related patent classes or subclasses. The patent subclasses “steam turbines” (PC 14c) and “water turbines” (PC 88a), for example, are assigned to the machinery type “turbines” (MT 27). As we have already mentioned above subclasses like PC 14c did not exist before 1900. To use the concordance of Table 5.3 also in the period between 1880 and 1900 we therefore reviewed all pre-1900 high-value patents of the relevant main patent classes like class PC 14 (steam engines) and allocated them to their respective subclasses PC 14c (steam turbines) whenever this assignment was justified by the name or the detailed description of the patent.[66]

Figure 5.5 shows the annual number of high-value machinery patents matched with the machinery types of the trade statistics (thick continuous line) in comparison to all German high-value patents annually granted between 1880 and 1913 (thin continuous line).[67] The later sums up to 30,838, the former comes to 7,266. Since we want to calculate the ratio of innovativeness between Germany and its main trading partners we have to distinguish between machinery patents which were granted to Germans and those which were given to foreigners. The thick dotted line depicts machinery patents hold by German patentees. The sum total of this subset of machinery patents is 4,797.

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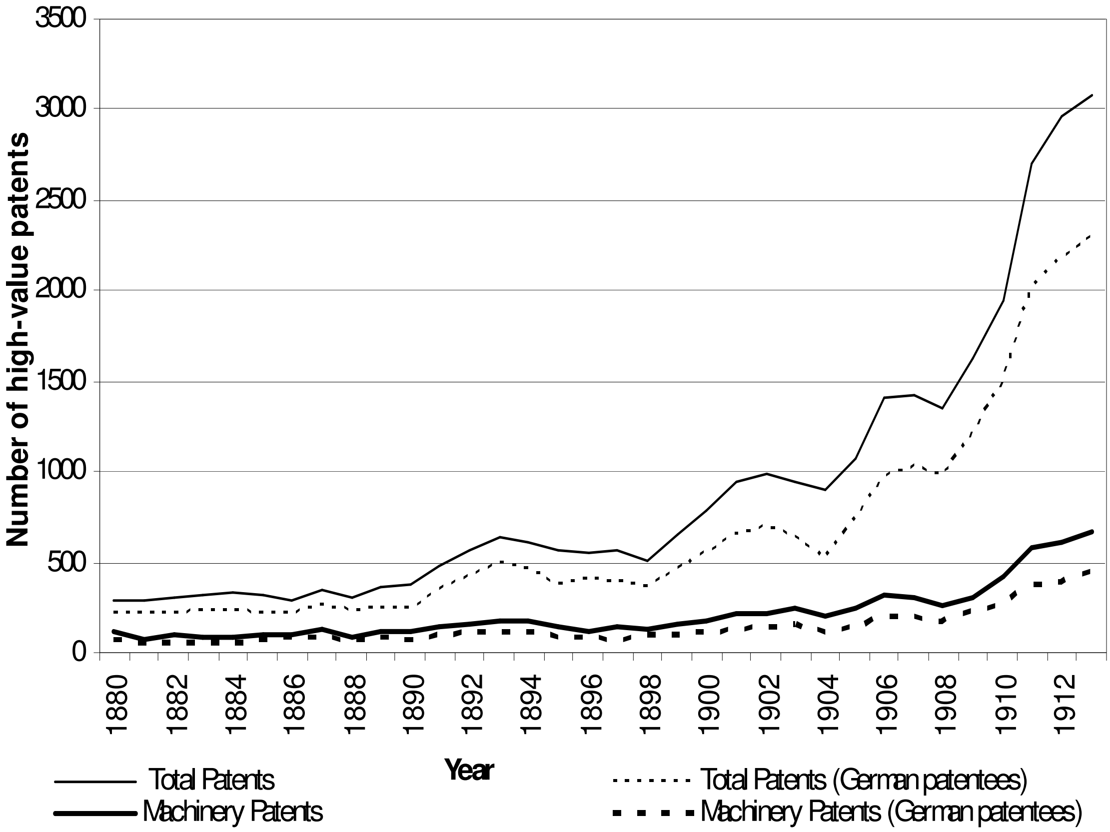
[66] The German patent office offers the possibility to review every historical patent online. See http://depatisnet.dpma.de.

[67] Figure 5.5 also reveals that the number of high-value patents noticeably increased in the decade before World War I. This boom of long-lived patents was probably not only caused by a rise in technological creativity but also by an anomaly brought about by a substantial decrease of the patent renewal fees between 1914 and 1923. See for more details Streb et al. (2006b). We do not control for this effect in this paper because it cancels out when the relation of Germany’s international innovativeness is calculated.

FIGURE 5.5: HIGH-VALUE MACHINERY PATENTS HELD BY GERMAN AND FOREIGN PATENTEES



Data sources: Own calculations, based on Baten / Streb patent data base. See Streb et al. (2006a).

Patent stock series for the different machinery types are constructed by adding up the annual patents of the assigned patent classes and subclasses from 1880 to 1913. Since we interpret patent stocks as a measure for the accumulated technological knowledge of the German machine builders we assume a positive correlation between export performance and this variable. However, even the most valuable patent might become both technologically and economically out of date after some years because of the ongoing technological progress. It seems therefore reasonable to assume that a particular high-value machinery patent fosters international competitiveness only for a finite time horizon, and has therefore to be depreciated over time. Schankerman and Pakes (1986) estimate for post-World War II Germany an average depreciation rate for patented knowledge of about twelve per cent per year. This depreciation rate implies that the value of an average post-World War II patent came down to zero after about nine years. Our sample, however, contains in contrast to Schankerman and Pakes' data base only those patents for which patentees were still willing to pay a high renewal fee in the tenth year of their life span. This fact indicates that the depreciation rate of our data set had to be considerably lower than twelve per cent. Our tests suggest that, for the case of high-value patents in the German Empire, a depreciation rate of five per cent is appropriate.

To test the impact of technological creativity on the export-import ratio it is reasonable to construct a corresponding ratio of innovativeness that compares the German technological creativity with the technological creativity in the countries being Germany's main trading partners. The later cannot be measured by high-value machinery patents granted to foreigners in their respective home market because such data are not available. We therefore decided to calculate the ratio of innovativeness by dividing the stock of high-value German machinery patents granted to inhabitants by the stock of high-value German machinery patents granted to foreigners located in the countries being Germany's main trading partners. The basic problem of this approach is that the innovative knowledge represented by the German patents of foreigners is usually older than the innovative knowledge embodied in the German patents of inhabitants granted in the same year. The reason for this is that, because of the cost of patenting, an inventor usually applied for a patent only in his or her home market first. Only then, when this patent actually turned out to be valuable at home, the inventor subsequently tried to get a respective patent abroad. To correct for this incongruence in the degree of novelty of German patents granted to Germans and foreigners we calculated the ratio of innovativeness by dividing the patent stock of Germans assigned to machinery type i at time t-3 by the patent stock of foreigners assigned to machinery type i at time t. The time lag of three years for German patent stocks is suggested by our statistical tests.

5.5 Empirical results

Table 5.1 presents the regression results for four versions of our random-effects model specification in which we measure the exogenous innovation variable by the ratio of innovativeness (ln(innoratio)). To calculate this annual innovation variable we, first, constructed depreciated patent stocks using an annual patent depreciation rate of five per cent and, then, divided the depreciated patent stock of German inhabitants assigned to machinery type i at time t-3 by the depreciated patent stock of foreigners from Germany's main trading partners assigned to machinery type i at time t. We tested the influence of this innovation variable on the export-import ratio (ln(eiw)) using economic data either of all trading partners (versions II-1 and II-2) or of the UK and the U.S. only (versions I-1 and I-2). Versions I-1 and II-1 exclude the real wages ratios whereas version I-2 and II-2 include them.

TABLE 5.1: UNBALANCED PANEL REGRESSION: DETERMINANTS OF EXPORT-IMPORT RATIO. (RANDOM-EFFECTS ESTIMATES)

Variable	I-1		II-1		I-2		II-2	
Constant	-19.882	*0.010*	-22.613	*0.003*	-19.042	*0.034*	-30.433	*0.019*
ln(innoratio)	0.075	*0.001*	0.018	*0.002*	0.094	*0.034*	0.109	*0.014*
ln(gdp_all)			3.189	*0.001*			4.731	*0.000*
ln(gdp_ukus)	8.289	*0.000*			7.227	*0.000*		
ln(gdp_ge)	-6.034	*0.029*	-6.147	*0.026*	-6.980	*0.001*	-4.470	*0.103*
ln(rw_geuk)					5.329	*0.013*	0.699	*0.769*
ln(rw_geus)					-1.113	*0.766*	-1.207	*0.764*
ln(rw_gerest)							-1.172	*0.716*
R^2 (within)	0.169		0.151		0.235		0.265	
R^2 (between)	0.053		0.040		0.010		0.006	
R^2 (overall)	0.047		0.042		0.050		0.050	
N	1023		1023		1023		1023	
Wald chi^2	30.38		26.36		67.09		77.48	
Prob > chi^2	0.000		0.000		0.000		0.000	

Note: P-values in italics. Shading indicates statistical significance at 0.05-level.
Data sources: see Figure 5.2, 5.3 and text.

In all versions of this model, the ratio of innovativeness has a positive impact on the export performance of the German machine builders at least at the five per cent significance level. This finding implies that technological creativity in fact fostered international competitiveness of the German mechanical engineering industry in the German Empire. The export-import ratio of German mechanical engineering is also positively and significantly influenced by the development of international demand measured by international GDP per capita (ln(gdp_all) or ln(gdp_ukus)). The fact that the equally weighted GDPs per capita of the UK and the U.S. alone has a higher quantitative impact than the weighted GDPs of all main trading partners indicates the above-average importance of the British and American export market for the German machine builders.

The expected negative influence of German GDP was mostly significant and robust to the inclusion of additional variables. In version I-2, for example, a one per cent increase of domestic GDP per capita led to an almost seven per cent lower export-import ratio at the one per cent significance level.

The influence of the real wage ratios being a less than perfect substitute for unknown unit labour cost is mostly insignificant. Interestingly enough, however, for the real wage ratio between Germany and the UK the sign of the coefficient of this exogenous variable is positive and in version I-2 even significant, whereas it is negative for the real wage ratios between Germany and the U.S. and between Germany and the rest of the main trading partners. This observation leads to the conjecture that in comparison to the UK the relative growth of German real wages might not indicate growing labour cost disadvantages but first and foremost mirrors the relative growth of German labour productivity catching up to the motherland of industrialisation. In contrast, as the negative signs of those real wage ratios suggest, the relative growth of German real wages in comparison to the U.S. and the remaining main European trading partners seems to be primarily determined by German wage rises that were not caused by respective gains in relative labour productivity.

We infer the following hypotheses with regard to the development of relative unit labour cost in the two decades before World War I. Taken together, the positive sign of the coefficient of variable ln(rw_geuk) and the growing real wage ratio between Germany and the UK depicted in Figure 5.3 indicate decreasing relative unit labour cost of German machine builders in comparison to their British competitors. In the light of the negative signs of the coefficients of variables ln(rw_geus) and ln(rw_gerest), the non-increasing real wage ratio between Germany and the U.S. and the slightly declining real wage ratio between Germany and the remaining main trading partners suggest at least non-increasing relative unit labour cost of German firms compared to their foreign competitors from these countries. As a result, the growing international competitiveness of German mechanical engineering in the pre-World War I period was apparently also caused by decreasing relative unit labour cost.

5.6 Conclusions

It is traditionally assumed that the growing international competitiveness of the German mechanical engineering industry in the pre-World War I period was determined by the fortunate combination of an outstanding technological creativity and the availability of a comparatively cheap labour force. In this chapter, we questioned this view by analysing the influence of technological creativity, demand factors, and labour costs on the development of export-import ratios of thirty-two different machinery types produced by German machine builders between 1880 and 1913. To measure technological creativity we developed a new innovation variable, named ratio of innovativeness, which compared the lagged and depreciated stock of high-value German machinery patents granted to Germans with the depreciated stock of high-value German machinery patents granted to those foreigners that were located in the countries of Germany's main trading partners. The weighted GDP per capita of the later was chosen to estimate international demand; German GDP per capita was employed as a proxy for domestic demand. Real wage ratios were used as an imperfect substitute for unknown ratios of unit labour cost with the help of which it would be possible to identify labour cost disadvantages exactly. Our unbalanced panel regression led to the following main results:

The ratio of innovativeness has a positive and significant impact on the export performance of the German machine builders which implies that technological creativity in fact fostered international competitiveness of the German mechanical engineering industry in the German Empire.

The export-import ratio of German mechanical engineering is also positively and significantly influenced by the development of international demand measured by international GDP per capita. In addition, it turned out that German machine builders especially relied on British and American export markets.

The impact of German GDP per capita measuring domestic demand was negative as expected. The influence of the real wage ratios on export-import ratios was ambivalent and mostly insignificant. For the real wage ratio between Germany and the UK we found a positive sign, whereas the signs are negative for the real wage ratios between Germany and the U.S. and between Germany and the rest of the main trading partners. Since in the two decades before World War I, first, the real wage ratio between Germany and the UK was growing, second, the real wage ratio between Germany and the U.S. was at least not increasing, and, third, the real wage ratio between Germany and the remaining main trading partners was slightly declining, this finding indicates that the growing international competitiveness of German mechanical engineering was probably also caused by decreasing relative unit labour cost.

D. Appendix to chapter 5

TABLE 5.2: THE MOST INNOVATIVE GERMAN MACHINE BUILDERS 1878-1914

Firm	High-value patents	Innovation period	Specialisation
Mergenthaler Setzmaschinenfabrik (Berlin)	101	1899-1914	Typesetting machines
Jagenberg (Düsseldorf)	59	1902-1914	Paper-processing machines
Wanderer Werke (Chemnitz)	59	1902-1914	Type-writer
Maschinenbauanstalt Humboldt (Cologne)	53	1887-1914	Ore preparing machines
Vogtländische Maschinenfabrik (Plauen)	52	1895-1914	Embroidery machines
Deutsche Maschinenfabrik (Duisburg)	52	1911-1914	Hoists
Berlin-Anhaltische Maschinenbau AG (Berlin)	43	1901-1912	Machinery parts
Hennefer Maschinenfabrik Reuther & Reisert (Hennef)	43	1886-1913	Instruments
Präcisions-Kugellagerwerke Fichtel & Sachs (Schweinfurt)	43	1902-1914	Bicycle brakes
Maschinenfabrik Rockstroh & Schneider (Dresden)	41	1902-1914	Printing machines
Rheinische Metallwaren & Maschinenfabrik (Düsseldorf)	40	1901-1914	Weapons
Elsässische Maschinenbau-Gesellschaft (Mühlhausen)	38	1881-1912	Spinning machines
Heinrich Lanz AG (Mannheim)	36	1896-1914	Agricultural machines
Daimler Motorengesellschaft (Stuttgart)	35	1886-1914	Combustion engines
Bleichert & Co. (Leipzig)	32	1887-1914	Railway installations
Julius-Pinsch AG (Berlin)	31	1898-1914	Locomotives
Schubert & Salzer AG (Chemnitz)	31	1904-1914	Knitting machines
Duisburger Maschinenbau AG (Duisburg)	29	1880-1911	Hoists
Singer & Co. (Hamburg)	28	1898-1906	Sewing machines
J. Pohlig AG (Cologne)	27	1901-1914	Conveyors

Note: The innovation period covers the time span in which the high-value patents were granted to the respective firm.

TABLE 5.3: ASSIGNMENT OF PATENT CLASSES TO MACHINERY TYPES

MT	Machinery type	Period	Patent Classes (PC)	Description of corresponding Patent Classes
1	Agricultural machines	1900-1905	45a, 45b, 45c, 45d, 45e, 45g	Machines for soil cultivation, sowing machines, harvesters, horse-gins, machines for crop processing, dairy machines
2	Threshing machines	1906-1913	45e	Machines for crop processing
3	Sowing machines	1906-1913	45b	Sowing machines
4	Machines for skimming milk	1906-1913	45g	Dairy machines
5	Machines for cleaning cereals, peas and beans	1906-1913	50a	Machines for cleaning corn as a preparation for milling
6	Milling machines	1900-1905, 1906-1913	50	Milling
7	Machines for refining sugar	1906-1913	89a, 89b, 89c, 89d, 89e, 89f, 89g	Machines for cleaning and shredding sugar beets, syrup production, boiling and vaporizing, centrifuging, grading and packing
8	Brewery and distillery machines	1900-1905, 1906-1913	6b, 6c	Machines for producing beer and other alcoholic drinks
9	Machines for wool processing	1900-1905	25a	Knitting machines
10	Weaving machines	1900-1905, 1906-1913	86	Weaving
11	Machines for spinning cotton	1900-1905, 1906-1913	76c	Spinning and twisting machines
12	Machines for preparing and spinning flax, hemp, yarn cotton and silk	1906-1913	76	Spinning
13	Machines for preparing yarn for weaving	1906-1913	86a	Machines for preparing yarn for weaving
14	Knitting machines	1906-1913	25a	Knitting machines
15	Machines for producing curtains and lace	1906-1913	25b	Machines for producing lace
16	Sewing machines, from cast-iron and wrought iron	1880-1905, 1906-1913	52a	Sewing
17	Leather and footwear machines	1906-1913	28b, 71c	Machines for processing skins, machines for producing footwear
18	Wood-processing machines	1906-1913	38	Wood processing
19	Machines for producing wood pulp and paper	1900-1905, 1906-1913	55	Paper and cardboard manufacturing
20	Machines for bookbinding and producing paper goods	1906-1913	11a, 11c, 15e	Stapling machines, bookbinding machines, machines for folding, perforating and edging
21	Printing machines	1906-1913	15d	Printing machines
22	Machines for cleaning, crushing and forming of coal, ore and rocks	1906-1913	80a, 80d	Machines for processing and forming clay, stones, cement, asphalt and plaster
23	Steam-boiler	1880-1905	13	Steam-boiler
24	Steam engines	1900-1905	14	Steam engines
25	Steam hammer	1900-1905	49e	Machines for hammering, pressing, riveting and cutting
26	Locomotives and locomobiles	1880-1905	20b, 20c, 20d, 20e, 20f	Locomotives, wagons, axles, coupling, breaks
27	Turbines	1900-1905	14c, 88a	Steam turbines, water turbines
28	Pumps and refrigeration machines	1900-1905, 1906-1913	17a, 59	Refrigeration machines, pumps
29	Blowers and ventilators for industrial use	1900-1905, 1906-1913	27	Blowers and ventilation
30	Lifting machines	1900-1905, 1906-1913	35	Hoisting devices
31	Machine tools, machines for metal processing	1900-1905, 1906-1913	49	Machines for metal processing
32	Electrical machines	1900-1905	21d	Electrical machines

6 FOREIGN DIRECT INVESTMENT OF GERMAN COMPANIES 1873-1927

6.1 Abstract

Based on firm-specific data on foreign direct investment of German companies from 1873 to 1927, we study firm characteristics that caused FDI, preferred host countries, and whether FDI was successful in terms of enhancing corporate profitability. Large companies with high profitability conducted more FDI. Market size and similarity of the respective host country triggered horizontal FDI. However, wage gaps and differences in human capital stimulated FDI flows; hence, incentives for vertical FDI existed. Considering endogeneity between FDI and profitability, we uncover that FDI did not enhance profitability, and profitability did not drive FDI. Interestingly, FDI was driven by the company's past FDI transactions.

Chapter is based on a working paper, see Baten et al. (2007a). The concept for the paper was developed jointly, the author of this thesis was responsible for the data collection, the analyses were done by Gerhard Kling, and the writing was equally shared.

6.2 Introduction

The end of the 19th century and the beginning of the 20th century marked a period of expanding demand, growth in productive capacity and rising exports in Germany. Germany became one the leading industrial countries and has taken a pioneering role especially in the chemical, electrical, and engineering industry until WWI (see Henderson, 1975, p.173). Inventions such as the dynamo and the electrical bulb were as important to the electrical industry as synthetic dyes to the chemical industry or the development of steam engines to the engineering industry. Relatively new companies, such as AEG or Siemens, had achieved industrial success. The fastest-growing electrotechnical firm AEG for example, invested thirty-seven times abroad from 1873 to 1927. AEG did its first FDI in UK in 1892, soon after Emil Rathenau acquired a license for Edison's patents on lamps and the foundation of AEG in 1887 (see Pohl, 1988). Growing competition, especially in those successful industries, required diversification and consequently triggered more and more FDI. After a period of enhanced economic and financial integration, WWI marked a turning point in international relations and a phase of protectionism and 'deglobalisation' started. Besides its economic costs, protectionism was to blame for the breakdown in the 1930s (see Chase, 2004).

In this chapter, we study FDI streams during the period 1873-1927 undertaken by German companies. Working with micro-level data on 948 individual FDI transactions of 377 joint stock companies, as well as a control group of 556 joint stock companies without FDI, we try to answer these questions. In particular, we work on a disaggregated level to reveal company characteristics that stimulated entering foreign markets. In a second step, we aggregate individual FDI decisions to a panel of country level investment streams. We apply an extended knowledge-capital model to identify country characteristics that attracted FDI and to uncover the nature of FDI streams. Based on firm-level data, we finally analyse the success of FDI taking into account the inherent endogeneity problem, as successful firms undertake more often FDI, and FDI in turn can make companies more successful.

Theoretical models for horizontal FDI focus on the trade-off between economies of scale and transportation costs, which suggests that in the absence of transportation costs, firms would prefer producing in one factory and exporting goods to foreign markets.[68] As transportation costs were relatively high from 1873 to 1927, we would expect a strong incentive to conduct horizontal FDI and thus a shift of production to host countries to meet the local demand. Due to limited data availability, we cannot estimate a translog cost function to determine economies of scale; however, we can measure the impact of size on the propensity to conduct FDI in our models.

In contrast, vertical FDI is driven by differences in factor intensities and factor prices suggesting that companies shift parts of the production process, which are not skill intensive, into countries with low wages for unskilled labour.[69] If countries with a high wage gap, namely lower real wages compared to Germany, and low relative skill levels (measured by our human capital proxy) attract FDI, we can regard these investments as being of vertical nature. There are many terms for vertical foreign direct investments (FDI) like 'slicing up the value chain' coined by Krugman (1996), fragmentation (see Jones and Kierzkowski, 1990) or outsourcing; however, these forms of vertical FDI were not observable in the first phase of globalisation. Nevertheless, shifting the entire production and not just parts of it to a different country for the sake of lowering production costs was possible from a technological point of view. Markusen (2002) combined both theoretical approaches into the knowledge-capital (KC) model, which was

[68] Helpman (1984) and Helpman and Krugman (1985) developed the first theoretical models that explain horizontal FDI.
[69] We refer to Markusen (1984) and Markusen and Venables (1998).

empirically tested and modified by Braconier et al. (2005) and Davies (2004). By aggregating our firm level FDI data, we apply a modified KC model to explain FDI across countries.

This chapter is organised as follows: the literature review stresses the current debate concerning horizontal and vertical FDI, globalisation periods, and the success of FDI and multinational enterprises; the third section highlights our data collection efforts and shows first descriptive findings; the fourth section presents our empirical findings regarding the following three questions: (1) which companies conducted FDI; (2) was it horizontal or vertical FDI; (3) was FDI successful? Finally, we conclude and discuss our findings.

6.3 Literature review

The traditional view of capital flows is that investments from capital abundant countries should mostly flow to economies that have low capital intensity and are "rich" in other factors such as unskilled labour or natural resources, unless capital flows are substituted by movements of goods (i.e., exports) or labour (migration). In contrast, most empirical studies found that the largest share of FDI usually flows from one rich, high-wage country to another rich, high-wage country. Hence, another set of theoretical models evolved that were better able to explain the empirical facts. The probably most prominent model is currently the knowledge-capital-model of the multinational enterprise (see, among others, Markusen, 1984, 2002; Carr et al., 2001). This model assumes that the assets of knowledge-based firms can be used in many types of economies, including rich and human capital-intensive countries. It comprises as special cases the "vertical" and the "horizontal" strategies: the horizontal strategy means that production processes are placed via FDI in countries that are very similar in human capital intensity to the headquarter economy. The main motivation is to gain market access more easily, by moving production into the proximity of foreign consumers. Economies of scale cannot be exploited by this strategy, but transport costs are lower. In empirical studies, GDP of the target economy should be a strong indicator for the horizontal strategy, as it indicates market potential.

Quite contrary, the “vertical” strategy of FDI follows the idea that the stages of the production process are sliced up vertically, and each stage of production takes place where the factor costs are lowest: simple stages of production are relocated to low-wage, low-human capital countries, and human capital intensive processes take place in high-wage countries, for example the headquarter economy. Intermediate products are moved between the countries. The empirical implication would be that GDP of the host country should not matter much, and similarity of GDP, wages or human capital measures should actually have a negative sign, as similarity represents the differences between economies that are exploited by a vertical MNE. The knowledge-based model of the MNE nests both models, and it predicts that companies employ the vertical or horizontal strategy, whichever might be most suitable for a given situation.

Most empirical studies for the last few decades tend to confirm the horizontal strategy as the more dominant strategy. But there is also some evidence for the vertical one, especially from interviews with central European firms that aim at using the wage differential between Central and Eastern Europe to slice up their production chain.

Most studies so far used aggregated data, whereas firm level data studies on the knowledge-based model have been only performed for the U.S., Sweden, and Germany during the last two decades. Especially long-run studies that could make use of the special feature of the knowledge-based model – that behaviour should be determined by varying economic environments – are lacking so far.

One interesting recent study on Germany compares results at the firm level and at the aggregated level (see Buch et al., 2005). The authors mobilised a very large panel dataset that was recorded at the *Bundesbank* and compared aggregate and individual adjustments to target country GDP, and similarity. On the aggregated level, an additional per cent of GDP results in almost one per cent additional FDI. This can be decomposed into (a) the increase of the number of affiliates and (b) a higher investment per affiliate. Buch et al. (2005) found that the investment per affiliate accounts for about one third of additional FDI volume, whereas additional affiliates account for the remaining two thirds (assuming no omitted variable and measurement error problems in their regressions). The authors also uncovered that similarity of GDP in the host country and Germany (which is the only headquarter economy in this study) has a positive influence on the size of the investment and sales per affiliate, whereas protectionism has a negative influence.

In sum, most of the recent literature stresses the "horizontal", market access motivation as the strongest determinant of FDI, although vertical cost-saving motivations play a role in some situations (especially where factor price differences are only separated by relatively open borders, such as within the EU, or between the U.S. and Mexico). Other motivations of FDI are taxation (although results are yet inconclusive), protectionism, chain migration of firms, brand name and proprietary knowledge effects.

Apart from the motivation to exploit different factor prices or to access markets known as vertical and horizontal FDI, respectively, the more prominent determinants of FDI can be classified as those (a) created by government activities (taxation, protectionism), (b) chain migration of FDI into similar regions and countries, and (c) the attempt to internalise the profit effects of brand names and proprietary knowledge.

(a) Taxation as determinant of FDI is, of course, a very attractive field of research, because it might allow direct policy interventions to stimulate foreign investment. However, the results for this factor have been somewhat inconclusive until now. Maskus (1998b) and Blonigen and Davies (2000) actually found that FDI flows are sensitive to tax regimes and other state interventions, whereas Brainard (1997) argued that the taxation strategy of host countries does not discourage FDI. Other interventions might also have ambivalent effects on FDI, for example protectionism: protectionism might be negative for trade with one's affiliate and re-exports (and it might be a proxy for illiberal economic policy in general), but the market access motivation might actually be reinforced by protectionist policies, at least of rich and large countries. Furthermore, changes in the exchange rate regimes and other macroeconomic change also affect FDI (see Blonigen, 1997).

(b) The histories of Coca Cola or Daimler Benz stand for famous brand names that have been marketing successes in many countries, and Kodak or Siemens were similarly able to exploit proprietary knowledge using FDI, in many countries of the world. Among others, the study by Brainard (1997) demonstrated the strength of those factors for U.S. multinationals (MNE). Patent rights in the host country also play a role for innovation-intensive MNEs (Maskus 1998a).

(c) Another interesting field is the chain migration of firms into similar environments. For example, Japanese firms tend to cluster together in U.S. regions (see Head et al., 1995). Those agglomerations provide some information processing advantages, and in the case of similar skills demanded on the labour market, there might also be clusters of similar producers in some regions (the 'Silicon Valley' effect).

6.4 Data

We use a new database to investigate the determinants and success of FDI in the period 1873-1927 on firm and country level. It is a unique database for the following reasons: fist, our database provides 948 individual FDI transactions of 377 joint stock companies, as well as a control group of 556 joint stock companies without FDI. The FDI data were drawn from the ´Handbuch der deutschen Aktiengesellschaften´ (various issues). Second, the database contains also firm specific information on total assets, common equity, profits, investment accounts, year of foundation of the company, and industry dummies. And finally, as only a few papers on FDI (for example Buch et al., 2005; Wagner and Schnabel, 1994) analysed recent micro data, we stress that this is the first approach to investigate German micro-level FDI data in the first globalisation period and the 1920s.[70]

Our analysis includes all joint stock companies listed on German stock exchanges and documented in the ´Handbücher der deutschen Aktiengesellschaften` of the selected years that undertook FDI. To reveal company characteristics that made FDI more likely, we need a reference sample consisting of companies without FDI. Thus, we add a randomly chosen control group in the period of interest. Generally, we have information about the year, the destination (town and country), the industry, and the amount of investment of the respective FDI transaction. When focusing on the type of FDI provided by the ´Handbücher der deutschen Aktiengesellschaften`, FDI in the form of holdings, agencies, and affiliates dominated. Due to the fact that the complete set of information is not available for all companies, we cannot include all variables into our regressions without a considerable loss of observations.

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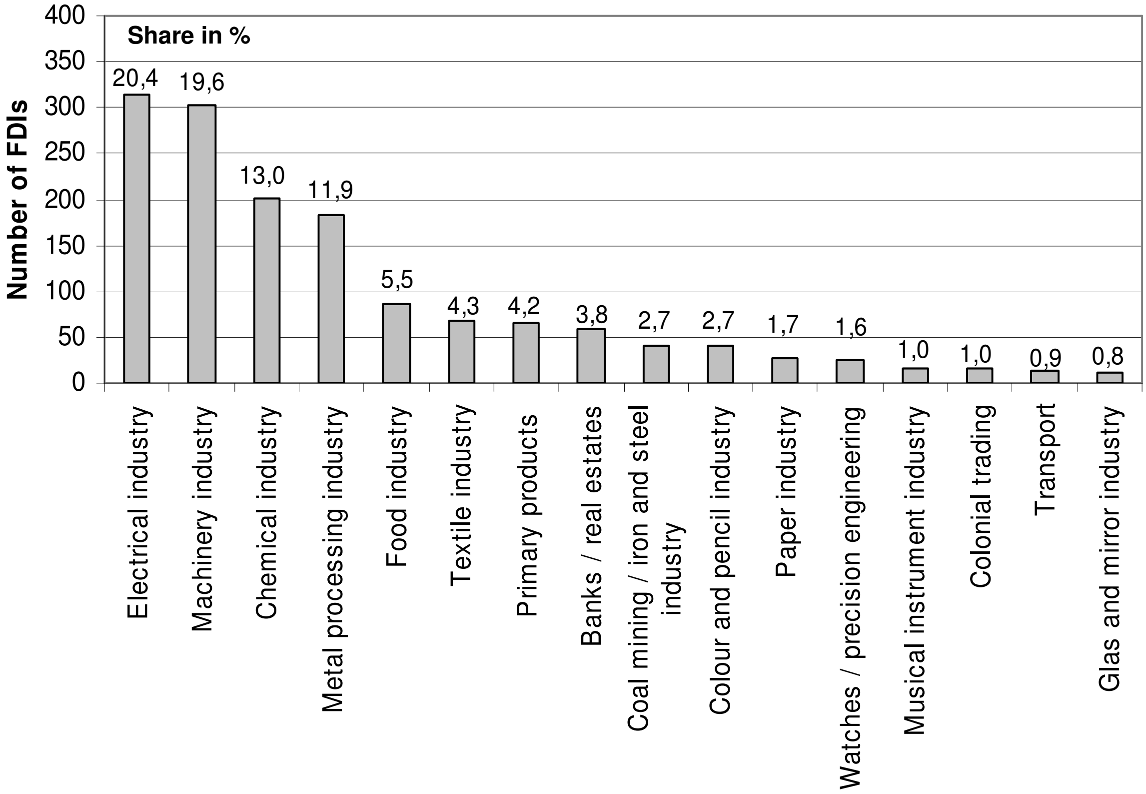
[70] Buch et al. (2005) pointed at the limitations of studies that only focus on macroeconomic or aggregated data, as they did not allow assessing firm-specific characteristics and incentives for FDI.

Summing up, the dataset provides information on FDI of German companies in fifty-five countries and thirty-seven industries. The ten most important countries were by far Austria-Hungary (current borders, after WWI: Austria and Hungary) and UK, followed by France, U.S., Italy, Russia (SU after WWI), Poland (before WWI: part of neighbour empires), Switzerland, Netherlands, and Czech Republic (before WWI: part of Austria-Hungary). Figure 6.1 plots the relative importance of specific industries regarding FDI. We observe a particularly high number of FDI in the electrical and machinery industry with a share of about 40% of all FDIs, followed by the chemical and metal processing industry. None of the remaining industries accounted for more than 5.6% of all FDI.[71]

[71] We account for the four most active industries concerning FDI by including dummy variables into our regression models.

FIGURE 6.1: THE MOST IMPORTANT INDUSTRIES AND THEIR SHARE IN TOTAL FDI 1873-1927



Data source: Handbuch der deutschen Aktiengesellschaften (1897-1901, 1912, 1927).

In the following regressions, we also include as potential determinant of FDI a macroeconomic human capital measure. Our proxy for human capital is partly based on patent statistics published by the German patent authorities. To distinguish between important and unimportant patents, we follow Labuske and Baten (2006, 2007) and Streb et al. (2006a) and concentrate only on patents that were prolonged for at least ten years (so called high-value patents). This is possible for foreign patents in Germany, because Germany had the highest patent fee among a group of sixty countries between 1850 and 1999. For one-year patent protection the German Patent authority charged an annual patent fee at the beginning of each year. In order to extend the validity of the patent, the patentee had to pay an increasing renewal fee. The patentee only renews the patent if the present value of expected future returns of the patented invention exceeds the present value of future costs. In chapter four constructed a measure for technical human capital that is the equally weighted average of primary school enrolment rates and adjusted patents. They adjusted the number of patents for distance and cultural proximity (measured by the use of the German language).[72] This adjustment accounts for the fact that neighbouring countries with the same cultural background tended to have more patents in Germany. In order to obtain "enrolment equivalents" in the second step, they used the predicted values from a regression of enrolment rates on adjusted patent rates. Hence, they obtain an adjusted measure for the innovativeness of a country's industry. In the third step, in chapter four we calculated the averages between those adjusted patents and primary school enrolment rates.

We use the ratio of custom revenues to total imports for a given country and time to test how protectionism affected FDI's streams in the respective countries. One major source of data was Accominotti and Flandreau (2006). They collected protection rates for Austria-Hungary, Belgium, Switzerland, Spain, France, United Kingdom, Italy, Netherlands, Russia, and the United States of America 1840-1890. As our database contains FDI's from German joint stock companies in fifty-five countries between 1873 and 1927, we had to add data from other sources as well. Another important source was Rubio's (2006) data for Latin American countries, so we were able to fill gaps until 1910 for some other countries. Finally, we use average tariff rates from the quite comprehensive Clemens and Williamson (2004) dataset for the 1920s.

The definitions of variables and sources used in the empirical part of the chapter are summarised in Table 6.4 in appendix E. To obtain an overview regarding the firm

[72] The number of patents is regressed on the distance between Germany and the respective country and the use of the German language (dummy variable). Patents explained by spatial and cultural proximity are deducted from the total number of observed patents.

characteristics of companies that conducted FDI and companies that did not, Table 6.5 in the appendix reports means, standard deviations, minimum and maximum values for firm size, value of investments, return on equity and year of firm creation. Based on group-wise descriptive statistics, we observe that companies with FDI activities tended to be larger, and more profitable indicated by a higher return on equity (ROE).

6.5 Empirical results

6.5.1 Which companies conducted FDI?

We first model the decision: "to invest or not to invest" from a business perspective; accordingly, we use firm-level data for the whole period from 1873 to 1927 and analyse individual FDI decisions. Our dataset reports every FDI transaction of the included companies and contains information about a reference sample consisting of firms without FDI. Economies of scale could reduce incentives for horizontal FDI (see Helpman, 1984; Helpman and Krugman, 1985); hence, we take the log of total equity as proxy of firm size to control for size advantages.[73] Following Helpman (1984) and Helpman and Krugman (1985), we should expect that small firms benefit from increasing their output and hence tend to conduct less horizontal FDI. Besides the interrelation of firm size and economies of scale, larger companies have easier access to capital markets. Thus, FDI is easier to finance, and cost of capital is lower, which makes FDI more attractive.[74] Helpman et al. (2004) emphasised the fact that firms conducting FDI are not only larger, but also more

[73] Note that other proxies like the number of employees would reduce the number of observations considerably due to missing data. In addition, alternative measures are highly correlated with our proxy.

[74] Tilly (1982) argued that the companies' laws of 1884 and the new exchange law established 1896 favored larger companies. For instance, the law required that the minimum issue volume had to exceed one million Mark. Hence, a larger company had advantages to finance expansion by issuing new shares. The companies' law and the new exchange law mainly determined the legal framework in the pre-1914 period.

efficient and productive than firms that produce for the home market or choose to export. Hence, we include additional factor advantages like companies' efficiency that make FDI more attractive, as these factor advantages create also competitive advantages in foreign markets. We use return on equity (ROE) as a measure of efficiency (profitability) and claim that a higher ROE makes FDI more likely, as companies that are profitable in their home country possess factor advantages when entering foreign markets. Moreover, we use the year of firm foundation to control for firm creation cohorts: did later cohorts conduct more often FDI, or were perhaps earlier cohorts with more experience more likely FDI candidates? As trade policies changed considerably over time, we incorporate a variable that accounts for protectionism of the respective host country.[75]

We also account for industry effects (denoted j) by using conditional (fixed-effects) logit models. Accounting for the most active industries in terms of FDI, we use four main categories (chemical, electric, machinery, and metal). Besides these major industries, we could distinguish thirty-seven different sub-industries. Consequently, we run the following logit model that explains the binary decision concerning FDI during the period 1873 to 1927.

$$\mathrm{fdi}_{\mathrm{i}} = \alpha_j + \beta_0 \cdot \mathrm{protect} + \beta_1 \cdot \log(\mathrm{size}_{\mathrm{i}}) + \beta_2 \cdot \mathrm{roe}_{\mathrm{i}} + \beta_3 \cdot \mathrm{foundation}_{\mathrm{i}} + u_i \qquad (1)$$

Table 6.1 shows the regression output for the basic model without industry effects (model 1), the conditional logit model with thirty-seven industries (model 2) and a specification with the four major industries (model 3).

[75] In the case of our control group that contains companies without FDI, we use the median of the level of protectionism based on the FDI transactions in the respective year.

Firm size stimulates FDI indicating that economies of scale, easy access to capital markets and other size advantages like market power were relevant for conducting FDI. Profitability in terms of higher returns on equity made FDI more likely; hence, profitable firms could use their factor advantages to enter foreign markets. The year of foundation, shows a negative but not significant impact (after controlling for industry effects) on the probability to conduct FDI. Protectionism stimulated FDI flows; however, the magnitude of the impact is rather limited. As a consequence, we can conclude that increasing tariffs and indirect barriers to trade creates an incentive for companies to circumvent these barriers by shifting their production facilities. To distinguish between horizontal and vertical FDI and its motives, our second step relies on aggregated data.

TABLE 6.1: LOGIT AND CONDITIONAL (FIXED-EFFECT) LOGIT MODELS

Variable	**I**		**II**		**III**	
	Basic model		**Industry-effects**		**Major industries**	
	Fdi		**Fdi**		**Fdi**	
Protect	**0.022**	*2.18*	**0.020**	*1.89*	**0.020**	*2.00*
Size (logarithm)	**0.751**	*12.35*	**0.848**	*12.02*	**0.771**	*11.93*
ROE	**0.817**	*2.39*	**0.815**	*2.10*	**0.857**	*2.40*
Foundation	**-0.010**	*-1.78*	-0.004	*0.64*	-0.009	*-1.57*
Chemical					**0.609**	*2.65*
Electric					0.002	*0.01*
Machinery					**0.424**	*2.06*
Metal					**-0.637**	*-2.52*
Constant	6.642	*0.63*			4.777	*0.43*
Pseudo R^2	0.192		0.209		*0.209*	
N	1023		987		*1023*	

Note: Z-values in italics. Shading indicates significance at 0.10-level.
Data sources: see Table 6.4.

6.5.2 Was it horizontal or vertical FDI?

After clarifying individual investment decisions and showing that firm size is the most important factor for FDI, we try to analyse which macroeconomic factors of the home and host country enhance FDI. We do this on an aggregated level by analysing the sum of FDI that flows into different countries. Our estimation strategy is motivated by Carr et al. (2001), Markusen and Maskus (2001, 2002), Blonigen et al. (2003) that applied gravity equations and the knowledge-capital model to macro-level data on FDI.

Based on gravity models and the extension with skill measures (knowledge-capital model), we state that FDI streams among countries can be explained by the following variables: (1) the sum of log GDP (host and home country) represents the gravity component, which underlines that larger countries attract more FDI. (2) The dispersion index (squared difference of home and host country's log GDP) highlights whether home and host countries are of similar size. Similarity of GDP leads to larger FDI streams between the two countries. (3) The distance parameter (km between the capitals of the home and host country) is a common proxy for transportation costs and cultural differences. Adjacent countries tend to trade more due to low transportation costs, similar culture and familiar regulatory frameworks (e.g. legal system). (4) We also include the official language of the host country to account for cultural aspects. (5) To account for skill differences, we use a human capital indicator, which is an equally weighted sum of primary school enrolment rates and the number of patents that firms of the respective host country hold in Germany (see chapter two and four). This macro-level proxy provides a better measure for skills in an economy compared to input-oriented measures like the number of scientists per 1000 workers (see Carr et al., 2001). As Germany can be regarded as skill abundant country, a high skill level in a host country suggests that the host country is more similar compared to Germany. If similarity in human capital triggers higher FDI flows, incentives for vertical FDI could be excluded.[76] Our variable denoted humancap measures the difference between the 75 percentile in the human capital proxy and the value of the proxy in the respective host country. If the variable humancap exhibits positive values, host country's human capital proxy is below the 75 percentile.

The relationship between protectionism and FDI is a particular interesting one. One the one hand, we would expect more FDI between well-integrated markets, if the costs of production are substantially different and the proximity of production to consumer markets plays a large role. On the other hand, FDI was often used as a substitute for trade, if protectionist barriers were high. In this kind of situation, intangible assets are necessary to produce the multinational's product. Special know-how, reputation, branding capital could be moved behind the protectionist walls by setting up an FDI plant in the chosen country. For example, the Singer sewing machine company was a famous U.S. multinational which often moved behind tariff walls and even pretended to become a multinational company of respective home countries (Wilkins 1986, O'Rourke and Williamson, 1999, p.218).

The log investment stream (based on individual FDI) serves as dependent variable, which we observe on a firm level. Yet, we have only 376 underlying observations (that we can aggregate to country level), because the investment stream was not always reported when companies conducted FDI.[77] Accordingly, we aggregate FDI

[76] As our human capital indicator is the equally weighted average of primary school enrolment rates and patents of foreign firms in Germany, we cannot determine the same measure for Germany itself. Hence, to discuss differences in human capital endowment, we calculate the deviation in the human capital proxy from the maximum of all host countries.

[77] Balance sheet information could help to overcome this data limitation; however, we cannot distinguish between new FDI and old stakes in foreign enterprises. In spite of 552 balance sheet observations regarding the foreign activities of a company (minority stakes, foreign subsidiaries etc.), we cannot rely on this information.

over all companies to form pairs of home and host countries. The following regression equations are used for our gravity and knowledge-capital models.

$$\log(\text{invest}_{\text{f}}) = \alpha_j + \beta_1\left(\ln(\text{GDP}_{\text{f}}) + \ln(\text{GDP}_{\text{Home}})\right) + \beta_2\left(\ln(\text{GDP}_{\text{f}}) - \ln(\text{GDP}_{\text{Home}})\right)^2 + \beta_3\text{distance}_{\text{f}} + \beta_4\text{language}_{\text{f}} + u_f \tag{2}$$

$$\log(\text{invest}_{\text{f}}) = \alpha_j + \beta_1\left(\ln(\text{GDP}_{\text{f}}) + \ln(\text{GDP}_{\text{Home}})\right) + \beta_2\left(\ln(\text{GDP}_{\text{f}}) - \ln(\text{GDP}_{\text{Home}})\right)^2 + \beta_3\text{distance}_{\text{f}} + \beta_4\text{language}_{\text{f}} + \beta_5 \cdot humancap_f + u_f \tag{3}$$

We could extent the standard model by inserting wage differences, as lower wages in host countries might trigger vertical FDI, for firms can reduce costs by shifting their wage intensive production to a labour abundant country.[78]

$$\log(\text{invest}_{\text{f}}) = \alpha_j + \beta_1\left(\ln(\text{GDP}_{\text{f}}) + \ln(\text{GDP}_{\text{Home}})\right) + \beta_2\left(\ln(\text{GDP}_{\text{f}}) - \ln(\text{GDP}_{\text{Home}})\right)^2 + \beta_3\text{distance}_{\text{f}} + \beta_4\text{language}_{\text{f}} + \beta_5 \cdot humancap_f + \beta_6\left(\ln(\text{wage}_{\text{Home}}) - \ln(\text{wage}_{\text{f}})\right) + u_f \tag{4}$$

Regression (4) is extended further by incorporating a measure for protectionism to control for differences with regard to trading policies.

$$\log(\text{invest}_{\text{f}}) = \alpha_j + \beta_1\left(\ln(\text{GDP}_{\text{f}}) + \ln(\text{GDP}_{\text{Home}})\right) + \beta_2\left(\ln(\text{GDP}_{\text{f}}) - \ln(\text{GDP}_{\text{Home}})\right)^2 + \beta_3\text{distance}_{\text{f}} + \beta_4\text{language}_{\text{f}} + \beta_5 \cdot humancap_f + \beta_6\left(\ln(\text{wage}_{\text{Home}}) - \ln(\text{wage}_{\text{f}})\right) + \beta_7 \cdot protect + u_f \tag{5}$$

[78] We collected real wages for host countries in the respective year of FDI inflows.

Table 6.2 reports the results for the capital-knowledge models with and without our proxy for human capital differences, wage gaps, and protectionism. The signs of the coefficients are interesting; as it shows that vertical FDI was important at least in the case of some host countries.

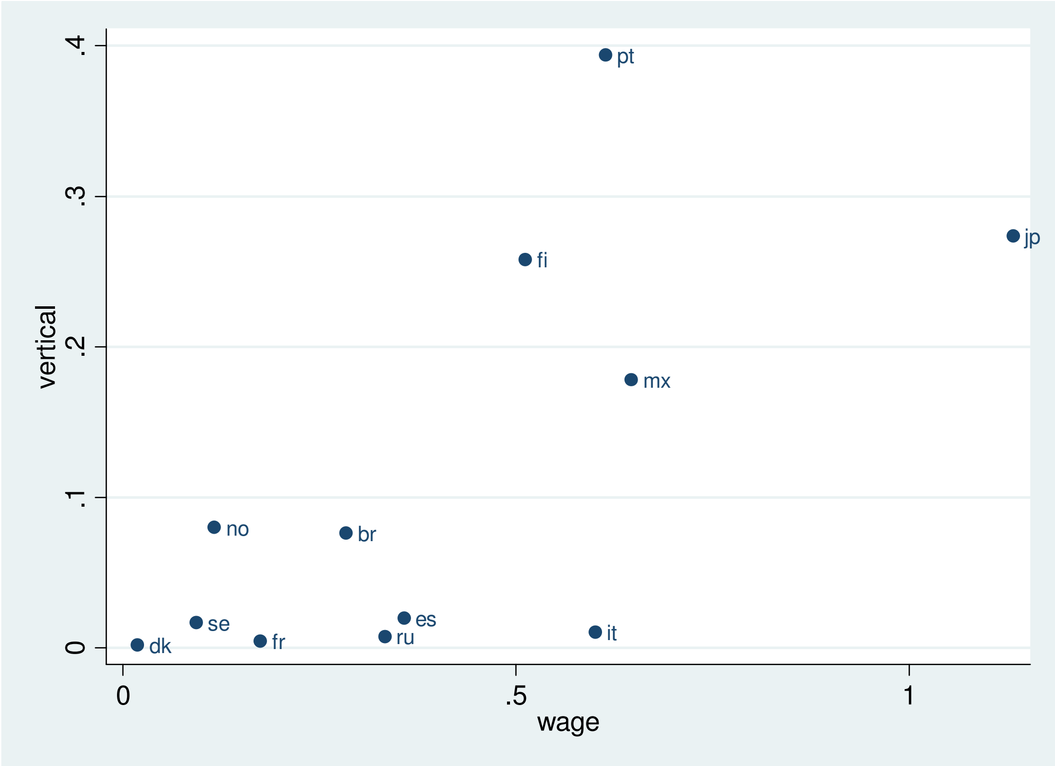
TABLE 6.2: OLS ESTIMATION OF GRAVITY MODELS ON COUNTRY LEVEL

Variable	IV country_fdi		V country_fdi		VI country_fdi		VII country_fdi	
Sum_gdp	**1.077**	*5.08*	**1.760**	*4.60*	**2.134**	*4.68*	**3.963**	*4.16*
Dispersion	-0.010	*-0.74*	**-0.062**	*-2.79*	**-0.078**	*-2.89*	**-0.202**	*-3.26*
Distance	-0.000	*-1.16*	-0.000	*-0.25*	0.000	*0.38*	0.000	*0.58*
Language	0.887	*1.25*	0.469	*0.57*	0.825	*0.98*	1.032	*0.63*
Humancap			-1.411	*-1.86*	-1.060	*-1.36*	1.569	*-1.59*
Wagediff					**1.748**	*1.92*	**5.220**	*3.49*
Protect							**0.147**	*2.29*
Constant	**-18.629**	*-3.88*	**-23.228**	*-4.56*	**-33.536**	*-4.31*	**-67.220**	*-4.06*
Adj. R^2	0.154		0.186		0.164		0.154	
N	281		229		225		158	

Note: Robust t-statistics in italics. Shading indicates significance at 0.10-level.
Data sources: see Table 6.4.

The standard gravity model (see model 4) with the sum of GDP, dispersion factor, distance, and common language dummy has explanatory power in our country panel. We confirm the presence of FDI motivated by horizontal strategies: large and rich host countries attract more FDI than the ones with smaller GDP. Distance has a negative impact on FDI in two of the four specifications; hence, it is not a robust predictor for cultural and institutional similarities. In fact, the dispersion factor has a strong negative impact on FDI flows, which shows that countries of similar size with regard to its GDP exhibit higher FDI flows. Common language has a positive but insignificant effect. To account for vertical FDI driven by human capital differences and wage gaps, we reveal that vertical FDI was relevant for some countries that had lower wages compared to Germany (see model 6 and 7). Differences in human capital, however, did not cause higher inflows of FDI. Hence, wage gaps were the driving force for vertical FDI. To illustrate our findings, Figure 6.2 plots the percentage of vertical FDI suggested by model 3 against the difference in human capital and wage gaps. The three countries that exhibited the highest estimated vertical (conditional) FDI are Portugal (39%), Japan (27%), and Finland (26%), of course conditional on the other factors included. Countries more similar to Germany, such as France, show a low figure of estimated vertical FDI, namely 0.4%. Accordingly, we confirm vertical FDI – but we also stress that horisontal FDI driven by access to foreign markets was predominant. We show that to some extent wage differences mattered for FDI decisions apart from access to foreign markets. Protectionism had a positive but small impact on FDI streams on the aggregated level, which highlights that restricting free trade could stimulate FDI.

FIGURE 6.2. WAGE GAPS AND VERTICAL FDI



Data sources: see Table 6.4.

6.5.3 Was FDI successful?

Our logit and conditional logit models reveal that firms with higher return on equity conduct more FDI. However, there might be an endogeneity problem in this relationship: FDI might also lead to higher returns on equity. There are at least two approaches that could solve the problem of endogeneity of FDI and firm performance, namely a two-step approach and a modified vector autoregressive model. The two-step approach is rather simple, but affects statistical inference, as error-terms in the second step depend on the precision of the first step. The first step could be a dynamic probit model that allows serial dependency of FDI, which reflects that FDI becomes more likely if the company has already conducted FDI before. As we can only observe whether a company undertakes FDI or not, the underlying decision process can be regarded as unobserved.

Based on a dynamic probit model, we could estimate the probability that company i executes FDI in period t. Following ROC analysis, a cut-off rate can be justified, which yields expected and unexpected FDI. The second step would insert unanticipated FDI into the regression framework (5); thus, only exogenous FDI influences ROE. Note that λ denotes a vector with additional exogenous variables like firm size. This procedure, however, has several pitfalls, namely the error-terms of the second step are contaminated and determining an appropriate cut-off rate is a tricky issue.[79]

$$ROE_i = \alpha + \beta_1 FDI_i + \boldsymbol{\beta}_2' \boldsymbol{\lambda} + u_i \tag{5}$$

VAR models in contrast do not require predefining exogenous variables; hence, they might be an alternative approach. We could write a standard VAR in the following manner assuming the same exogenous variables in both equations

$$\begin{aligned} ROE_{it} &= \alpha_1 + \sum_{j=1}^{q} \beta_{1j} ROE_{it-j} + \sum_{j=1}^{q} \gamma_{1j} FDI_{it-j} + \vartheta_1' \boldsymbol{\lambda} + u_{it} \\ FDI_{it} &= \alpha_2 + \sum_{j=1}^{q} \beta_{2j} ROE_{it-j} + \sum_{j=1}^{q} \gamma_{2j} FDI_{it-j} + \vartheta_2' \boldsymbol{\lambda} + e_{it} \end{aligned} \tag{6}$$

For continuous and observable variables, OLS or GMM produce reliable estimates – but the variable FDI is binary. As the decision to conduct FDI could be described as a Bernoulli-process (“to invest or not to invest”) with probability p, we cannot insert FDI and ROE into a standard VAR specification. Dueker (2005) proposes a Qual VAR

[79] One can avoid determining a cut-off rate by inserting predicted probabilities instead of unanticipated FDI into regression (5); however, the first step still influences the error terms of regression (5).

(Qualitative VAR) approach that accounts for the latent variable problem and hence can deal with binary variables.[80] We apply his procedure and specify a Qual VAR; thus, FDI follows a Bernoulli-process, and a logit model that accounts for lagged ROE and other exogenous variables can explain the probability of FDI. Lagged FDI in turn affects ROE as described in model (6). Returns on equity follow a normal distribution as implicitly assumed in standard VAR models; however, we could also allow fat-tails – but our results do not differ. Consequently, our model has the following structure.[81]

$$
\begin{aligned}
ROE_{it} &\sim N(\mu_{it} | FDI_{it}, \sigma^2) \\
E(ROE_{it} | FDI_{it}) &= \alpha_1 + \sum_{j=1}^{q} \beta_{1j} ROE_{it-j} + \sum_{j=1}^{q} \gamma_{1j} FDI_{it-j} + \vartheta_1' \boldsymbol{\lambda} \\
FDI_{it} &\sim Bernoulli(p_{it} | ROE_{it}) \\
\text{logit}(p_{it} | ROE_{it}) &= \alpha_2 + \sum_{j=1}^{q} \beta_{2j} ROE_{it-j} + \sum_{j=1}^{q} \gamma_{2j} FDI_{it-j} + \vartheta_2' \boldsymbol{\lambda}
\end{aligned} \qquad (7)
$$

As the total likelihood of the two-equation system cannot be easily specified, we again follow Dueker (2005), who proposed a Markov-Chain Monte Carlo technique (MCMC).[82] Initial values for parameters can be specified; however, we prefer to sample initial values from priori distributions, namely normal distributions for coefficients and gamma distributions for variance terms.[83] The Gibbs sampler can handle parameters that should be determined simultaneously – but are actually estimated in a sequential

[80] The latent variable in Dueker (2005) is an indicator variable of recessions, which might improve forecasts of macroeconomic time series.
[81] Note that we specify conditional distributions, as the complete likelihood of the two-equations model cannot be easily derived (see Dueker, 2005).
[82] We used Openbugs 2.1.1 to run MCMC models. This software package can be downloaded.
[83] Note that Openbugs works with precision matrices instead of variance-covariance matrices; hence, one has to invert precision matrices to obtain estimates for variances and covariances.

process.[84] All coefficients have a flat normal distribution as prior; thus, our Bayesian MCMC approach converges to maximum likelihood estimates. To run the MCMC, we apply a standard Gibbs sampler with 1000 iterations. In order to generate a possibility for comparison with our MCMC estimates, we also run model (6) using OLS and hence treating the model as normal VAR. Based on Hannan-Quinn, Schwarz, and Akaike information criteria, we set the lag number q equal to one. Table 6.3 contains our results and underlines that FDI does not increase returns on equity; thus, we cannot claim that FDI was generally successful. Our results suggest that FDI was more likely if the company conducted already FDI in previous periods. Besides the serial dependency of FDI, firm size is the only consistent predictor for FDI emphasising the overall importance of economies of scale for entering foreign markets. To show that our MCMC estimates converge, Figure 6.3. plots the history of the estimation procedure for every iteration.

[84] Note that we can only determine conditional distributions, as the complete likelihood of the two-equation system cannot be determined analytically (see Dueker, 2005). Hence, we treat a simultaneous system as a sequential problem.

TABLE 6.3: VAR MODEL WITH ONE LAG

	OLS				MCMC			
	7		8		9		10	
	fdi		roe		fdi		roe	
L.fdi	**0.435**	14.2	**0.052**	2.50	**0.433**	6.23	-0.010	-0.36
L.roe	**-0.057**	-1.66	**0.808**	35.20	0.103	0.38	**0.736**	31.09
Size	0.009	1.57	-0.002	-0.39	**0.365**	4.01	-0.045	1.29
Foundation	-0.000	-0.46	**-0.001**	-2.38	**-0.002**		**-0.011**	-59.12
Chemical	-0.016	-0.69	-0.011	-0.67	-0.054	-0.20	-0.038	1.48
Electric	-0.025	-1.10	0.009	0.56	0.088	0.34	0.078	1.61
Machinery	**-0.048**	-2.23	**-0.035**	-2.41	-0.202	0.93	**-0.033**	-2.00
Metal	**-0.075**	-2.40	0.009	0.43	-0.231	1.09	0.043	1.77
Constant	0.834	0.94	**1.395**	2.33	0.086	0.30	**34.690**	673.72
Observations	610		610		610		610	
ROE causal	2.74							
Prob>Chi2	0.0977							
FDI causal	6.270							
Prob>Chi2	0.0123							

Note: z-statistics in parentheses, Shading indicates significance at 0.10-level.
Data sources: see Table 6.4.

6.6 Conclusion

We have studied a new database on German FDI transactions that were conducted by joint stock companies between the 1870s and late 1920s. We collected data on 377 companies, which conducted almost 1000 foreign direct investments, and added a control group of 556 companies that exhibit the same industry composition. Following Helpman et al. (2004) who emphasised the importance of firm size and efficiency for the late 20th century, we find that similar factors were at work in the late 19th and early 20th centuries.

Companies founded in later years exhibited a lower tendency to invest abroad; however, the impact was not significant.

In a second step, we analysed the destination choice of German companies going abroad. We aggregated individual investment streams by host countries and by the time of investment, which resulted in an unbalanced panel. Our extended capital-knowledge model confirmed the predominant role of horizontal investment strategies already in the late 19th and early 20th century. Interestingly, we also found some evidence for vertical FDI, as wage differential caused FDI inflows. In contrast, differences in human capital did not have a measurable impact presumably because German firms brought their proprietary knowledge with them and hence did not have to rely on human capital of host countries. We also assessed the effect of distance, both geographic and cultural, the latter captured by the proxy common language. It turned out that the same language was by far more important than simple geographic distance, which is certainly an interesting result.

Finally, we addressed the potential endogeneity between profitability and FDI: do firms conduct FDI, because they are already successful on the home market, or is their profitability stimulated by entering foreign markets? Controlling for this dual causality by a Qual VAR approach, we actually find that profitability was not a significant determinant of FDI and vice versa. In contrast, previous FDI was a relatively strong predictor of subsequent FDI, and firm size remained a crucial determinant for FDI also in this specification.

E. Appendix to chapter 6

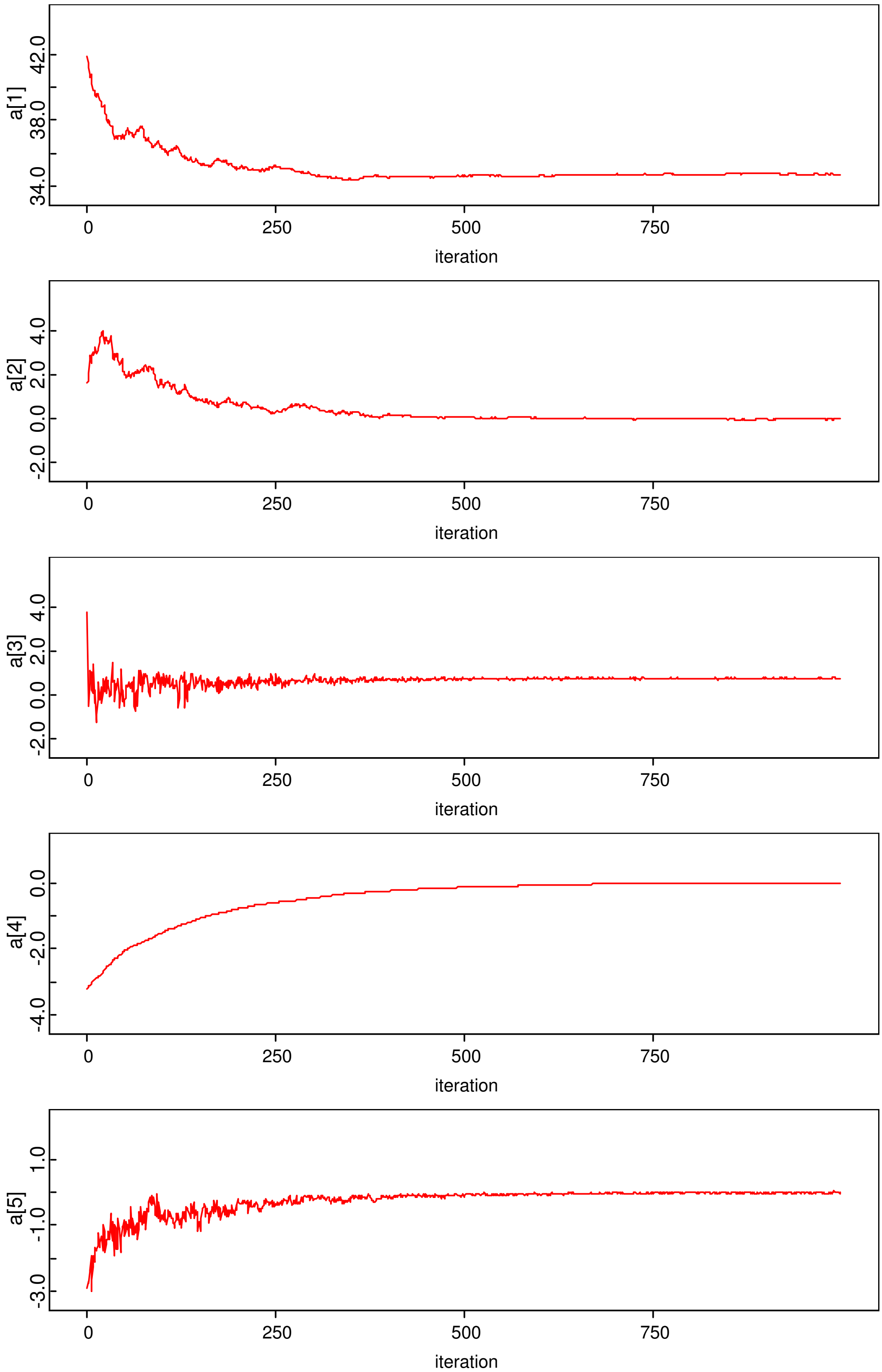
TABLE 6.4: VARIABLE DEFINITIONS AND DATA SOURCES

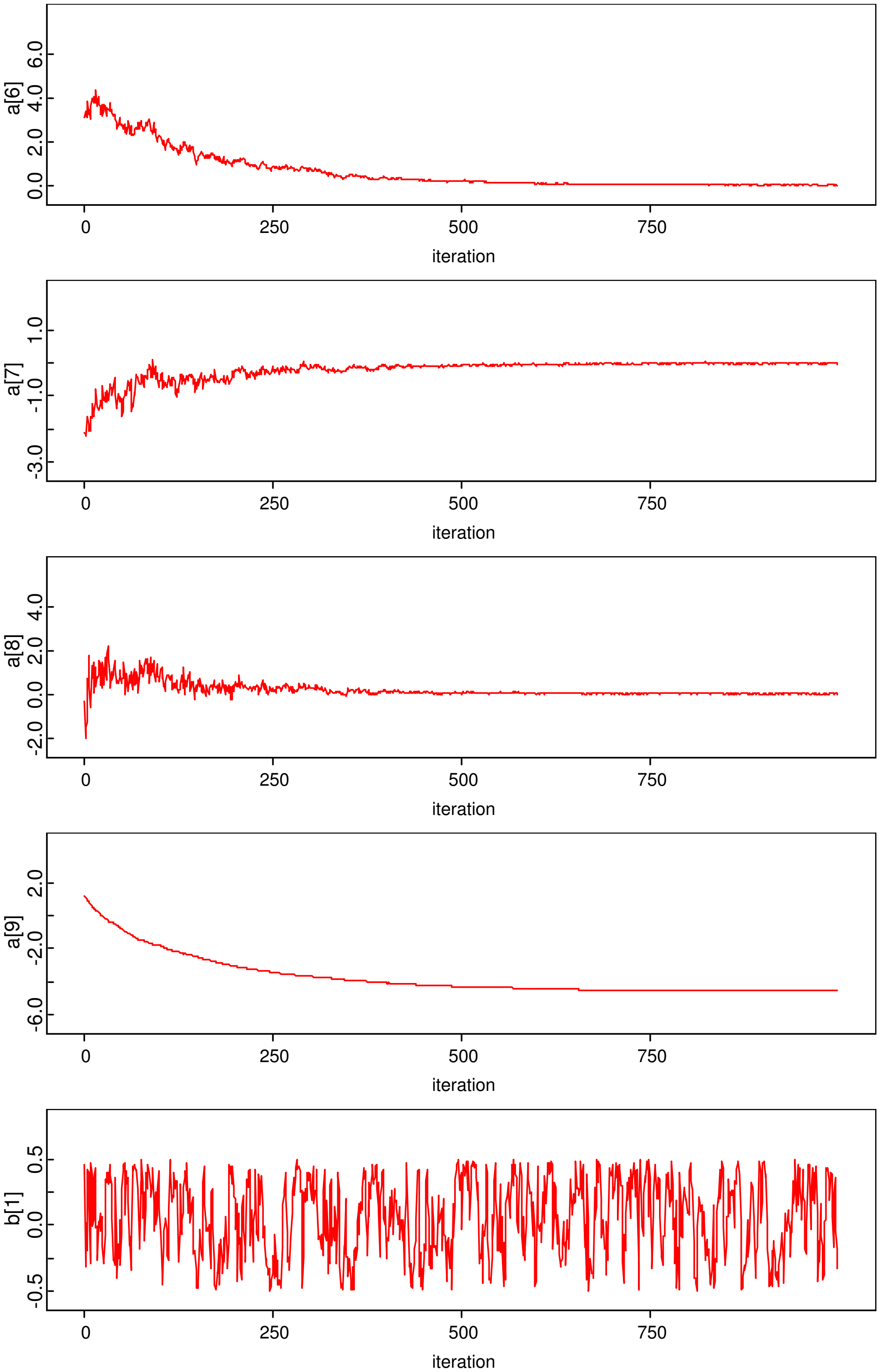
	Endogenous Variables:
fdi	Dummy variable, 1 = FDI, 0 = no FDI
log (invest)	LN of deflated amount of investment of the respective FDI Data source: ´Handbuch der deutschen Aktiengesellschaften´ (1897-1901, 1912, 1927). Amount of investment was deflated, using Hoffmann, W.G. (1965), p.601, col.15.
	Exogenous Variables:
chemical	Dummy variable, 1 = chemical industry, 0 = other industries
dispersion	$(\ln(GDP_f)-\ln(GDP_{Home}))^2$ Maddison (1995).
distance	Distance between Germany and the country of FDI in km. Data source: http://www.macalester.edu/research/economics/PAGE/HAVEMAN/Trade.Resources/Data/Gravity/dist.txt
protect	Protectionism: average tariff rate = ratio of custom revenues to total Data sources: Accominotti and Flandreau (2006), Clemens and Williamson (2004), Rubio (2006).
electric	Dummy variable, 1 = electrical industry, 0 = other industries
foundation	Year, when joint stock company entered share register Data source: ´Handbuch der deutschen Aktiengesellschaften´ (1897-1901, 1912, 1927).
humancap	Measure for technical human capital, see text. Data source: Labuske and Baten (2007).
language	Dummy variable, 1 = official language of the host country is German, 0 = other language
machinery	Dummy variable, 1 = machinery industry, 0 = other industries
metal	Dummy variable, 1 = metal working industry, 0 = other industries
patent	Number of patents in the year of FDI Data source: Verzeichnis der von dem kaiserlichen Patentamt im Jahre 1875-1918 erteilten Patente.
roe	Return on equity Data source: ´Handbuch der deutschen Aktiengesellschaften´ (1897-1901, 1912, 1927).
log(size)	LN of total equity Data source: ´Handbuch der deutschen Aktiengesellschaften´ (1897-1901, 1912, 1927).
sum_gdp	$\ln(GDP_f)+\ln(GDP_{Home})$ Data source: Maddison (1995).
wagediff	$\ln(wage_{Home})-\ln(wage_f)$ Data source: Williamson (1995).

TABLE 6.5: DESCRIPTIVE STATISTICS

Joint stock companies …	N	Mean	Std. Dev.	Min	Max
with FDI					
Foreign direct investment	376	636508.700	1705981.000	1000.000	23700000.000
log(size)	948	15.808	1.541	9.210	20.500
roe	948	0.101	0.224	-0.996	1.759
year of firm creation	948	1893.956	16.546	1825	1927
without FDI					
Foreign direct investment	0	0.000	0.000	0.000	0.000
log(size)	595	14.503	1.349	9.210	19.388
roe	595	0.058	0.297	-3.419	1.242
year of firm creation	594	1895.382	16.328	1816	1927
in electrical industry					
Foreign direct investment	95	1148860.000	1552101.000	2036.000	7374750.000
log(size)	315	16.515	1.753	9.903	18.982
roe	315	0.120	0.090	-0.283	1.008
year of firm creation	315	1898.251	12.222	1871	1927
in machinery industry					
Foreign direct investment	45	7.914	4.344	2.485	14.403
log(size)	302	14.983	1.272	9.210	17.074
roe	302	0.010	0.330	-2.102	0.958
year of firm creation	302	1898.185	16.769	1846	1927
in chemical industry					
Foreign direct investment	53	451707.400	868974.000	1000.000	4000000.000
log(size)	201	14.866	1.259	10.127	17.399
roe	201	0.118	0.226	-0.485	1.673
year of firm creation	200	1893.295	17.292	1835	1923
in metal processing industry					
Foreign direct investment	32	480198.200	707181.600	2000.000	2894477.000
log(size)	184	15.110	1.629	10.309	20.500
roe	184	0.077	0.326	-2.252	1.759
year of firm creation	184	1896	13.856	1844	1927
with FDI in Austria-Hungary					
Foreign direct investment	63	766628.200	1059818.000	2036.000	4766800.000
log(size)	178	15.433	1.424	10.926	20.500
roe	178	0.118	0.215	-0.996	1.759
year of firm creation	178	1893.742	13.864	1862	1927
with FDI in UK					
Foreign direct investment	73	142987.500	249040.900	1000.000	1024590.000
log(size)	126	15.608	1.427	13.122	19.114
roe	126	0.154	0.202	-0.631	1.647
year of firm creation	126	1893.889	14.137	1851	1927
with FDI in France					
Foreign direct investment	33	593384.100	864915.200	8000.000	3214050.000
log(size)	67	15.634	1.424	12.612	18.892
roe	67	0.195	0.315	-0.631	1.759
year of firm creation	67	1893.164	13.257	1856	1922
with FDI in the US					
Foreign direct investment	29	812175.200	2706315.000	5000.000	14700000.000
log(size)	66	15.370	1.199	12.142	18.867
roe	66	0.122	0.158	-0.631	0.643
year of firm creation	66	1891.803	20.435	1824	1923

FIGURE 6.3: CONVERGENCE OF THE MCMC ESTIMATION

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500
750
iteration
a[8]
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0.0
2.0
4.0
0
250
500
750
iteration
a[9]
-6.0
-2.0
2.0
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500
750
iteration
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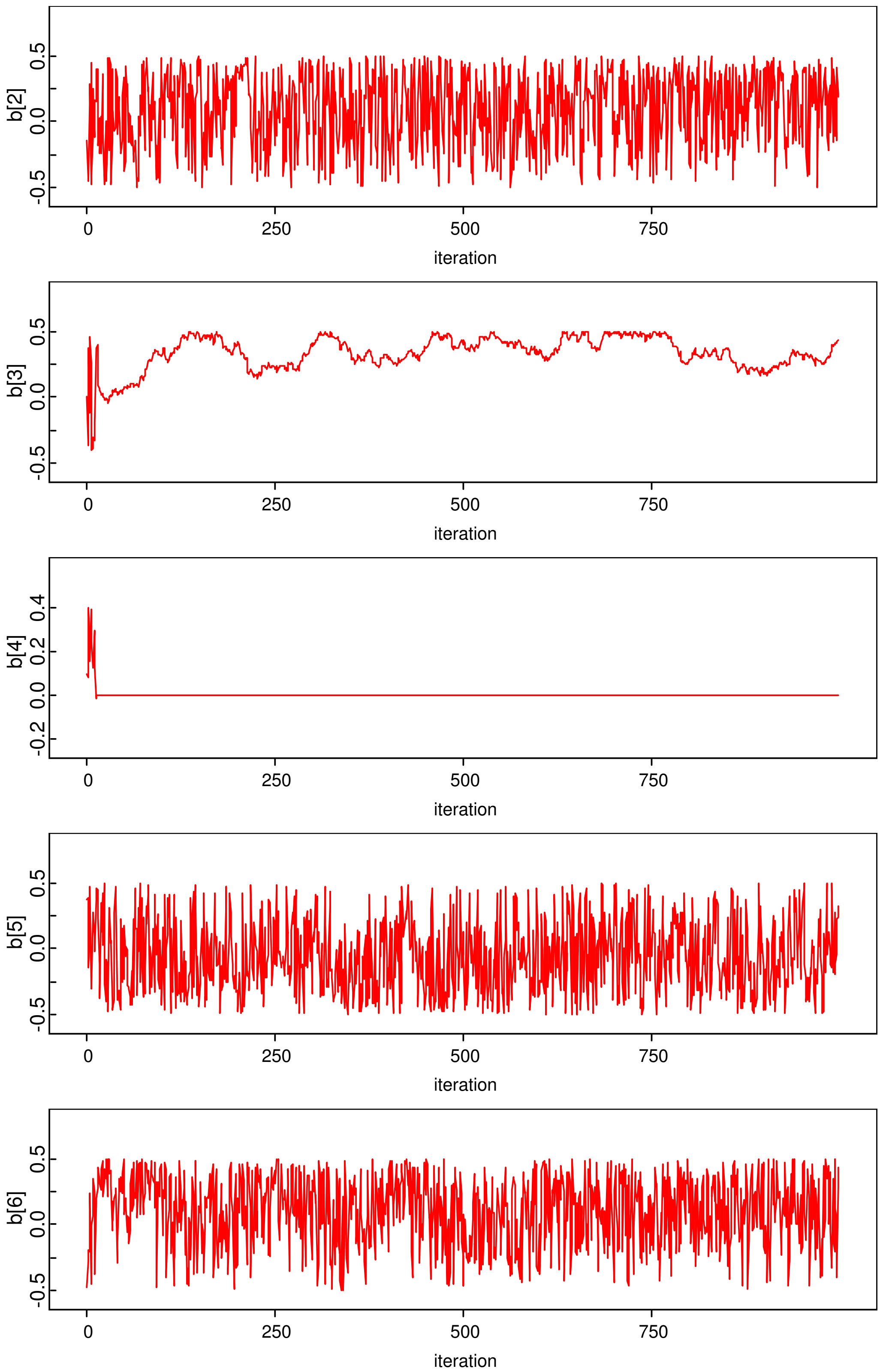
0
250
500
750
iteration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500
750
iteration
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0.2
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500
750
iteration
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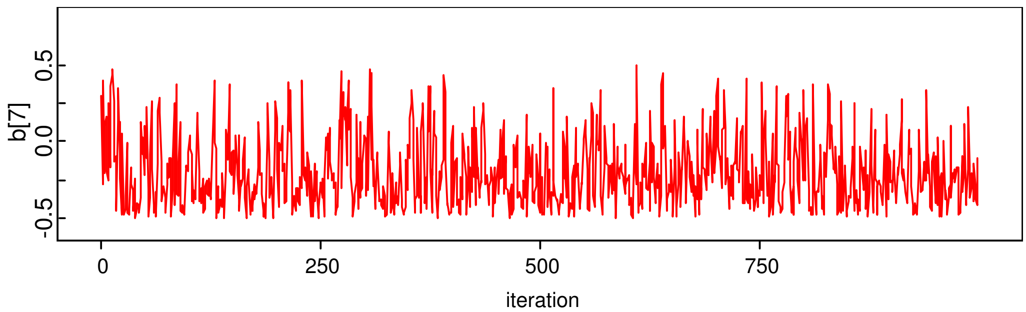
750
iteration



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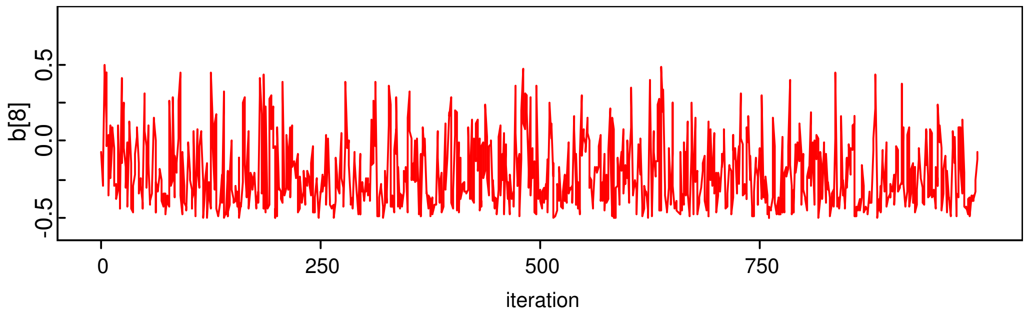

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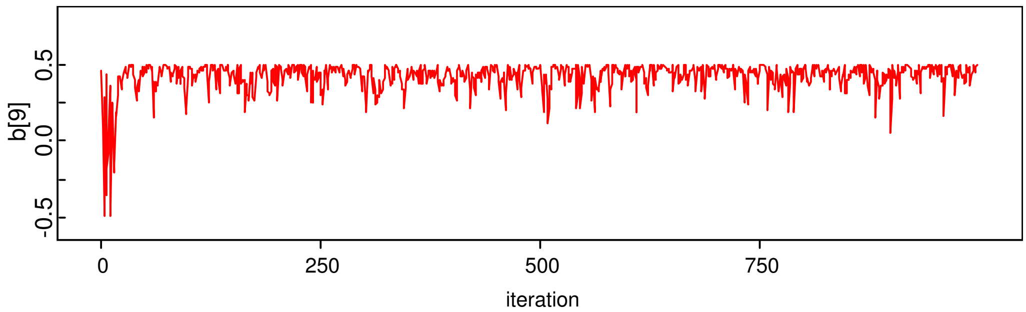

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500
750
iteration

7 CONCLUDING REMARKS

This doctoral thesis is a contribution to close the gap in the literature on the relevancy of patent protection for domestic and foreign inventors and economies. Research on this topic is scarce especially for pre- and post-WWI Germany. The global significance of German high-value patents for domestic and foreign inventors and economies arose due to the first Germany-wide patent law enacted in 1877. This patent act enabled both national and foreign patentees equally to reap the fruits of their intellectual investment by restraining competitors to adapt the patented invention. The richness of the high-value datasets and its accurate information on each and every domestic and foreign patentee stimulated the analysis of high-value patenting in Germany in an international perspective. Furthermore, the possibility to combine the datasets with other databases such as Germany's machinery exports and imports and FDI of German joint stock companies led to interesting research questions.

In chapter two, we focussed on the innovativeness of fifty-one countries around the world 1880-1914 and studied determinants of their high-value patenting activities in Germany. Thereby we corroborated three hypotheses: first, we asked whether the existence of patent protection in the native country had a positive influence on innovativeness. In our cross-sectional and panel regressions, we found a positive impact of sufficient patent protection in the inventor's home country on the number of high-value patents. Second, we prove that primary schooling was a driving force for inventive activities from inventors and inventing companies abroad at the turn of the century. Third, a high risk of expropriation by a monarch in the native country discouraged inventors to establish economic relations and thus to patent there. More secure general property rights stimulated not only growth, but also innovativeness – or perhaps via innovativeness also growth.

As shown in chapter three, the aftermath of WWI affected also the patenting behaviour of foreign actors in the world markets. The focus of interest was especially the Germany's WWI opponents between 1919 and 1932. We found empirical evidence that warfare was hindering particularly inventors from Allied countries to hold German patents due to economic and political conflicts and ongoing enmities. Furthermore, we compared our results to the pre-1914 phase and analysed whether first signs of differences in patenting behaviour between the Central and Allied powers were already in place before the outbreak of WWI. This was not the case.

We estimated new figures for human capital formation between 1880-1910 based on primary schooling and high-value patents in chapter four. We found that our newly created variable "Human Capital Formation" could explain a substantial share of economic growth even half a century later. There is a strong positive effect of human capital in 1910 on the level of GDP per capita between 1950 and 1985.

In chapter five, we analysed whether the growing international competitiveness of the German mechanical engineering industry in the pre-war period was determined by the fortunate combination of outstanding technological creativity and availability of comparatively cheap labour force. The ratio of innovativeness had positive and significant impact on the export performance of the German machine builders which implies that technological creativity in fact fostered international competitiveness of the German mechanical engineering industry in the German Empire. The influence of the real wage ratios on export-import ratios was vague and mostly insignificant.

Finally, we studied firm characteristics that prompted FDI, preferred host countries, and whether FDI was successful in terms of enhancing corporate profitability. To our knowledge, this study is the first historical analysis of German FDI streams at firm level. We came to the conclusion that firm size and profitability in terms of higher returns on equity made FDI more likely, whereas the year of foundation, shows a negative but insignificant impact. On an aggregated level, our extended capital-knowledge model confirmed the predominant role of horizontal investment strategies already in the late 19th and early 20th century. Interestingly, we also found some evidence for vertical FDI. Conversely, human capital did not have a measurable impact.

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