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The Historical Market for
Technology Licenses:
Chemicals, Pharmaceuticals,
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in Imperial Germany

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MAX PLANCK SOCIETY



The Historical Market for Technology Licenses: Chemicals, Pharmaceuticals, and Electrical Engineering in Imperial Germany

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The Historical Market for Technology Licenses: Chemicals, Pharmaceuticals, and Electrical Engineering in Imperial Germany^{*}

by

Carsten Burhop[‡] and Thorsten Lübbers

Abstract

We investigate a sample of 180 technology licensing contracts closed by German chemical, pharmaceutical, and electrical engineering companies between 1880 and 1913. A regression analysis shows that licensing contracts closed before a patent was granted and contracts closed between firms and individual inventors had a higher probability of including a profit-sharing clause. This supports Jensen and Thursby's (2001) model, who propose equity-sharing licensing contracts to solve moral hazard problems. Moreover, we show that milestones were a substitute for profit shares. Furthermore, exclusive licences offered a significantly higher profit share to the licensor.

JEL-Classification: N 83, O 32, L 14

Keywords: Economic History; Germany; pre-1913; Licensing contracts; Technology transfer

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I. Introduction

Today, licenses are a common instrument of the owners of patents to make their innovation accessible to other users. This is, in general, good for users as well as innovators, since it generates profits and license fees for licensor and licensee. Consequently, many innovators share their patents via licensing contracts: In a survey of U.S. patent holders, nearly 18 percent of all patents in the respondents' patent portfolio were licensed (Scotchmer, 2006: 161). Moreover, about 20 percent of the foreign direct investment income of U.S. multinational companies is currently generated from technology licensing agreements (Vishwasrao, 2007).

Prospering markets for technology are not a recent phenomenon. They already existed in the U.S. during the mid-19th century facilitating the transfer of patents from individual inventors to firms. In particular, Lamoreaux and Sokoloff (1999, 2001) demonstrate that a large fraction of U.S. patents were fully or partially assigned, i.e., transferred, by the inventor. During the 1870s, inventors commercialised their ideas themselves, but often granted geographically bounded licenses to producers in distant regions. At the turn of the century, innovation and commercialisation were increasingly separated activities and inventors sold or licensed their patents to firms. The use of licenses to commercialise innovations is also highlighted by Khan and Sokoloff (1993) and by Lamoreaux and Sokoloff (2000), who describe some of the licensing contracts closed by America's great inventors during the 19th-century and the means of technology transfer in the American glass industry in the late 19th- and early 20th-century, respectively.

Evidence for technology transfer is also available for Germany. For example, Streb et al. (2006) show that inter-industry knowledge spillovers between technologically, economically, and geographically related industries were a major source for further innovative activity during the German industrialisation. In addition, Streb et al. (2007) demonstrate the existence of knowledge spillovers between the textile and dyestuff industry: innovations in one branch caused output and innovations in the other branch. Furthermore, Baten et al. (2007) illustrate the positive impact of intra- and inter-industry knowledge externalities for the innovative activity of firms located in Baden, a small state in south-west Germany. In summary, the evaluation of patent data using econometric methods reveals an impact of knowledge spillovers on innovativeness in Germany at the turn of the 20th century. Yet, these studies do not identify the channels of knowledge spillovers. Our paper thus complements these findings by offering a systematic, microeconomic analysis of one possible channel of technology transfer, i.e., by analyzing licensing contracts sealed between 1880 and 1914.

So far, no comprehensive historical study on the licensing activity of German companies is available. Nonetheless, some evidence from studies that focus on either the research activities or the general history of specific companies exists. In his study on the synthetic dye research programmes of BASF and Hoechst, Reinhardt (1997), for example, gives a detailed account of the companies' cooperation with individual researchers. In addition, he also briefly mentions licensing agreements that BASF and Hoechst closed with other companies. For the pharmaceutical research activities of Bayer, Hoechst, and Merck, Wimmer (1994) provides details about these

companies' cooperation with individual researchers, too. Furthermore, he also investigates in depth several licensing contracts with companies. Some information on both, licensing contracts with companies and the cooperation with individual researchers is available in Abelshausen's (2002) monograph on the corporate history of BASF, Burhop's (forthcoming) article on Merck, Reinhardt's (1995) work on pharmaceutical research at BASF, and Reinhardt and Travis' (2000) study on Heinrich Caro, BASF's head of research. Finally, Pohl (1988) and Strunk (2000) as well as Feldenkirchen (2003) and Weiher and Goetzler (1981) here and there refer to licensing contracts closed by the electrical engineering firms AEG and Siemens, but hardly ever offer detailed information on the agreements. Thus, a number of case studies are available. However, they lack a common structure, making comparison and analysis in light of theory difficult.

Economic theory has produced scores of models explaining licensing activity and the optimal structure of contracts. The typical model starts with the assumption that a licensing market exists (see, e.g., Arora et al., 2007, for a general discussion of the problems related to the existence of technology markets) and that contracts are structured around a fixed fee and a per-unit royalty (see, e.g., the seminal model by Gallini and Wright, 1992). More recently, theorists focus on the moral hazard problem emerging between licensor and licensee if non-contractible effort of the licensor is necessary after closing the contract to commercialise inventions (Jensen and Thursby, 2001; Macho-Stadler et al., 2008; Dechenaux et al., 2009). These models yield some testable implications regarding the optimal structure of contracts. We are going to test some of these propositions.

Our empirical results, based on 180 licensing contracts closed in Germany's chemical, pharmaceutical, and electrical engineering industries between 1880 and 1913, suggest that moral hazard problems between licensors and licensees were indeed relevant. In particular, we show that early-stage technology not ready for commercialisation, e.g., non-patented innovations or technology licensed by individual inventors to firms, were more likely to be licensed using profit-sharing agreements. Moreover, our results suggest that the size of profit shares and the size and existence of milestone payments were substitutes.

Beyond our contribution to economic history, we thus contribute to the empirical industrial organization literature. Most empirical studies investigating licensing contracts do not contain much information about the details of the contracts. The main reason for this gap is that the licensing agreements are private contracts, which are unobservable to the researcher most of the time. For example, less than ten percent of licensors sent the questionnaire back in one of the most comprehensive studies of licensing contracts (Brousseau et al., 2007). Consequently, econometric investigations of licensing behaviour often employ binary choice variables indicating if a licensing contract was closed (or not) as dependent variable and a set of observable firm- or industry-specific variables as explanatory variables (see, e.g., Anand and Khanna, 2000). Only recently, Mendi (2005) and Vishwasrao (2007) used official forms filled by the licensees of cross-country licensing agreements to evaluate the content of licensing contracts. The official forms, however, do not contain the original licensing contract, but only some binary coded information of interest to the government. Nonetheless, important insights could be derived. In

particular, Mendi (2005) demonstrates that a positive relation between contract duration and the probability of a variable payment in the first year of the contracts' runtime exists for a sample of Spanish licensing contracts. Yet, Mendi (2005) cannot differentiate if this variable payment based on output or profits and this implies that he cannot distinguish if a contract was designed to solve a moral hazard problem between licensor and licensee.

The remaining parts of this paper are organized as follows. In section II, we describe the general historical background for our study. Section III sketches the main insights of Jensen and Thursby's (2001) model. The following section IV presents the data sources and the descriptive statistics. An econometric analysis is contained in section V. The final section VI concludes.

II. Historical background

During the second half of the 19th century, Germany was transformed from a rural economy to one of the leading industrialised countries in the world. Between 1851 and 1913, the net national product (NNP) increased by almost 2.5 per cent per annum (Burhop and Wolff, 2005). At the same time, the share of the agrarian sector in the German workforce decreased at the expense of the industrial sector (Pierenkemper and Tilly, 2004, 18-21). The leading sectors in the early years of Germany's industrialisation were transportation (i.e., railways) and also, to a smaller extent, iron and steel production as well as mining. Then, from the 1870s onwards, in an accelerating process that is often referred to as the 'Second Industrial Revolution', two other sectors gained ever greater importance: the chemical industry and electrical engineering.

The growth of the chemical industry was, first of all, fuelled by advances in the fabrication of synthetic dyes from coal tar. Later on, pharmaceutical innovations and breakthroughs in inorganic chemistry became almost equally important.¹ Between 1891 and 1913, the output of the chemical sector increased by an annual rate of 6.4 per cent (Hoffmann, 1965, 361-362). The growth rate of electrical engineering was even more impressive: Total sales in the sector grew on average by more than 16 percent annually during the same period (Schulz-Hanßen, 1970, 29-31). The major factor behind this impressive growth was the introduction of electrical energy and its utilisation in a wide area of applications, such as transportation, lightning, and power generation.²

The Second Industrial Revolution can also be understood by looking at patenting activity. By investigating long-living patents (i.e., patents in force for at least ten years), Streb et al. (2006) identify four major technology booms between 1877 and 1918. The first boom occurred between 1877 and 1886. It is labelled "railway wave", since most valuable patents were used in this industry. The second and the third boom (1887 to 1896 and 1897 to 1902) were shaped by the

1 On the development of the chemical industry in Germany, Europe, and the USA, see Beer (1959); Haber (1958); Homburg, Travis, and Schröter (1998).

2 On the development of electrical engineering, see the literature on the two major companies, AEG (Pohl, 1988; Strunk, 2000) and Siemens (Feldenkirchen, 2003; Kocka, 1969).

chemical industry and are labelled the “dye wave” and the “chemical wave”, respectively. The final boom, which lasted from 1903 up to the end of the First World War, is identified as the “wave of electrical engineering”.

Apart from the impressive quantitative changes, an important qualitative innovation took place during the late 19th and early 20th century: the incorporation of science into industrial production and the industrialisation of scientific research. Beginning in the 1870s, the companies from the chemical industry made increasing use of the abundant reservoir of scientifically trained chemists: at first, by deepening their cooperation with universities and other external research facilities;³ then, in a next step, by the internalisation of scientific research. The major companies from the chemical industry – BASF, Bayer, and Hoechst – hired an ever-growing number of university-trained scientists between the late 1870s and early 1890s and founded central research laboratories (Homburg, 1992). Electrical engineering profited from the translation of engineering from a practically orientated occupation to a scientific discipline that was taught at universities and other institutions of higher education (König, 1996). In addition, and as a result of this development, the companies from this sector also increased their research staff. However, the internalisation of scientific research was not conducted on the same scale and with the same rigour as in the chemical industry.⁴

Apart from substantial investment in universities and other research facilities, the single most important political contribution to the emergence of the knowledge-based economy was the enactment of the first federal German patent law in 1877. In the preceding years, a patchwork of numerous patent legislations existed in the individual German states, and in many cases, the state authorities regarded patents as privileges rather than as rights.⁵ The first federal patent law of 1877 included some stipulations that supported the interest of industrial companies vis-à-vis individual inventors. At first, a patent did not necessarily belong to the inventor, but was granted to the person or institution who registered it at the patent office.⁶ This stipulation allowed companies to apply for patents of inventions made by their employees in the companies’ names. Thus, it facilitated their research activities based on division of labour. Second, a patented invention had to be worked. If the patentee did not do so herself or licensed the patent, the protection could disappear after three years. In effect, this stipulation favoured companies over individual inventors, as individuals were usually unable to produce an invention themselves. Furthermore, the duty to use a patent hindered strategic patenting behaviour aimed at the blockade of market entrants, because companies could not apply for a wide range of patents in one line of business without being able or willing to use all the property rights. Third, all patent applications were

3 There are numerous studies on the linkage between the state, universities, and the chemical industry. See, e.g., Borscheid (1976), Murmann (2006), and Wetzel (1991).

4 Siemens had not created a central research laboratory until the beginning of the 1920s. However, this does not mean that that no research took place within the company, but that it was decentralised in different departments and various small laboratories. On the development of research at Siemens, see Erker (1990), Hack (1998: 109-118), Trendelenburg (1975: 1-50), and Schubert (1987). A comprehensive study on the organisation of research at AEG is not available.

5 For the history of the patent laws of different German territories, see Heggen (1975), Seckelmann (2006, 57-106).

6 The patent law of 1877 and the revised version of 1891 are printed in Seckelmann (2006, 427-436, 440-451).

made subject to a thorough pre-examination by the German patent office, which had to judge whether the application really constituted a patentable invention (Seckelmann, 2006, 257-260). This stipulation again hindered the blockade of actual or potential competitors, as it also reduced the possibility of extensive patenting. Finally, the patent fees that had to be paid annually in order to uphold a patent for another year were designed progressively.⁷ These again favoured companies over individual inventors, as the latter might in many cases not have been able to pay the renewal fees. Moreover the high renewal fees also hindered excessive patenting activity and a blockade of technological progress, as a patent owner would uphold meaningful and valuable patents only.

For the emergence of the market for technology licenses, some of the above-mentioned peculiarities of the German patent law proved beneficial: The compulsory working of a patent and the progressive nature of the renewal fee must have substantially increased the willingness of individual inventors – and also of firms – to share their findings with industrial partners, as they would have been unable to exploit them themselves. Moreover, the in-depth pre-examination by the patent office increased potential licensees' willingness to pay, as it made it less likely that a patent would be successfully attacked by litigation once it was granted.⁸

III. Theory

Our theoretical considerations base on the model proposed by Jensen and Thursby (2001). They model the licensing relationship between an inventor employed by an university, the university technology transfer office, and a firm. They show that equity-based licensing contracts can be Pareto-superior to royalty-based licensing contracts, but not Pareto-inferior. We simplify the analysis by eliminating the university technology transfer office from the model, since such offices played no role in our historical context. We focus on the advantages and disadvantages of licensing contracts using piece-based royalties or profit-sharing rules.

The licensing game has the following structure. An inventor decides to offer a licensing contract to a firm. Thus, we exclude other ways to exploit the invention, e.g., by founding a firm or selling the patent on the market. If the firm rejects the offer, the game ends. Otherwise, the firm pays a fixed amount m , a period of further development by the inventor and the firm follows, and the effort undertaken by the licensor during this period increases the probability of a commercial success. We assume that effort of the inventor, e , is necessary to bring the product to the market, but that this effort is not contractible. Thus, the inventor is subject to moral hazard and the licensing contract must specify payoffs to motivate him. Three types of payoffs for the inventor are possible: a fixed fee, m , an output-based royalty rate, r , and a profit share, ρ .

7 The renewal fee was 50 Mark for the first and 50 Mark for the second year. Afterwards, the fee increased by 50 Mark each year. If a patentee wanted to uphold a patent for the maximum period of 15 years, he thus had to pay 700 Mark in the last year and 5,300 Mark in total. This compares to an annual per capita income of about 800 Mark in 1913.

8 Secure property rights were also highlighted by Khan (1995) and Khan and Sokoloff (2004) as relevant for the emergence of the U.S. market for patent assignments and technology licenses.

Let us assume that the probability of commercial success is zero if the inventor invests no effort, but is strictly positive and below one, if the inventor invests effort, i.e. $p(0) = 0$, $p(e) > 0$, and $p(\infty) < 1$. In addition, we assume that the firm maximizes its profits under monopoly conditions, i.e., marginal revenues equal marginal costs in equilibrium. The revenue function $R = p(x) \cdot x$ neither includes the royalty rate r nor the profit-sharing rate ρ , whereas the cost function $C = c \cdot x + r \cdot x$ includes the royalty rate, r , but not the profit share, ρ . This implies that output-based royalties r increase the marginal costs, whereas a profit share ρ does not affect the optimization conditions of the firm. Consequently, the optimal output depends on the royalty rate, but not on the profit share. Let $x(r)$ denote the profit maximizing output under the royalty contract. In case of, for example, linear demand and constant marginal costs, the optimal output is decreasing in the royalty rate. We assume that the optimal output is positive if the royalty rate is zero, i.e., $x(0) > 0$.

The firm's expected profit from the invention given a licensing contract (r, m) and effort level e is $P_F(e, E, r, m) = p(e)[\Pi(x(r)) - rx(r)] - m - E$, with E denoting the effort (investment) of the firm to commercialise the invention. $\Pi(x(r))$ is the profit gross of licensing royalty, $rx(r)$ is the cost of the licensing agreement to the firm, and $p(e)$ denotes the probability that the innovation is a commercial success. Clearly, P_F should be non-negative; otherwise, the firm would not accept the licensing contract.

The inventor chooses his effort to maximize expected utility from the contract. Let us assume that an inventor has a separable utility function giving him positive utility from licensing income and negative utility from effort, i.e., $U_I(Y_I) - V_I(e)$, where Y_I denotes the licensing income, U_I the inventor's utility from this income, and V_I his utility from effort. V_I has a negative sign, since effort yields disutility. Furthermore, we assume that the marginal utility of income is positive and non-increasing – this implies the inventor is either risk-neutral or risk-averse – and that the marginal disutility of effort is positive and increasing. The inventor seeks to maximize his utility, i.e., $P_I(e, r, m) = p(e)U_I(m + rx(r)) + (1 - p(e))U_I(m) - V_I(e)$. The inventor's expected utility is the probability of commercial success times the utility derived from royalty income and the fixed upfront payment plus the probability of project failure times the upfront payment less disutility of effort.

The first-order necessary condition for maximization of expected utility is: $\frac{\partial P_I}{\partial e} = p'(e)[U_I(m + rx(r)) - U_I(m)] - V_I'(e) = 0$. Note that the inventor earns the amount m , whether he provides any effort or not. Due to the marginal disutility of effort, the inventor does not expand effort unless the royalty rate is positive. Moreover, a higher royalty rate must lead to a higher licence fee income; otherwise the licensor will not expand his effort. From the firm's point of view, the optimal output is negatively affected by an increasing royalty rate since a higher royalty increases the marginal costs. Thus, at some point, increasing royalties induce falling royalty income.

Based on these assumptions, Jensen and Thursby (2001: 248, Theorem 1) prove that, if development occurs: (i) inventor effort e decreases in the fixed fee m if the inventor is risk-averse, but

effort e is independent from m if the inventor is risk-neutral; (ii) inventor effort increases (decreases, is constant) in the royalty rate r as royalty income increases (decreases, is constant) with respect to the royalty rate.

We now turn to profit-sharing contracts.⁹ In this contract, the inventor receives a positive profit share ρ instead of a per-unit royalty. Clearly, a profit-sharing rule does not affect the profit-maximisation conditions of the firm, since the firm seeks to equalize marginal costs and marginal revenues. Nonetheless, the participation constraint of the firm must hold, i.e., $P_F(e, E, \rho, m) = p(e)[(1-\rho)P(x)] - m - E > 0$. One should note that output is always as least as large under profit sharing agreements as under royalty regimes. In some cases, profit-sharing agreements will result in higher output, lower prices, and higher consumer surplus. Moreover, a profit-sharing agreement always solves the moral-hazard problem because profit shares are only paid after a commercial success of the invention and this commercial success is only possible if $e > 0$. Thus, the contract shall specify a positive profit-share for the inventor. The licensor now maximizes his expected utility $P_I(e, \rho, m) = p(e)U_I[m + \rho P(x)] + (1-p(e))U_I(m) - V_I(e)$.

Jensen and Thursby (2001: 251, Theorem 3) show that: (i) inventor effort is increasing in the profit share; (ii) inventor effort is decreasing in the fixed fee if the inventor is risk-averse, but does not depend on the fixed fee if the inventor is risk-neutral.

Consequently, the decisive difference between a profit-sharing contract and an output-based royalty contract is the effect on the inventor's effort. If a high effort e is necessary, it is possible that such a high effort is only possible with a royalty rate higher than the licensing-revenue-maximizing royalty rate. Thus, the moral hazard problem cannot be fully solved in this case. This cannot occur in profit-sharing agreements since the effort is strictly increasing in the profit share.

Some important variables of the model are, unfortunately, not directly observable, making an econometric test of the model difficult. In particular, we do not observe the stage of an invention, i.e., if it is an early stage invention requiring a high degree of inventor effort or not. Consequently, observable proxies are employed in the empirical part of the paper. First, we assume that non-patented inventions or inventions offered by individual inventors – who most likely do not possess the resources to develop an invention to the market – are early stage inventions. They are more likely to be licensed using a profit-sharing agreement. Moreover, looking only at profit-sharing agreements, the profit-share of the inventor should be higher for early stage inventions. Second, fixed upfront payments should be insignificant for the choice of the contractual design and for the size of the profit-share if inventors are risk-neutral. If, on the other hand, inventors are risk-averse, a high fixed fee reduces inventors' effort. Thus, keeping the effort level constant requires higher profit-shares and the probability of agreeing on a profit-sharing agreement should be higher, since there is a point where a high fixed upfront payment drives the required royalty

9 Jensen and Thursby (2001) model equity shares, not profit shares. The difference between equity shares and profits shares is that equity shares are securitized and can thus be sold on the equity market. This does not affect the optimal structure of the licensing contract.

rate beyond the license-revenue-maximizing royalty rate. If the inventor is risk-neutral, an upfront fixed payment affects neither the type of the agreement nor the size of the profit-share.

Beyond the model proposed by Jensen and Thursby (2001), a variety of alternative models were proposed. Closely related is, first of all, the incomplete contract model of Aghion and Tirole (1994a, 1994b). They are concerned with the optimal distribution of profit shares if an effort on the part of both parties, licensor and licensee, is necessary to develop the invention towards the market. The main proposition of Aghion and Tirole is that the higher the necessary effort of one party, the higher its profit share. This result is similar to the main result derived by Jensen and Thursby (2001), but Aghion and Tirole do not investigate per-unit royalty contracts versus profit-sharing contracts.

Second, Mendi (2005) evaluates the relationship between contract duration and licensor compensation structure. He shows that contracts with a longer duration have a higher probability of including a per-unit royalty payment during the first period of the contract duration. Thus, his model suggests that contract duration is a control variable to be included in econometric investigations.

Third, Macho-Stadler et al. (2008) investigate a similar problem, but allow a negative upfront payment to the inventor, i.e., a financial contribution of the inventor to start development. They show that the inventor effort is strictly increasing in his profit share, but that the incentive must be complemented by a financial contribution of the inventor at some point. Yet, a look into our historical data set shows that negative upfront payments were never agreed upon.

Fourth, Dechenaux et al. (2009) show that per-unit royalties can be inefficient. They propose milestone payments and annual payments of the licensee to the licensor to solve the moral hazard problem. Thus, they hypothesize that milestones and annual payments solve the same problem as profit-sharing contracts, i.e., milestones and annual payments can complement profit-shares in contract choice. Furthermore, if both milestones and profit-shares are agreed upon, the size of the two incentive mechanisms should be negatively related to each other, i.e., they substitute each other. Consequently, we include the existence or the size of milestone payments as a control variable.

Finally, one should note that some contract-theoretical problems were – to our best knowledge – not investigated in the context of licensing contracts. For example, we are not aware of a model investigating the impact of ex-post asymmetric information about the product market success. Obviously, the compensation of the licensor depends on sales figures in case of per-unit royalty and on profit figures in case of profit-sharing contracts. Thus, costly state verification models – verifying sales numbers, prices, and production costs – might be an extension to be incorporated into future licensing models. In the empirical section, we will evaluate if the existence of auditing rights for the licensor affected the contract choice or the size of the profit share.

IV. Data sources and descriptive statistics

The information on the licensing agreements evaluated in this paper is gathered from archival sources. We selected seven companies for our study.¹⁰ Three of them – Allgemeine Elektrizitäts-Gesellschaft (AEG), Telefunken, and Siemens – were engaged in electrical engineering, the other four – Bayer, BASF, Hoechst, and Merck – are from the chemical and pharmaceutical industry. Our sample thus covers the major companies from the two leading sectors of the Second Industrial Revolution. BASF, Bayer, and Hoechst were the dominant players on the market for synthetic dyes and – with the exception of BASF – also in the fabrication of pharmaceutical innovations. Merck was of smaller size and engaged in pharmaceuticals and specialised chemicals. AEG, Siemens, and their joint-venture Telefunken dominated electrical engineering.

In total, we were able to gather 180 licensing contracts closed between 1880 and 1914. 159 of the contracts are from the chemical and pharmaceutical industry and 21 are from electrical engineering companies. Most of the available contracts from the chemical and pharmaceutical companies were sealed during the 1890s, a slightly smaller number in the years between the turn of the century and the First World War. For the electrical engineering companies, all but one of the agreements are from the 20th century.

From all of the 180 licensing contacts, we were able to gather information on the following features: 1) contracting parties, 2) scope of the agreement, 3) licensing fees, 3) duration of the contract, 4) pre- or post-patent contracting, 5) auditing rights, and 6) exclusivity. Only in two cases, an individual appeared as licensee. The findings on the licensors are less clear-cut. Overall, in one-fourth of the available contracts, the licensor was a company, in the remaining cases one or more individuals licensed the product or process. This indicates that individual inventors transferred technology to firms, which have better complementary assets to use the technology.

10 This seems to be a small sample, but since we hand-collected the data from corporate archives, we decided to focus on firms active in technology-intensive branches. Moreover, the records of the firms must still be available for inspection.

TABLE 1: FRACTION OF LICENSING CONTRACTS CONTAINING THE FOLLOWING CLAUSE

Feature / Sector	Chemical & Pharmaceutical	Electrical Engineering	p-value of Fisher's exact test	TOTAL
Number of observations	159	21		180
Firm as licensor	20.1 %	57.1 %	0.000	24.4 %
Payment				
Up-front fix	25.2 %	47.6 %	0.039	27.8 %
Milestone	42.1 %	19.0 %	0.056	39.4 %
Profit share	71.7 %	0.0 %	0.000	63.3 %
Revenue share	8.2 %	66.7 %	0.000	15.0 %
Quantity share	17.0 %	33.3 %	0.081	18.9 %
Other form of variable payment	9.4 %	4.8 %	0.698	8.9 %
Duration				
Patent duration	86.8 %	61.9 %	0.008	83.9 %
Years	14.8 years	8.4 years		13.0 years
Exclusive license	89.3 %	61.9 %	0.003	86.1 %
Auditing right	21.4 %	42.9 %	0.001	23.9 %
Pre-patent contracting	57.9 %	23.8 %	0.004	53.9 %

Source: Archival database. Fisher's exact test tests the null hypothesis of equal means in the two samples.

Turning first to licensing fees, we find that upfront fixed payments were more common in electrical engineering, but less often contracted in chemicals and pharmaceuticals. In the former, almost half of the licensing agreements included an upfront fixed payment; in the latter, in roughly one quarter of the cases, upfront fixed payments were agreed on. In addition, many contracts from the chemical industry specified milestone payments conditioned on some event, e.g., the grant of a patent or successful clinical trials. In four contracts from the chemical and pharmaceutical industry, an upfront fixed payment was the only payment made. One company, Siemens, hardly ever agreed on upfront fixed payments. Only in one of Siemens' contracts, in which the company appeared as joint licensee with AEG, such a payment was included. The average upfront fixed fee amounts to 9,237 Mark. Yet, the variation of the upfront fixed fees is substantial, ranging from zero to 630,000 Mark.¹¹

Nearly all contracts included some kind of variable payment. In general, these took four different forms: 1) a percentage of the profits generated by the licensed product or process, 2) a percentage of its revenue, 3) per piece or with reference to some other physical attribute (e.g., per kilo, per litre, per kilowatt) of the licensed product or process, and 4) other forms of variable payments (e.g., a percentage of the cost reductions due to the licensed technology). In electrical engineering, fees as a percentage of profits seem to have been uncommon, as they appeared in none

¹¹ This compares to a per-capita income of 800 Mark in 1913.

of the available contracts. In contrast, most of the available agreements from this sector included variable payments that were calculated as a percentage of revenues. In almost all other cases, fees calculated on the basis of a physical attribute were agreed on. The picture in the chemical and pharmaceutical industry looks completely different. Here, variable payments that were calculated as a percentage of profits were the rule. In more than 70 per cent of the cases, the contracting parties agreed on this type of variable payment.

In general, the clauses on variable compensation were quite complex. For example, the contract sealed in 1913 between the individual inventor Georg Seibt and the radio communication firm Telefunken specified an annual minimum payment of 3,000 Mark for each year of the duration of the patent and a licence fee of 30 Mark per unit if annual sales were 100 units or less, a licence fee of 27,50 Mark per unit if the annual sales were 200 units or less, a licence fee of 25 Mark for sales of up to 300 units, a licence fee of 22,50 Mark for sales of up to 400 units, a licence fee of 20 Mark for sales of up to 500 units, a licence fee of 17,50 Mark for sales of up to 750 units, and a licence fee of 15 Mark per unit for sales of up to 1,000 units.

The duration of the available licensing agreements was longer in the chemical and pharmaceutical industry and more often based on the patent duration. In almost 87 per cent of the cases the duration of the contract was linked to the duration of the respective patent.¹² In the remaining cases, the average contract period was 14.8 years. In electrical engineering, the share of those contracts whose duration was linked to the duration of the respective patent was substantially smaller than in the chemical and pharmaceutical industry. However, more than 60 per cent of all contracts were of this type. The average contract period of the other agreements was 8.4 years.

Another difference between the chemical and pharmaceutical industry, on the one hand, and the electrical engineering industry, on the other, was the timing of the licensing agreement, i.e., whether at the time when the respective contract was closed, a patent on the respective product or process had already been granted or whether it was only applied for or intended to be applied for. In electrical engineering, in the overwhelming majority of the cases a patent existed at the time that the contract was closed. In contrast, in the chemical and pharmaceutical industry licensing contracts were more often agreed on at an early stage of the patenting process.

V. Econometric evaluation

The model developed by Jensen and Thursby (2001) suggests that a profit-sharing licensing contract is superior to a royalty contract if a large amount of inventor effort is necessary to commercialise an innovation. Thus, early-stage innovations, e.g., non-patented innovations and innovations made by individual inventors should be more likely to be licensed using profit-sharing contracts. Moreover, theory suggests that the level of fixed upfront payments can influence the contract design if the innovator is risk-averse. We put three hypotheses to an econometric test: (i)

12 The maximum patent duration was 15 years.

non-patented innovations and innovations offered by individual inventors are more likely to be licensed using profit-sharing agreements; (ii) high fixed upfront payments increase the likelihood that a profit-sharing agreement is closed; (iii) high fixed upfront payments are correlated with higher profit shares. Hypothesis (i) should be rejected if inventor moral hazard was unimportant. Moreover, hypotheses (ii) and (iii) should be rejected, if the inventor is risk-neutral. The first two hypotheses are evaluated using a probit model (see Table 2), whereas the third hypothesis is assessed using OLS (see Tables 3 to 5).

The Probit regressions employ a zero-one coded dummy variable taking the value of one if the contract specifies a profit share. The baseline regression employs three explanatory variables (see equation 1).

$$(1) \quad \eta_i = c + \text{prepatent}_i + \text{individual}_i + \text{fixed}_i + \varepsilon_i$$

with $\eta_i = 1$ if $\rho_i > 0$.

The dummy variable ‘prepatent’ takes the value of one if the licensing contract is sealed before a patent is granted for the licensed technology. We expect a significantly positive coefficient for this variable. The dummy variable ‘individual’ takes the value of one if the licensor is an individual. We expect a significantly positive coefficient for this variable. The variable ‘fixed’ reflects the size of the upfront fixed fee (in 1,000 Mark) paid by the firm to the inventor. If the inventor is risk-neutral, this variable should be insignificant. If the inventor is risk-averse, this variable should be significantly positive.

Our stability check employs four additional variables capturing contractual clauses, see equation (2).

$$(2) \quad \eta_i = c_2 + \beta_1 \text{prepatent}_i + \beta_2 \text{individual}_i + \beta_3 \text{fixed}_i$$

$$\beta_4 \text{milestone}_i + \beta_5 \text{exclusive}_i + \beta_6 \text{duration}_i + \beta_7 \text{auditing} + \varepsilon_i$$

with $\eta_i = 1$ if $\rho_i > 0$.

The dummy variable ‘milestone’ takes the value of one if the licensing contract specifies a fixed payment of the firm to the inventor if a certain milestone, e.g. successful clinical trials for a new drug, is reached. Dechenaux et al. (2009) show that milestone payments can also be used to overcome the moral hazard problem between inventor and firm. Consequently, milestone payments can substitute profit shares – this would be reflected in a significantly negative coefficient – or they can complement profit shares – this would result into a significantly positive coefficient. The dummy variable ‘exclusive’ takes the value of one if the firm is the only licensee. The vari-

able ‘duration’ measures the duration of the licensing contract in years.¹³ Mendi’s (2005) model and his empirical results suggest that a longer contract duration should be positively correlated with some form of variable payment. Yet, Mendi (2005) does not specify the type of variable payments in his empirical specification; his theoretical model assumes a per-unit royalty. We are not aware of licensing models investigating the relationship between auditing rights, exclusivity, and inventor compensation and thus make no predictions regarding the sign of the coefficient.

Equations (1) and (2) are estimated using $i = 1, \dots, 180$ licensing contracts. Table 2 presents the results. As expected, pre-patent contracting and contracting with individual inventors positively affects the probability of a profit sharing agreement. For non-patented innovations, the probability of closing a profit-sharing agreement is nearly 22 percent larger than for a patented innovation. If the licensor is an individual inventor, the probability of agreeing on a profit-sharing agreement is nearly 62 percent larger compared to the case with a firm as licensor. In contrast to our expectations, the marginal effect of a fixed upfront fee is slightly negative and weakly significant. Increasing the fixed upfront fee by one percent decreases the probability of a profit sharing agreement by 0.006 percent. Thus, increasing the fixed fee by one standard deviation (i.e., by about 49,500 Mark) from its sample mean of 9,200 Mark increases the probability of closing a profit sharing agreement by about 3.2 percent. Therefore, the coefficient is close to zero from an economic point of view and this can be taken as evidence for nearly risk-neutral licensors.

13 If a licensing contract only specifies that the contract duration equals the patent duration, we set the contract duration to 15 years, the maximum duration of a patent in Germany. Assuming another duration, e.g., the average number of years explicitly stated in the other contracts, does not affect the results.

TABLE 2: DETERMINANTS OF CONTRACT DESIGN

Explanatory variable	All observations		All observations		Chemical & pharmaceuticals only	
	Coef.	Marginal effect	Coef.	Marginal effect	Coef.	Marginal effect
Constant	1.145***	0.418***	-0.289	-0.107	0.155	0.052
Pre-Patent contracting	0.568**	0.216**	0.472*	0.182*	0.487*	0.160*
Licensor is an individual inventor	1.794***	0.624***	1.362***	0.502***	1.375***	0.496***
Fixed upfront fee in 1,000 Mark	-0.016*	-0.006*	-0.014	-0.005	-0.009	-0.003
Milestone			0.355	0.136	0.170	0.054
Auditing right			-0.394	-0.155	-0.641*	-0.226*
Exclusive license			1.250**	0.459***	1.132*	0.420*
Contract duration			-0.000	-0.000	-0.000	-0.000
McFadden pseudo R ²	0.342		0.395		0.400	
Fraction correctly predicted	0.828		0.828		0.849	
Chi ² Test	80.81***		93.48***		75.84***	
Number of obs.	180		180		159	

*Method: ML Bivariate probit regression. *, **, *** denotes significance on ten, five, and one percent level. Dependent variable: Dummy variable, equals 1, if profit sharing contract and 0 otherwise. Marginal effect for dummy variable is $P(0) - P(1)$.*

The additional control variables used in equation (2) do not affect our main conclusions. The sign, significance, and magnitude of our three major variables remain quite similar. Milestone payments do not affect the probability of agreeing on a profit share. In contrast, closing an exclusive license does substantially affect the contract type; such a clause increased the probability of agreeing on a profit-sharing agreement by nearly 50 percent. Furthermore, a longer contract duration is not correlated with a higher probability of agreeing on a profit sharing agreement. This finding stands in contrast to Mendi's (2005) findings. Furthermore, auditing rights have nearly no effect on the choice of inventor compensation clauses.

Moreover, Table 2 contains another stability check, assessing the empirical fit of regression equation (2) if we restrict the sample to firms from the chemical and pharmaceutical industry. This seems reasonable since only firms from these industries used profit-sharing agreements. Nonetheless, the main conclusions remain quite similar. A licensing contract closed before a patent was granted for the licensed technology had a 19 percent higher probability of containing a profit-sharing clause. Moreover, if the licensor was an individual inventor, the probability of a profit-sharing clause was about 55 percent higher than in the case of a firm as licensor. The regression coefficients connected to fixed upfront payments, milestone payments, and contract duration are statistically insignificant in the restricted sample.

So far, we were only concerned with the determinants of the probability of agreeing on a profit-sharing agreement. We now turn to the quantitative effects of a contractual clause on the size of profit shares. From theory, we expect that higher fixed upfront payments are correlated with higher profit shares if the inventor is risk-averse. Moreover, early-stage inventions licensed by an individual inventor should have higher profit shares since more effort of the licensor is necessary to commercialise the innovation.

The dependent variable in regressions (3) and (4) is the mean profit share $\rho_{i,m}$ agreed upon in contract i . If the contract i specifies $\tau=1,2,\dots,k$ different profit shares for different states of the world (e.g., levels of profits or output), we use the arithmetic mean of all profit shares mentioned in the contract. For example, a contract might specify a profit share of 10 percent for the profits generated by the first 10,000 units and a profit share of 5 percent for the profits from all other units. We then employ the mean profit share of 7.5 percent as dependent variable. The explanatory variables are the same as in regressions (1) to (2).

$$(3) \quad \frac{1}{k} \sum_{\tau=1}^k \rho_{i,\tau} = \rho_{i,m} = c_3 + \delta_1 \text{prepatent}_i + \delta_2 \text{individual}_i + \delta_3 \text{fixed}_i + \varepsilon_i$$

$$(4) \quad \frac{1}{k} \sum_{\tau=1}^k \rho_{i,\tau} = \rho_{i,m} = c_4 + \gamma_1 \text{prepatent}_i + \gamma_2 \text{individual}_i + \gamma_3 \text{fixed}_i \\ \gamma_4 \text{milestone}_i + \gamma_5 \text{exclusive}_i + \gamma_6 \text{duration}_i + \gamma_7 \text{auditing}_i + \varepsilon_i$$

Table 3 presents the results of regression equations (3) and (4) based on a sample of 118 profit-sharing agreements. These contracts were all closed in the chemical and pharmaceutical industry. In contrast to our theoretical expectations, neither the dummy variable capturing pre-patent contracting nor the dummy variable capturing that the licensor is an individual affects the size of the profit shares. Moreover, the size of the fixed upfront payment does not affect the size of the profit share either. Consequently, the overall model is rejected by the F-Test and the variables included explain nothing of the variance in the data. The additional control variables used in regression equation (4) improve the fit of our empirical model substantially. The extended model is statistically significant and explains 18.5 percent of the variance in the data. In particular, the granting of an exclusive license is correlated with a substantially larger profit share for the licensor; adding an exclusivity clause to the licensing contract increases the profit share of the licensor by about 23 percent.

TABLE 3: DETERMINANTS OF THE SIZE OF THE PROFIT SHARE - BASELINE

Explanatory variable	Dependent variable: Average profit share agreed upon in the contract	
	(1)	(2)
Constant	20.298***	-0.260
Pre-Patent contracting	-0.540	-0.397
Licensor is an individual inventor	-6.378	3.563
Fixed upfront fee in Mark	-0.023	-0.075
Milestone		-6.804***
Auditing		10.465**
Exclusive license		23.852***
Contract duration		0.002
adjusted R ²	0.000	0.185
F-Test	0.65	4.66***
Number of observations	118	118

Method: OLS, corrected for heteroscedasticity. All observations from chemicals & pharmaceuticals.

, **, * denotes significance on ten, five, and one percent level, respectively.*

Furthermore, contracts giving the inventor the right to inspect the accounts of the firm allocate, on average, a substantially higher profit share to the inventor. We can think of at least two explanations for this finding: it becomes more important to have an auditing right if the profit share is higher; and inventors getting the right to inspect the accounts might be inventors with substantial bargaining power. However, bargaining power and costly state verification is not included in current licensing models. Thus, our findings point to some noteworthy gaps in the theoretical literature. Moreover, milestones can, as expected from theory, be used as a substitute for profit shares. Including a milestone into the contract reduces the profit share agreed upon by nearly 6.8 percent.

Table 4 presents two slight variations of regression equation (4). First, we replace the dummy variable “milestone” by the actual monetary equivalent of the milestone (Table 4, regression 1). Second, we use the first profit share agreed upon in the contract as dependent variable (Table 4, regression 2). Implicitly, the specification used above assumes that all states specified in the contract have the same probability and we can use the average of all profit shares specified for different states of the world as a dependent variable. However, inventor effort might be more important to reach the first state of the world, whereas the other states of the world are dominated by events outside the control of the licensor and licensee.

TABLE 4: DETERMINANTS OF THE SIZE OF THE PROFIT SHARE - STABILITY

Explanatory variable	Dependent variable: <i>Average</i> profit share agreed upon in the contract	Dependent variable: <i>First</i> profit share agreed upon in the contract
	(1)	(2)
Constant	-1.466	-3.132
Pre-Patent contracting	0.108	1.102
Licensors is an individual inventor	-4.047	-6.344
Fixed upfront fee in Mark	-0.070	-0.088
Milestone payment in 1,000 Mark	-0.843*	-0.677*
Auditing	11.665**	13.394***
Exclusive license	22.862***	24.871***
Contract duration	0.001	0.000
adjusted R ²	0.114	0.169
F-Test	3.07***	4.28***
Number of observations	114	114

Method: OLS, corrected for heteroscedasticity. All observations from chemicals & pharmaceuticals.

, **, * denotes significance on ten, five, and one percent level, respectively.*

It turns out that our baseline results are robust to these modifications. Pre-patent contracting, the fact that the licensor is an individual inventor, the size of the fixed upfront payment, and the contract duration do not affect the size of the profit share. Contracts allocating an auditing right to the licensor or exclusivity rights to the licensee specify a substantially higher profit share to the licensor. Milestones are still weakly significant and negatively related to profit shares. Regression 2 of Table 4 shows that the choice of the left-hand side variable does also not affect the results. Exclusivity and auditing are still substantially positively associated with the profit share granted to the licensor, the size of the milestone payment is somewhat negatively associated with the size of the profit share, and the remaining variables are statistically insignificant.

V. Conclusion

We provide evidence that a modern technology market emerged as early as 1880 in Germany and this market was quite similar to modern technology markets. Using a sample of 180 technology licensing agreements sealed by a sample of firms between 1880 and 1914, we show that licensing contracts in chemicals, pharmaceuticals, and electrical engineering often contained fixed upfront payments and in nearly all cases royalties based on profits, revenues, or physical output. Profit-sharing contracts were the most common type of agreement. Moreover, many contracts were sealed between individual inventors and firms. Consequently, profit-sharing or equity-

sharing licensing contracts are not a recent phenomenon as, for example, argued by Feldman et al. (2002) or Sampat (2006). Such contracts were already in use more than one century ago.

A regression analysis reveals that contracts most likely reflected moral hazard problems between licensor and licensee, as suggested by Jensen's and Thursby's (2001) model. In particular, we demonstrate that early-stage innovations, i.e., non-patented innovations and innovations offered by individual inventors, were more likely to be licensed using profit-sharing agreements. The contract duration, which was highlighted in Mendi's (2005) model, turned out to be unimportant in our historical context. Moreover, we demonstrate that Macho-Stadler's et al. (2008) investigation of the role of financial stakes taken by the inventor was empirically irrelevant at the turn of the 20th century. In contrast, we confirm a hypothesis put forward by Decheneaux et al. (2009) by showing that milestones were a substitute for profit shares. Moreover, we present evidence that inventors seem to be risk-neutral. Furthermore, we show that exclusive licenses were more likely to include a profit-sharing clause and that they usually include higher profit shares for the licensor. Finally, auditing rights were associated with substantially higher profit shares.

Turning to economic history, we can, broadly speaking, claim that the development of technology markets in Germany at the turn of the 20th century was similar to the emergence of a market for technology in the United States during the second half of the 19th century, as highlighted, among others, by Lamoreaux and Sokoloff (1999, 2001), Sokoloff and Khan (1993), and Khan (1995). Moreover, our findings can be taken as microeconomic evidence for the existence of knowledge spillovers between firms and regions, which were identified in recent cliometric research about Imperial Germany by Streb et al. (2006, 2007) and Baten et al. (2007).

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