The Historical Market for Technology Licenses:

Chemicals, Pharmaceuticals, and Electrical Engineering

in Imperial Germany*

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Abstract:

We investigate a sample of 145 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 milestone payments were a substitute for profit shares. Furthermore, exclusive licences offered a significantly higher profit share to the licensor.

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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 both, users as well as innovators, since it increases the use of knowledge in the economy and 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 existed already during the mid-19th century in the U.S. and they facilitated the transfer of technology from individual inventors to firms. In particular, Lamoreaux and Sokoloff (1999, 2001) demonstrated 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), who describe some of the licensing contracts closed by America's great inventors during the 19th century.

Econometric evidence for technology transfer and a set of case studies 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 time-series and spatial econometric methods reveals a significant impact of knowledge transfers on economic growth and innovativeness in Germany at the turn of the 20th century. Our paper complements these findings by offering a systematic, microeconomic perspective on technology transfer by analyzing licensing contracts sealed in Germany between 1880 and 1913.

So far, no comprehensive historical study on the licensing activity of German companies is available. Only scattered 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 several licensing contracts with companies in depth. Some information on both, licensing contracts with companies and the cooperation with individual researchers is available in Abelshauser's (2002) monograph on the corporate history of BASF, Reinhardt's (1995) work on pharmaceutical research at BASF, and Reinhardt and Travis' (2000) study on Heinrich Caro, BASF' 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 illustrative 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 contain a fixed fee plus 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).

Our empirical results, based on 145 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, early-stage innovations often require further effort of the licensor to commercialise the product after sealing of the licensing contract. 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. This type of contract solves the moral hazard problem, since profit shares are only paid to the licensor if he puts effort into the commercialisation of the technology. Moreover, our results suggest that milestone payments complemented profit sharing agreements, but that the size of profit shares and the existence of milestones were substitutes.

Thus, we thereby contribute to the empirical industrial organization literature. Most empirical studies investigating licensing contracts do not contain much information about the details of the contract. The main reason for this gap is that the licensing agreements are private contracts, which are most of the time unobservable to the researcher. For example, less than ten percent of licensors send 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 depended variable and a set of observable firm- or industry-specific variables as explanatory variables (see, e.g., Anand and Khanna, 2000). Only very recently, Mendi (2005) and Vishwasrao (2007) use official forms filled by the licensees of cross-country licensing agreements of Spanish and Indian firms to evaluate the content of licensing contracts. The official forms, however, did 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. This differentiation would be relevant to assess if the 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 to a smaller extent also iron and steel production as well as mining. Then, from the 1870s onwards, in an accelerating process that is oftentimes 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 between 1891 and 1913 (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) identified four major technology booms between 1877 and 1918. The first boom occurred between 1877 and 1886. It was 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 chemical industry and 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 was 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

[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).

[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).

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 at 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 on 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 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

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[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 diffferent 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 resaerch 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).

[7] The renewal fee was 50 Mark for the first and 50 Mark for the second year. Afterwards, each year, the fee increased by 50 Marks. 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.

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 the willingness to pay of potential licensees, 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 university employed inventor, 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 cannot be 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 and profit sharing rules.

The licensing game hast the following structure. An inventor decides to offer a licensing contract to a firm. 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 that motivate him. Three types of payoffs for the inventor are possible: a fixed fee, m, and an output-based royalty rate, r, or a profit share ρ.

Let us assume that the probability of commercial success positively depends on effort e, i.e. $p(e) > 0$, but that the probability of success is always smaller than one, even with infinite

[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.

effort. In addition, we assume that the firm maximizes its profits under monopoly conditions, i.e. marginal revenues equal marginal costs in equilibrium. 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 royality 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 firms 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 $rx(r)$ are 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 inventors 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 inventors' 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: $\frac{\partial P_I}{\partial e} = p'(e)\left[U_I(m + rx(r)) - U_I(m)\right] - V_I'(e) = 0$. Note that the inventor earns the amount m, whether he expends 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. 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) proof that, if development occurs: (i) inventor effort *e* is decreasing 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 is increasing (decreasing, constant) in the royalty rate *r* as royalty income is increasing (decreasing, 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. Cleary, 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 into 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 $P_I(e,\rho,m) = p(e)U_I[m+\rho P(x)] + (1-p(e))U_I(m) - VI(e)$.

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 seems 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 fully solved in this case. This cannot occur in profit-sharing agreements since the effort is strictly increasing in the profit share.

The model implies several hypothesises for the econometric analysis conducted in Section V. First, early-stage inventions, e.g. non-patented inventions or inventions offered by individual inventors – who most likely have not the resources to test an invention intensively – 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

[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.

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 rate beyond the license revenue maximizing royalty rate. If the inventor is risk neutral, an upfront fixed payment does neither affect the type of the agreement, nor 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. Even more than BASF, Bayer, and Hoechst in the chemical industry, AEG, Siemens, and their joint-venture Telefunken dominated electrical engineering. The organisation of R&D was different at the firms: the chemical and pharmaceutical firms operated centralized research laboratories, whereas the electrical engineering firms operated decentralised offices for product development. In addition, privately owned companies (Merck, Siemens), a technology joint-venture (Telefunken), and listed companies (BASF, Bayer, Hoechst, AEG) are in our sample.

In total, we were able to gather 145 licensing contracts closed between 1880 and 1914. 124 of the contracts are from the chemical and pharmaceutical industry and 21 are from the companies engaged in electrical engineering.[11] 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 companies engaged in electrical engineering, all but one of the agreements are from the 20th century.

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[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.

[11] Almost 60 per cent of the available observations are from one company (Hoechst), another fifth is provided by another company (Merck).

From all of the 145 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, and 5) exclusivity. Only in three cases (all of them from the chemical industry), 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.

Table 1: Features of licensing contracts

Feature / Sector		Chemical & Pharmaceutical	Electrical Engineering	p-value of Chi-square test	TOTAL
Number of observations		124	21		145
Firm as licensor		17 %	57 %	0.770	23 %
Payment	Up-front fix	28 %	52 %	0.381	32 %
	Milestone	48 %	19 %	0.002	43 %
	Profit share	70 %	0 %	0.000	60 %
	Revenue share	6 %	62 %	0.743	14 %
	Quantity share	17 %	38 %	0.506	20 %
	Other form of variable payment	5 %	5 %	0.971	5 %
Duration	Patent duration	87 %	62 %	0.000	83 %
	Years	10.5 years	8.4 years		9.8 years
Exclusive license		91 %	62 %	0.000	87 %
Post-patent contracting		44 %	81 %	0.669	50 %

Source: Archival database. The Chi-square test tests the null hypothesis of equal means in the two sub-samples.

There are some significant differences between the electrical engineering and the chemical industry: milestone payments, profit sharing contracts, and exclusive licences were more common in the chemical industry. Moreover, the use of the patent duration as a measure for the duration of the licensing contracts was significantly more common in the chemical industry. Yet, most differences between the two industries are insignificant from a statistical point of view.

Turning first to licensing fees, we find that upfront fixed payments were common in electrical engineering, but less often contracted in chemicals and pharmaceuticals. In the former, almost one half of the licensing agreements included a fixed payment; in the latter, in roughly one quarter of the cases fixed payments were agreed on. In addition, many contracts 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, a fixed sum was the only payment made. One company, Siemens, hardly ever agreed on 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 fixed fee amounts to 30,070 Mark, about 40 times the annual per capita income in 1913. Yet, the variation of the fixed fees is substantial, ranging from 50 to 630,000 Mark.

Nearly all contracts included some kind of royalty. 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 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 as many 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, royalties that were calculated as a percentage of profits were the rule. In almost 70 per cent of the cases, the contracting parties agreed on this type of royalty. The second most common type of variable payment was a royalty that had to be paid apiece or with reference to another physical attribute. Fees calculated as a percentage of revenues were only seldom agreed on.

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.

Another example concerns the licensing contract sealed in 1890 between the individual inventor Carl Heumann and BASF. Heumann received an upfront payment of 2,000 Mark, a milestone payment of 3,000 Mark when 300 kg were produced and a royalty of 0,50 Mark per kg for the first 10,000 kg produced, a royalty of 0,25 Mark per kg for the production of the next 90,000 kg, and a royalty of 0,10 Mark per kg for each kg produced above the threshold of 100,000 kg total production.

The duration of the available licensing agreements was similar in both investigated industries. In the chemical and pharmaceutical industry, in almost 90 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 10.5 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 hand, 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.

The correlation structure between different contract clauses reveals some relatively strong relationships between characteristics, see Table 2. In particular, contracts sealed with an individual inventor as a licensor were correlated with pre-patent contracting. In addition, those contracts were more often profit-sharing agreements and the duration of the contract was more often connected to the patent duration. Furthermore, profit sharing agreements display strong positive correlations with pre-patent contracting. We will investigate these relationships more intensively in the following section V.

[12] The maximum patent duration was 15 years.

Table 2: Correlation of contract clauses

			Payment						Duration		
		Individual inventor as licensor	Up-front fix	Milestone	Profit share	Revenue share	Quantity share	Other form of variable payment	Patent duration	Exclusive license	Pre-patent contracting
Individual inventor as licensor		1.00	-0.02	-0.31	-0.60	0.38	0.26	0.03	-0.42	-0.57	0.45
Payment	Up-front fix		1.00	-0.24	-0.32	0.18	0.14	-0.02	-0.17	-0.04	-0.09
	Milestone			1.00	0.29	-0.24	-0.06	-0.00	0.24	0.18	0.15
	Profit share				1.00	-0.50	-0.61	-0.14	0.32	0.39	0.43
	Revenue share					1.00	-0.21	-0.00	-0.19	-0.19	-0.26
	Quantity share						1.00	-0.11	-0.19	-0.21	-0.30
	Other form of variable payment							1.00	0.01	-0.01	0.09
Duration	Patent duration								1.00	0.27	0.23
Exclusive license										1.00	0.31
Pre-patent contracting											1.00

Source: Archival database.

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, i.e., non-patented innovations and innovations made by individual inventors, should be more likely to be licensed using profit-sharing contracts. Moreover, theory suggest that the level of fixed upfront payments can influence the contract design if the innovator is risk-averse. In that case, a fixed upfront payment reduces inventors' effort and the profit share or royalty offered by the firm must be higher to reach a given level of effort. In case of royalty contracts, this could drive the necessary royalty rate beyond the licensing revenue maximizing rate. In this case, the firm should switch to a profit sharing agreement.

We put three hypothesises to an econometric test: (i) 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. The first two hypothesises are evaluated using a probit model (see Table 3), whereas the third hypothesis is assessed using OLS (see Table 4) and Tobit (see Table 5) regressions. Moreover, some stability checks account for the impact of other contractual features on the probability of closing a profit sharing contract and on the profit sharing rate.

The Probit regressions employs 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).

$$(1)\quad \eta_i = c + \text{prepatent}_i + \text{individual}_i + \text{fixed}_i + \varepsilon_i$$
$$\text{with } \eta_i = 1 \text{ if } \rho_i > 0.$$

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 Marks) 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 three additional dummy variables capturing contractual clauses, see equation (2).

$$(2)\quad \eta_i = c_2 + \beta_1 prepatent_i + \beta_2 individual_i + \beta_3 fixed_i$$
$$\beta_4 milestone_i + \beta_5 exclusive_i + \beta_6 duration_i + \varepsilon_i$$
$$\text{with } \eta_i = 1 \text{ if } \rho_i > 0.$$

The dummy variable 'milestone' takes the value of one if the licensing contracts 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 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 dummy variable 'duration' measures the duration of the licensing contract in years. Mendi's (2005) model and his empirical results suggest that a longer contract duration should be correlated with some form of variable payment.

Equations (1) and (2) are estimated using i = 1,….,145 licensing contracts. Table 3 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 23 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 65 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 negative. Increasing the fixed upfront fee by one percent decreases the probability of a profit sharing agreement by 0.007 percent. Thus, increasing the fixed fee by two standard deviations (i.e., by about 110,000 Mark) from its sample mean of 30,000 Mark increases the probability of closing a profit sharing agreement by about 2.6 percent. Therefore, the coefficient is close to zero from an economic point of view and this can be taken as evidence for risk-neutral licensors.

The additional control variables used in equation (2) do not affect our main conclusions. The sign, significance, and magnitude of our three major variables (pre-patent contracting, licensor is an individual inventor, fixed upfront fee in 1,000 Mark) remains nearly the same. Milestone payments are complementary to profit shares. Including a milestone clause in the licensing contract increases the probability of agreeing on a profit sharing agreement by about 18 percent. Closing an exclusive license does not affect the contract type. This seems reasonable, since the moral hazard problem between licensor and licensee is still present. Furthermore, a longer contract duration is correlated with a higher probability of agreeing on a profit sharing agreement. This seems also reasonable, since the uncertainty of product market conditions and production costs might be increasing in the contract duration. Less information about prices and costs is necessary in profit sharing agreements than in royalty contracts. This suggest that contracts having a long duration are easier to design using profit sharing agreements. Moreover, Mendi (2005) demonstrates theoretically and empirically a positive relationship between contract duration and the probability of agreeing on some form of variable payment. He makes no specific prediction regarding the type of the variable payment, but our result conform well with his model.

TABLE 3: DETERMINANTS OF CONTRACT DESIGN

Explanatory variable	All observations		All observations		Chemical & pharmaceuticals only	
	Coef.	Marginal effect	Coef.	Marginal effect	Coef.	Marginal effect
Constant	1.063***	0.422***	-1.090	-0.433	-0.241	-0.075
Pre-Patent contracting	0.584**	0.228**	0.550**	0.216**	0.533*	0.182*
Licensor is an individual inventor	2.040***	0.645***	1.638***	0.559***	1.746***	0.617***
Fixed upfront fee in 1,000 Mark	-0.018**	-0.007**	-0.019**	-0.007**	-0.016	-0.006
Milestone payment			0.461*	0.181*	0.266	0.090
Exclusive license			0.626	0.244	0.389	0.142
Contract duration			0.092**	0.036**	0.067	0.023
McFadden pseudo R^2	0.346		0.391		0.349	
Fraction correctly predicted	0.821		0.807		0.839	
Chi^2 Test	67.48***		76.37***		52.81***	
Log-likelihood	-63.8		-59.4		-75.6	
Number of obs.	145		145		124	

*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).

Furthermore, Table 3 contains a further 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 closes before a patent was granted for the licensed technology had a 18 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 62 percent higher than in the case of a firm as licensor. However, the regression coefficients connected to 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 τ=1,2,..,k different profit shares for different conditions (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). We estimate regressions (3) and (4) using two different methods: OLS and Tobit. OLS is our baseline specification, but the results might be biased, since the dependent variable is censored at zero.

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

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

Table 4 presents the results of regression equations (3) and (4) using OLS based on a sample of 87 profit sharing agreements. These contracts were all closes 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 also not affect the size of the profit share. Yet, one should keep in mind that the model proposed by Jensen and Thursby (2001) predicts a positive relationship between inventor effort and the size of the profit share. Our data only differentiate high- and low effort contracts using two dummy variables. Thus, our dummy variables might be to imprecise to take the regression results as hard evidence against Jensen's and Thursby's (2001) model.

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 nearly one-fifth of the variance in the data. In particular, the grant 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 15 percent. Moreover, milestones can be used as a substitute for profit shares. Including a milestone into the contract reduces the profit share agreed upon by nearly 8.7 percent.

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

Explanatory variable	Dependent variable: Average profit share agreed upon in the contract	
	(1)	(2)
Constant	20.945***	1.521
Pre-Patent contracting	1.112	-0.249
Licensor is an individual inventor	2.110	3.396
Fixed upfront fee in Mark	0.090	-0.001
Milestone payment		-8.677***
Exclusive license		15.018***
Contract duration		0.615
adjusted R^2	0.000	0.191
F-Test	0.080	4.39***
Number of observations	87	87

Method: OLS, corrected for heteroscedasticity.

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

Since the profit shares are non-negative, a Tobit estimator might be adequate to assess the quantitative impact of certain contractual clauses on the profit share. Thus, Table 5 presents re-estimations of equations (3) and (4) using a Tobit estimator. Qualitatively, this does not affect the results. A milestone payment clause in a licensing contract reduces the profit share agreed upon by nearly nine percent. Yet, the estimated effect of an exclusivity clause is larger using the Tobit estimator. The re-estimation of equation (4) suggest that agreeing on a exclusivity clause increases the profit share by about 19 percent, compared to only 15 percent in the OLS regression.

TABLE 5: DETERMINANTS OF THE SIZE OF THE PROFIT SHARE - TOBIT

Explanatory variable	Dependent variable: Average profit share agreed upon in the contract	
	(1)	(2)
Constant	20.949***	-2.079
Pre-Patent contracting	1.268	-0.034
Licensor is an individual inventor	-2.185	3.481
Fixed upfront fee in Mark	0.007	-0.002
Milestone payment		-8.882***
Exclusive license		19.275**
Contract duration		0.585*
ANOVA based fit	0.003	0.227
LM Test for Tobit	2.027	2.829
Normality Test	21.503***	40.181***
Number of observations	87	87

Method: Tobit.

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

V. Conclusion

A technology licensing market emerged as early as 1880 in Germany and this market was quite similar to modern technology markets. Using a sample of 145 technology licensing agreements sealed by a sample of German firms between 1880 and 1913, 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 connected to the existence of patent rights, contracts were often sealed between individual inventors and firms.

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. In addition, we show – in accordance with the model developed by Dechenaux et al. (2009) – that milestone payments were most likely used to solve similar moral hazard problems and that milestone payments were a substitute for high profit shares. Furthermore, we demonstrate that exclusive licenses usually included higher profit shares for the licensor. 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 to solve moral hazard problems between licensor and licensee.

Finally, we provide evidence that a modern technology market emerged in Germany during the late 19th and early 20th century. In this respect, the development in Germany was similar to the emergence of a national market for technology in the United States during 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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