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Incentives and Innovation?
R&D Management in Germany's High-Tech Industries During the Second Industrial Revolution*

Carsten Burhop / Thorsten Lübbers‡

Abstract

The allocation of intellectual property rights between firms and employed researchers causes a principal-agent problem between the two parties. We investigate the working contracts of inventors employed by German chemical, pharmaceutical, and electrical engineering firms at the turn of the 20th century and show that some firms were aware of the principal-agent problem and offered performance-related compensation schemes to their scientists. However, neither a higher total compensation nor a higher share of variable compensation in total compensation is correlated with a higher innovative output. Thus, incentives techniques were already used during the early history of industrial research laboratories, but their impact on innovative output was unsystematic.

JEL-Classification: N 83, O 31, J 33

Keywords: Compensation packages; incentives; innovation; economic history; Germany, pre-1913

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I. Introduction

The invention of the company-sponsored research organisation is undoubtedly the greatest single contribution made by the German dyestuff industry (Beer, 1959: 73). At least since Beer's observation, the research laboratories of the dyestuff industry had itself been an object of scientific research (Murmann, 2006, reviews the literature). Moreover, the emergence of similar institutions in other industries and countries had been a matter of investigation.[1] With respect to Germany, most studies focused on the creation of research laboratories (Beer, 1959; Erker, 1990), or the career of key researchers like Carl Duisberg at Bayer, Heinrich Caro at BASF, and Werner von Siemens (Flechtner, 1959; Travis, 1998; Feldenkirchen and Posner, 2005) or the relationship between industrial research on the one hand and university research and government policy on the other hand (Borscheid, 1976; Johnson, 1985; Johnson, 1989; Wetzel, 1991; König, 1995; König, 1996). In contrast, the management of early research laboratories has not been investigated in detail.

Once a firm had decided to establish a corporate laboratory, it had to solve the emerging incentive problem between the firm – the principal – and the employed researchers – the agents: why should employed inventors transfer potentially valuable innovations to their employers? From a theoretical point of view – see Section III of this paper – the allocation of intellectual property rights between principal and agent is a key factor influencing the optimal organization of R&D laboratories and the design of working contracts for researchers. In 19th-century Germany, the intellectual property rights of inventions made by employed scientists were generally allocated to the employer. Thus, to approach the optimal level of investment and effort, research workers had to be motivated by other means, i.e., by explicit contractual incentives or by monetary rewards.

We address this topic and investigate the working contracts of a sample of researchers employed by BASF, Bayer, and Siemens, leading firms of Germany's chemical, pharmaceutical, and electrical engineering industries at the turn of the 20th century. We describe the level and composition of remuneration, the assessment base for variable compensation, and related characteristics specified in the working contracts (see Section IV). Many scientists received substantial bonus payments, but only one firm – Bayer – explicitly based the bonus payments on profits made by using a certain invention. In addition, Bayer laid explicit incentive schemes down in the working contracts, whereas the two other firms mostly relied on discretionary reward schemes. Furthermore, we show in an econometric evaluation (see Section V) that the structure and the level of researchers remuneration was not systematically correlated with the number of patents or the number of valuable patents granted to a firm.

Partly, our results stand in contrast to findings of the few quantitative studies using modern data. On the one hand, Lerner and Wulf (2007) show that long-term incentives – i.e., stock options –

1 See, e.g., Hounshell and Smith, 1988, for DuPont; Wimmer 1994, for pharmaceutical research at Bayer, Schering, and Merck; König, 1995, for the German electrical engineering industry; Galambos and Sewell, 1995, for Merck; Chandler, 2005, for the pharmaceutical industry; Church and Tansey, 2007, for Borroughs, Wellcome & Co.

offered to the heads of corporate R&D of a sample of about 140 large U.S. corporations were correlated with innovative output of these firms during the 1990s, but that short-term incentives – i.e., bonus payments – were not significantly correlated with innovative output. In addition, Lerner and Wulf (2007) hypothesised that incentives were flat before the 1990s. On the other hand, Honig-Haftel and Martin (1993) demonstrate that bonuses and discretionary monetary rewards were positively correlated with the patenting activity of high-tech firms in Connecticut during the 1980s. In contrast to Honig-Haftel and Martin (1993), we show that short-term incentives were not correlated with the innovative output at the turn of the 20th century. Thereby, we confirm a similar finding of Lerner and Wulf (2007). Yet, in contrast to Lerner and Wulf (2007), our data clearly show that bonus payments were already in use a century ago.

Our result of an insignificant role of researchers' remuneration for the extent of innovative output contributes to the national histories of innovation systems. In general, German firms did not compensate employees for inventions (see Section II). For example, survey of the German Association of Engineers (*Deutscher Techniker-Verband*) conducted in 1908 showed that 87 percent of the 385 employed inventors included in the survey did not receive a remuneration for their inventions (Seckelmann, 2006: 338). Only sparse findings are available for other branches or countries. MacLeod (1999), for example, offers a set of case studies for discretionary bonus payments to some successful shop-floor inventors in Victorian Britain. Furthermore, Fisk (1998) illustrates that bonus payments to inventors in the United States during the 19th century occurred, but were not the rule. Moreover, in the United States company sponsored research laboratories also emerged at the turn of the 20th century and the 'shop-floor-right' allocated intellectual property rights to firms, not to employed inventors (Fisk, 1998). Consequently, an incentive problem similar to the one in Germany existed in the United States. Yet, our findings suggest that the incentive problem did not had negative effects on the innovative output of firms. Thus, shop floor rights and flat incentives for scientists should not have hampered economic growth.

II. Historical and legal background

Germany's rise to one of the leading industrial economies during the second half of the 19th century was, among many other reasons, ascribed to its ability to innovate. For example, the success of Germany's mechanical engineering industry on the World market can be explained by its innovativeness (Labuske and Streb, 2008). Moreover, innovative branches had spill-over effects to other industries, e.g., from dyestuffs to textiles (Streb et al., 2007). In turn, the inventive activity of the modern sectors was fostered by the high quality of Germany's system of higher education, the substantial government support for science, and, last but not least, the emergence of industrial research laboratories (Landes, 1999: 290-291; Cameron and Neal, 2003: 242-243).

The innovative capacity of the German economy is, for example, reflected in the rising number of patents granted, as well as in the rising number of economically valuable patents granted, i.e., patents in force for at least ten years.[2] The total number of patents granted varied between 4,000 and 5,000 per annum during 1877-1890. Thereafter, their number increased to about 10,000 per year. After 1906, the number of patents issued fluctuated at around 13,000 annually. Moreover, the share of valuable patents varied between six and eight percent until 1886. Thereafter, the fraction of valuable patents was about eight to ten percent until 1904. Subsequently, their share increased to more than ten percent. This sharp increase of innovativeness, however, might be an artefact, since patent renewal fees were lifted during the Great War and real patent fees were virtually zero during the hyperinflation of the early 1920s. Consequently, patent renewal data might overstate the innovativeness of the German economy during the immediate pre-war years (Streb et al., 2006). Nonetheless, the number of long-living patents is a much more precise measure of innovative output than the number of patents granted. Altogether, the increasing number of patents granted and the growing share of valuable patents points to increasing research activity.

Locking at the number of valuable patents, four waves of technological progress had been identified (Streb et al., 2006). First, patents used for railways and related industries dominated the high-value patents between 1877 and 1886. Thereafter, patents used in the dyestuff industry conquered the leading position from 1887 until 1896. This wave was followed by the wave of chemical products (1897-1902). Finally, electrical engineering dominated from 1903 until 1918. Thus, the industrial branches covered in our set of case studies – dyestuffs, chemicals, and electrical engineering – belonged to the most innovative: During the period 1877-1918, the Imperial Patent Office granted 5,046 valuable patents to the chemical industry – including dyestuffs and pharmaceuticals – and 3,350 valuable patents to the electrical engineering industry. Therefore, more than one-fifth of all valuable patents were granted to these three industries (Streb et al., 2006) and within these industries about one fifth of the valuable patents were granted to the firms in our sample.

However, the relevance of employed inventors for innovative output is not known, since the data published by the Imperial Patent Office do not distinguish between patentee and inventor and the annually published patent directory *(Verzeichnis der im Vorjahr ertheilten und noch in Kraft befindlichen Patente)* includes only the name of the patentee. Yet, inventions can only be made by individuals. Thus, the fraction of patents granted to firms is a first indication for the extent of inventions made by employed inventors. However, it is a crude measure and includes, for example, inventions made by owners of a firm, but registered in the name of the firm. Yet, it is the best available indicator.

2 Streb et al. (2006) collected information about all patents granted between 1877 and 1913 and in force for at least ten years. See Griliches (1990) for a general discussion of the use of patents as indicators for innovations. Grupp et al. (2002) and Metz and Watteler (2002) describe the German patent system since the late 19th century from an economic perspective.

TABLE 1: PATENTING BY FIRMS AND INDIVIDUALS

	1890	1900	1910
Sample size	512	440	606
Number of patents granted to firms	79	97	203
Share of patents granted to firms	15.4 %	22.0 %	33.5 %

Source: Kaiserliches Patentamt (various years), own calculation.

We address the issue of patenting by firms by using a five percent random sample of all patents granted in three benchmark years. The results presented in Table 1 show that the fraction of patents granted to firms increased over time from about 15 percent in 1890 to about one-third in 1910.[3] In sum, the number of patents granted increased over time, the fraction of valuable patents increased over time, and a rising fraction of patents was granted to firms. This indicates that the compensation of employed inventors was a relevant problem with rising importance.

The lack of information regarding the inventors' name in the official sources is a consequence of Germany's federal patent law enacted in 1877. This law was based on the principle of registration, i.e., the patent was granted to the first individual or firm that filed the patent at the patent office.[4] The main motivation for this regulation was to foster the fast diffusion of knowledge via the published patents. If an inventor delayed the registration, anybody else could register the invention in the meantime (Kurz, 1997: 23). The legislators did not consider the principle of registration or the related issue of inventions by employees to be problematic (Kurz, 1997: 26-27; Seckelmann, 2006: 330-336).

Nevertheless, the topic was debated by legal scholars early on. The Law Professor Carl von Gareis (1879: 6) was the first to define the invention without inventor. This was an invention made within a firm (or some other organisation) by the interplay of several actors and without a well-defined contribution of an individual. In this case, the firm had to be considered as inventor. Alternatively, if the invention was made by a certain employee, Gareis (1879: 7) postulated that the inventor would be entitled to be patentee, if his working contract or company agreements did not define an ownership of the firm.[5]

Yet, neither the Patent Office nor the Imperial High Court (*Reichsgericht*) shared Gareis' view. On 2 January 1879, the Patent Office decided that the results of all work performed by an employee belonged to the employer, including all inventions made. Moreover, the employee was not entitled to receive remuneration for his invention, since he already received his wage or salary (Bartenbach and Volz, 1982; Kurz, 1997: 34; Seckelmann, 2006: 377-378). Some innovative firms like Siemens manifested these rules as early as 1877 in company agreements.[6] The first

3 In 1885, about 12 percent of all U.S. patents were granted to firms (Fisk, 1998: 1139)
4 § 3 of the German patent law.
5 Seckelmann (2006: 339-370) discussed the views of legal scholars in more detail.
6 See the memorandum „Unser Patentrevers" by chief engineer Waldemar Meisser, dated 27 June 1899 (Siemens Record Office, file no. 4/Lk 78).

judgement of the Imperial High Court concerning inventions made by employees was given on 29 October 1883 and it basically confirmed the view of the Patent Office (Bartenbach and Volz, 1982; Seckelmann, 2006: 388). The second judgement of the Imperial High Court followed about 15 years later, on 22 April 1898: this time, the judges decided that an invention would be the property of the firm if such a clause was contained in the working contract, or if the position of the employee within the firm or organisation or the use of assets of the firm suggested that such an arrangement was implicitly agreed upon (Bartenbach and Volz, 1982; Kurz, 1997: 36; Seckelmann, 2006: 370-377). For the first time, this judgement accredited the contribution of employed inventors, but it explicitly denied that staff members of a research laboratory were entitled to receive compensation for an innovation.

Until circa 1900, the debate was mostly a scholarly affair and caused only few disputes in the courts. This changed after the turn of the century, when the topic of inventions made by employees was controversially debated in the public as well as in the national parliament. In particular, associations of white collar employees asked for a stronger protection of inventors' rights during the early years of the 20th century. In 1901, the *Deutscher Technikerverein* (German engineers' society) demanded the naming of the individual inventor in the patent certificate if the patent was issued to the employer (Bartenbach and Volz, 1982; Kurz, 1997: 38). A few years later, in 1905, the *Bund der technisch-industriellen Beamten* (Association of technical employees) tightened the claim by demanding a monetary compensation of the employed inventor. The association asked for a share in profits of one third of the profit made by the firm using the patent (Bartenbach and Volz, 1982; Kurz, 1997: 40-41; Gesellschaft für soziale Reform, 1919). Of course, the industrial firms declined such radical claims and referred to the rise of the German economy under the current system (Kurz, 1997: 43-47). Nevertheless, the Imperial High Court softened its pro-business position somewhat. A decision made on 17 April 1907 allocated for the first time the property right of an employee invention to the employee. However, if the working contract, the position of the inventor within the firm, or a company decree suggested that the invention belonged to the firm, the firm received the property right without a duty to compensate the inventor (Kurz, 1997: 62-63). Thus, researchers employed in the laboratories of the large chemical, pharmaceutical, and electrical engineering firms still had no title to receive a remuneration for an invention. Finally, in 1913, the national parliament discussed a bill that would have strengthened the rights of employed inventors substantially, but – due to the war – the bill was never turned into law.

III. Theory

A fundamental organisational choice of a firm is the make-or-buy decision regarding innovative activity and, after this decision has been taken, the design of contracts with in-house and outside researchers. The seminal contribution by Aghion and Tirole (1994) offers a theoretical analysis of this management problem in a setting with symmetric information and secure intellectual property rights.[7] They start from the observation that a researcher can perform research for a firm either inside the firm or as an outside contractor. In both cases, an innovation has some positive value for the firm and the probability of invention depends on the effort of the researcher and of the amount of additional inputs delivered by the firm, e.g., access to laboratory facilities, financial support, or access to the final consumer. From a more technical point of view, Aghion and Tirole (1994) assume that the researcher and the firm are risk-neutral and that their efforts enter additive and separable in the production function for innovation. Furthermore, the researcher puts in a minimum effort – in the model normalized to zero – to fulfil the obligations of his working contract and to account for potential career concerns. Finally, the researcher has no wealth and his wealth cannot be negative. In the first best world, effort levels will be chosen to maximize the net value of the innovation, i.e., the probability of an innovation – the probability depends on the sum of both parties efforts – times the value of the innovation, less the efforts of the two parties.

For in-house researchers, the German labour law allocated the property right of an invention to the firm, and the patent law allocated the property right to the person registering the patent with the patent office, and not to the true inventor. Consequently, it seems reasonable to assume an allocation of the property right to the firm. In this case, the researcher will choose an effort level of zero – i.e., the minimum effort called for in his labour contract including his career concerns – and the firm will optimise its own effort under this condition. This optimisation problem yields underinvestment of the firm in research effort, since no additional effort by the scientist enters the production process. Clearly, the more the researchers' effort matters for the total output, the more the allocation of the property right to the firm hurts overall efficiency. Offering a profit share to the researcher can mitigate this incentive problem and thus we can expect a positive correlation between profit shares and the number of valuable patents. Moreover, a higher fixed salary increases the expected minimum effort of the researcher and we can expect a positive correlation between the fixed salary and innovative output.

Yet, the incentive problem is even more complex in the real world. For example, a researcher can perform multiple tasks: he might perform groundbreaking research leading to few, but valuable patents; he might undertake straightforward research projects yielding a set of worthless patents; or he might focus on incremental process innovations without the possibility of receiving a patent. Moreover, each researcher has a time constraint and he will reallocate his working time in accordance with the incentives explicitly or implicitly set by his principal. A standard result from the multi-tasking literature is the effect that the agent will reallocate his effort to activities yielding a reward (see Holmstrom and Milgrom, 1991). Thus, if a firm established implicit or explicit incentive schemes for the production of valuable patents, a researcher will reallocate working time from the production of worthless innovations to the production of valuable innovations. Consequently, the number of patents granted to a firm might be negatively related

7 Anton and Yao (1994, 1995) analyse the case of missing or weak property rights. We do not follow this approach, since only 0.4 percent of the patents granted in the German Empire were repealed, i.e., patent rights represented secure property rights.

to the extent of reward schemes, whereas the number of valuable patents should be positively correlated with the extent of reward schemes. In sum, the theoretical considerations suggest that the even the sign of the correlation between patenting activity and incentive pay is indeterminate.

IV. Data

Our most important data sources are the personnel files of individual inventors. Moreover, we use some information from related files and from the secondary literature. We selected seven firms from the chemical (BASF, Bayer, Hoechst), pharmaceutical (Merck, Schering), and electrical engineering (Siemens, AEG) industries to investigate working contracts of employed inventors. The investigation period ranges from 1877 to 1913, the period between enactment of the federal patent law and the First World War. At AEG, we did not discover any evidence regarding the management of R&D or researchers' compensation. The protection of data privacy impeded the use of personnel files of Merck and Hoechst. The Schering record office holds only one working contract of a researcher and some information regarding a second researcher. Yet, Schering's file did not contain time series information about the remuneration of researchers. Thus, the sample effectively boils down to three firms – Bayer, BASF, and Siemens.

For Bayer, we gathered 28 working contracts from the personnel files of five of the company's top researchers (Bayer Record Office, file no. 271-1). In addition, from a collection of data sheets that contain information on contractual details as well as fixed and variable payments of all chemists employed by Bayer in the time period under consideration, we drew a random sample of another 103 individuals. 79 out of these 103 chemists were active researchers at some point in time during the investigation period. For BASF, personnel files provided us with working contracts as well as information on fixed and variable payments for a random sample of 21 researchers. All investigated chemists worked in the main research laboratory of BASF at some point in time.[8] For Siemens, we gathered information on fixed and variable payments of 60 individuals from personnel files and a compilation of payments made to the technical employees of the Siemens factory in Berlin (Siemens Record Office, file no. 13/Li 64). Working contracts of these individuals were not available. Only in one case, we obtained a draft version of a contract (Siemens Record Office, personnel file Werner Bolton). Furthermore, we were able to collect 19 working contracts of 18 employees in the department of electric trains (Siemens Record Office, file no. 13/Lk 764). Yet, due to the decentralisation of the company's research activity and missing detailed primary and secondary sources on its organisation, in general, it proved hard to identify original research personnel. Thus, we cannot be sure, which technical employees, whose payment information we use, were actually engaged in some sort of research.

8 The sample was constructed using a list of researchers that worked in BASF's central research laboratory compiled by Reinhardt (1997: 335-364).

V. Descriptive Statistics

We start the discussion of our findings by looking at Bayer, since this firm was traditionally in the focus of historians' investigations into the rise of the modern research laboratory in Germany (e.g. Beer, 1959; Meyer-Thurow, 1983; Murmann, 2006). So far, only Meyer-Thurow (1983) had presented data regarding the level and structure of compensation for a small sample of seven researchers employed at Bayer in three benchmark years during the early 20th century. The findings by Meyer-Thurow suggest that performance-related compensation was important for researchers at Bayer.

We investigate the issue by evaluating the total compensation and its structure for 79 researchers. Until the 1890s, fixed income and total income at Bayer were virtually identical (see Figure 1). Only about 1.1 percent of the total income paid to researchers were bonus payments. In the 1890s, the two series started to diverge.[9] However, the total income of Bayer's researchers did not exceed the level of the 1880s and late 1870s; the share of bonus payments in total income remained very small at 2.8 percent. Nevertheless, at least one researcher earned substantial bonus payments during the 1890s. Then, after the turn of the century both fixed and total income were significantly increasing. Furthermore, variable payments grew much faster than fixed payments, so that the gap between the two became ever larger. For the period after the turn of the century, we confirm Meyer-Thurow's findings: incentive pay now accounts for about 17 percent of the total income of researchers.[10]

In most cases, bonus payments at Bayer were agreed on in the labour contracts. The standard contractual clause stipulated that a researcher would receive three percent of the net profits of a patented invention and one and a half percent if the invention was patented but relied on some other patent of Bayer or one of the company's competitors. If an invention was made by more than one researcher, the bonus was divided between the inventors. Occasionally, higher sharing rates were agreed on.[11] Here and there, researchers also received bonus payments outside of what was agreed on in their working contracts. In these cases, they were either given a fixed payment for some specific achievement[12] or a percentage of the net profits of some chemical substance that was related to their outstanding efforts.[13] Until the late 1880s, bonus payments were only offered to about five percent of the research staff, but all researchers with such an offer actually received bonus payments. During the 1890s, Bayer offered bonus payments to about 12 percent

9 The finding that Bayer boosted incentive related compensations at the beginning of the 1890s is also corroborated by a letter of the company's director Carl Duisberg to Dr. J. Rosenberg (dated 23 June 1909). In this letter, Duisberg claims that Bayer made very positive experiences with these kinds of payments since they were introduced 20 years ago (Bayer Record Office, file no. 022-012).

10 This compares to about 18 percent of total compensation paid as bonuses and 32 percent of total compensation paid as long-term incentives in the modern U.S. (Lerner and Wolf, 2007).

11 In five cases, researchers were at least temporarily given five percent of net profits. The working contract of one researcher provided him with ten percent.

12 In a letter (dated 6 June 1907), Bayer awarded 20,000 Mark to Bernhard Heymann for his achievements in developing a new indigo synthesis. Heymann's assistants Braun and Guericke received 10,000 Mark each.

13 By a letter (dated 28 July 1905) and in addition to what was stipulated in his working contract, Bayer granted Robert E. Schmidt 0.25 per cent of the net profits from alizarin red for his achievements in reducing the production costs of this dye.

of the researchers, but only half of them received bonuses. After the turn of the century, two-thirds of the researchers had a bonus regulation in their working contracts and most of them actually received a bonus.

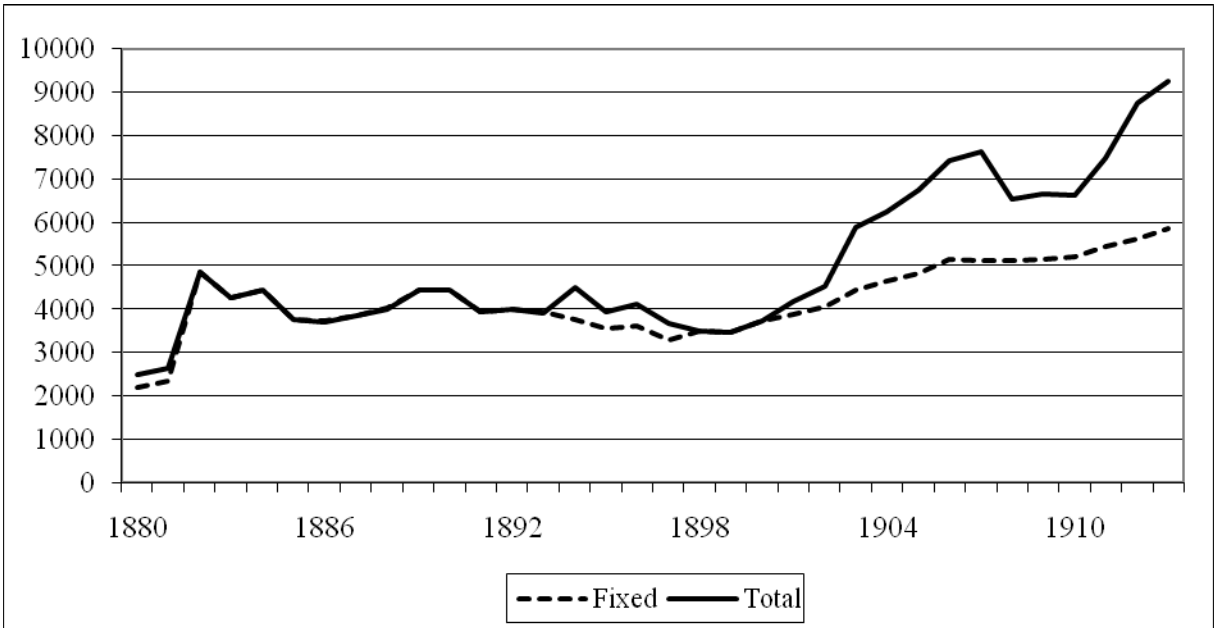

Figure 1
Average Income of Chemists at Bayer, 1880-1913 (in Mark, 1913 prices).
Source: Bayer Record Office, file no 271-1; own calculations.

In addition to the clauses on fixed and variable payments, all working contracts at Bayer included stipulations on a time of competitive restriction. Based on the available evidence, it appears that Bayer protected the human capital and tacit knowledge of its researchers increasingly over time. Until the mid 1890s, the research chemists had to agree not to convey any information on substances, procedures, and other business secrets of Bayer for a period of three years after they had left the company. In addition, Bayer was allowed to prohibit them to work for any competitor for a one-year period. In the following, the latter period was increased twice: at first, to two years and finally to three years. The standard contract penalty for non-compliance with the stipulations on the time of competitive restriction was the fivefold of the last fixed salary, on average about 25,000 Mark.

For BASF, we investigate the total compensation and its structure based on a sample of 21 researchers. The data show that variable compensation was common at BASF and quite high compared to Bayer. Figure 2 displays the evolution of the mean fixed and total income for scientists at BASF between 1877 and 1913. It turns out that the fixed income of the chemists in our sample was nearly constant between the mid-1880s and World War I. In contrast, the total income was increasing throughout the whole period. The gap between fixed and total income became ever larger. Thus, Borscheid (1976), in his study about the chemical industry in Baden, underestimated the income dynamics and the income levels at BASF substantially since he did not include variable compensation packages into his average income time series for chemists employed by BASF. Consequently, his data show nearly constant incomes of chemists employed by BASF, whereas our income series shows a marked upward trend.

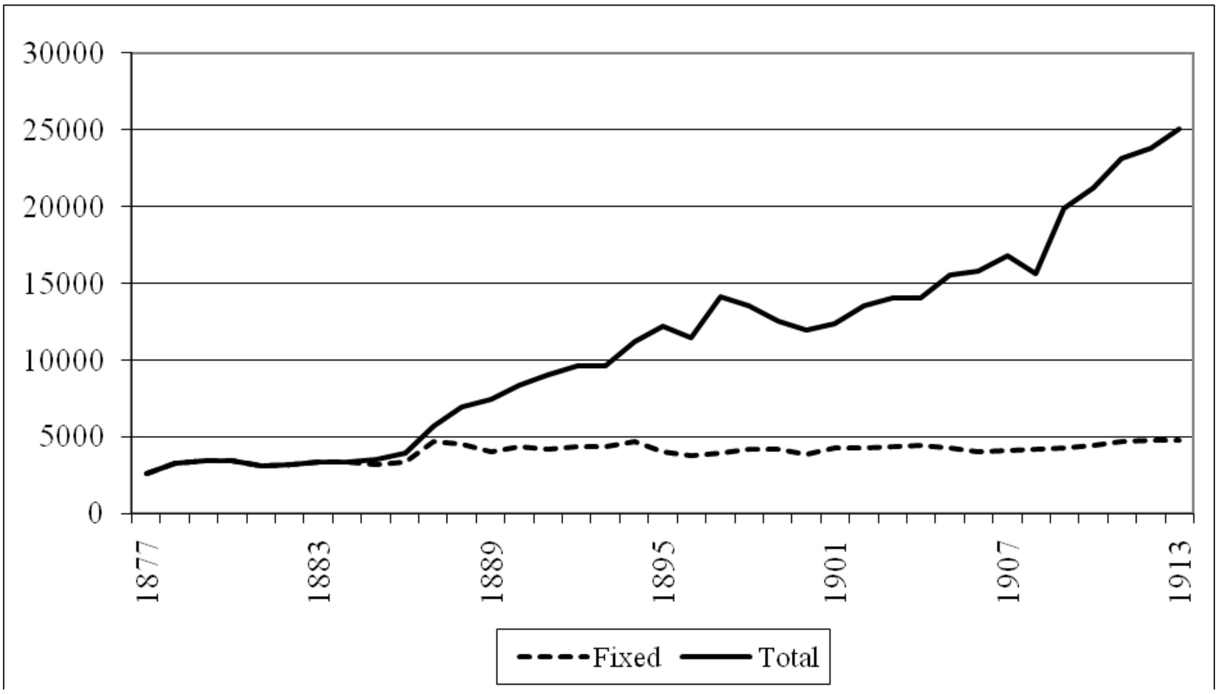

Figure 2
Average Income of Chemists at BASF, 1877-1913 (in Mark, 1913 prices)
Sources: BASF Record Office, personnel files; own calculations.

Compared to Bayer, the available evidence suggests that the ratio of variable payments to total income of BASF's research chemists was substantially higher for all individuals and at any point in time. Moreover, BASF started to use comprehensive variable compensation schemes about ten years earlier than Bayer. However, the bonus schemes at the two companies were very different. In contrast to Bayer, at BASF the size of the bonuses (called *Gratificationen*) was almost completely at the discretion of the company. The working contracts of BASF's chemists only stipulated that some bonus payments ought to be made and they defined a minimum payment in the first year. As a result, almost all research chemists received some bonus payments, but there was no obvious link to the performance of the respective individuals. In most of the cases, the bonus payment simply increased every year.

Yet, four of the 21 investigated chemists at BASF received variable bonuses that were explicitly related to specific inventions. Another researcher got a fixed award for some non-specified achievement. Unlike the practice at Bayer, the variable bonuses were not calculated on the basis of net profits, but on the basis of output or sales. In general, the available data suggest that if and how these payments were made was at the discretion of the company.[14] At least, it was not laid down in the investigated working contracts.

Apart from these differences in the bonus schemes, the working contracts of the two companies also differed in other respects. Unlike Bayer, BASF did not offer annually increasing fixed payments to its research chemists: increases in fixed salaries were discretionary and unevenly granted by the company.[15] In addition and again in contrast to Bayer, the typical working contract at BASF did not have a fixed duration, whereas Bayer's working contracts had a standard duration of five years. BASF stipulated only that the contracts could be terminated with a period of notice of six months. Like the working contracts at Bayer, those at BASF also included a clause that defined a time of competitive restriction. In the overwhelming majority of cases, researchers were not allowed to work at competing companies for a three-year period.[16] The contract penalty for non-compliance with these stipulations was usually set at 50,000 Mark.[17]

Finally, we turn to Siemens, Germany's leading electrical engineering firm, and evaluate fixed and variable payments for 60 researchers and technical employees. The findings indicate that in all the years between 1890 and 1913, all researchers and technical employees at Siemens received some variable payments, but that they could be very different in size. Furthermore, it becomes clear that variable components made up a substantial part of the total income of the investigated individuals: they accounted for roughly one quarter of total income.[18] The evolution of the mean fixed and total income of researchers and technical employees at Siemens over time is displayed in Figure 3. Both series show a secular upward trend. Roughly up to the turn of the century, they are co-moving. Then, the total income series is increasing at a larger growth rate than fixed income series, indicating the relative increase in the importance of variable payments.

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14 For example, Richard Arheidt was granted a payment of four Mark for every 1,000 Kilograms of hydrogen in 1896 and another payment of 2 Mark for every 100 Kilograms of cyrogenic dyes in 1902. Then, in 1905 BASF informed Arheidt that his payments for cyrogenic dyes did not reflect the actual profitability of this line of business and as a result, his payments were reduced to 1 Mark for every 100 Kilograms. Finally, in 1908 BASF changed the assessment base of the bonuses. Arheidt now received a certain fraction of the profits from the anilin dye department (BASF Record Office, personnel file Richardt Arheidt).

15 The personnel files of several researchers included one or more letters, in which the company told them that their fixed income will be increased.

16 In one case, a five-year period was agreed on.

17 In one case, a slightly lower and, in another, a substantially higher penalty was included (40,000 and 100,000 M, respectively).

18 Based only on the technical employee data that is also included in our Siemens sample, Conrad (1986: 71) estimated about the same share of variable bonuses in total incomes after the turn of the century.

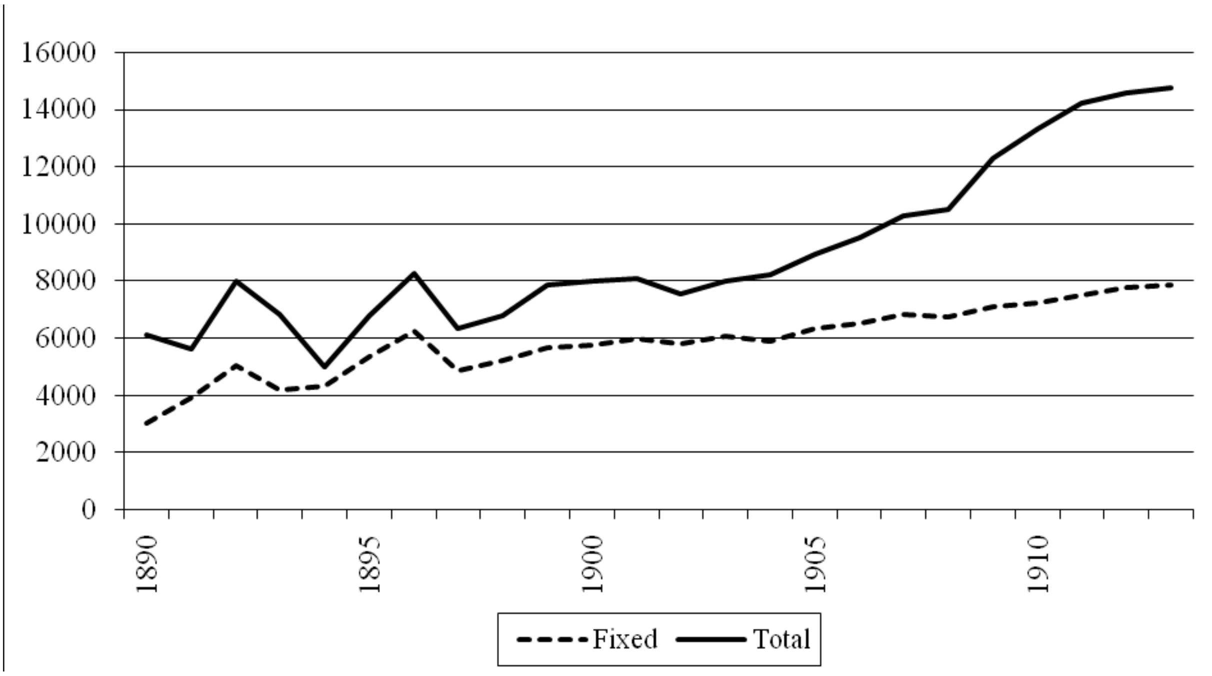

Figure 3
Average Income of Researchers and Technical Employees at Siemens, 1890-1913 (in Mark, 1913 prices)
Sources: Siemens Record Office, personnel files, file no. 13/Li 67; own calculations.

In general, employees received two different kinds of variable payments in addition to their fixed annual salary. Employees at the lower end of the hierarchy got inventory bonuses (*Inventurprämien*) at the end of each year. The higher-ranked employees received participations (*Beteiligungen*). The absolute and relative size of the latter were substantially larger than those of the former. Both kinds of payments were completely at the discretion of the company. A predefined assessment base did not exist. In his seminal work on Siemens, Kocka (1969: 262-263) shows that up to the end of the 1880s and the beginning of the 1890s, at least to some extent the inventory bonuses and the participations were linked to individual effort and/or the profitability of Siemens' businesses in general. Afterwards, both lost much of their variable nature. The former were reduced in size at the expense of higher fixed salaries and were more and more transformed into a thirteenth monthly salary. The participations were set to round sums and fixed, or they increased with the fixed salary.

In contrast to the inventory bonuses and the participations that were paid to virtually all of Siemens' employees, specific bonus payments for inventions seem to have been a rare exception[19] and were only reluctantly given[20]. General regulations were consequently ruled out.[21] Among the

19 In a reply to a request by the Allied Control Commission (dated 1 March 1946) concerning the payments made to Reinhold Rüdenberg, Siemens replied that there was no special agreement between him and the company with respect to inventions and patents, as those kinds of agreements were not common at Siemens (Siemens Record Office Personnel File Reinhold Rüdenberg).

20 In a memorandum (dated 20 June 1906), Carl Köttgen, who was a member of the board of directors at that time, argued against both fixed and variable payments for inventions made by Siemens' employees. While he dismissed the former kinds of payments in principle, he offered practical arguments why Siemens would not grant variable payments to its inventors. In particular, Köttgen stresses that in practice the contribution of one

employees included in our database, only two received such payments.[22] However, if such a payment was granted, it could be extraordinary profitable for the respective individual.[23]

Based on the evaluation of the information from working contracts from the department of electric trains, we can confirm the existence of substantial variable remuneration. Inventory bonuses (defined in ten out of 19 contracts) were fixed to one monthly salary. Those employees that received participations (nine out of 19 contracts) were in most cases at least granted a minimum payment each year. In two cases, even the annual increases were defined *a priori*. In addition to these clauses on variable components, the working contracts determined a fixed annual salary and usually also one increase of the salary within the duration of the contract, with the exact timing of any increase at the discretion of the company. The usual duration of a contract was five years, but occasionally shorter time periods were agreed on. If a contract expired, it would have to be terminated within a period of notice of six months. Otherwise, it would automatically be prolonged for another period of between one and five years. None of the available contracts included stipulations on a period of competitive restriction. However, Siemens' decree on the property rights of employee-inventions stipulated that employees were not allowed to apply for a patent within two months after termination of their employment.[24]

specific invention to the overall sales price of a product was highly arbitrary and, thus, it was nearly impossible to assign a share of any price to a specific patent (Siemens Record Office VVA Carl Köttgen).

21 The company's decree on the property rights of inventions made by employees stipulated: "Es bleibt dem freien Ermessen der Gesellschaft vorbehalten, bei Erfindungen von besonderer Genialität und geschäftlichem Werte den Angestellten, der diese Erfindung gemacht hat, durch Verbesserung seiner Stellung, durch Bewilligung einer einmaligen oder fortlaufenden Tantieme oder auf eine andere, ihr passend erscheinende Weise für solche außerordentliche Leistung zu honorieren" (Cited from the decree issued in 1899, Siemens Record Office, file no. 4/Lk 78).

22 In a draft of his working contract (dated 4 July 1905), Werner Bolton was granted 5,000 M. for every 1 million tantal light bulbs up to a total income of 60,000 M. (Siemens Record Office, Personnel File Werner Bolton). Due to the decision of a special conference (headed by Werner von Siemens and dated 20 March 1897), Waldemar Meißner received 50 M. for every stone drilling machine sold (Siemens Record Office, Personnel File Waldemar Meißner).

23 For example, Werner Bolton received substantial bonus paymets for the invention of the tantal light bulb.

24 Siemens Record Office, file no. 4/Lk 78.

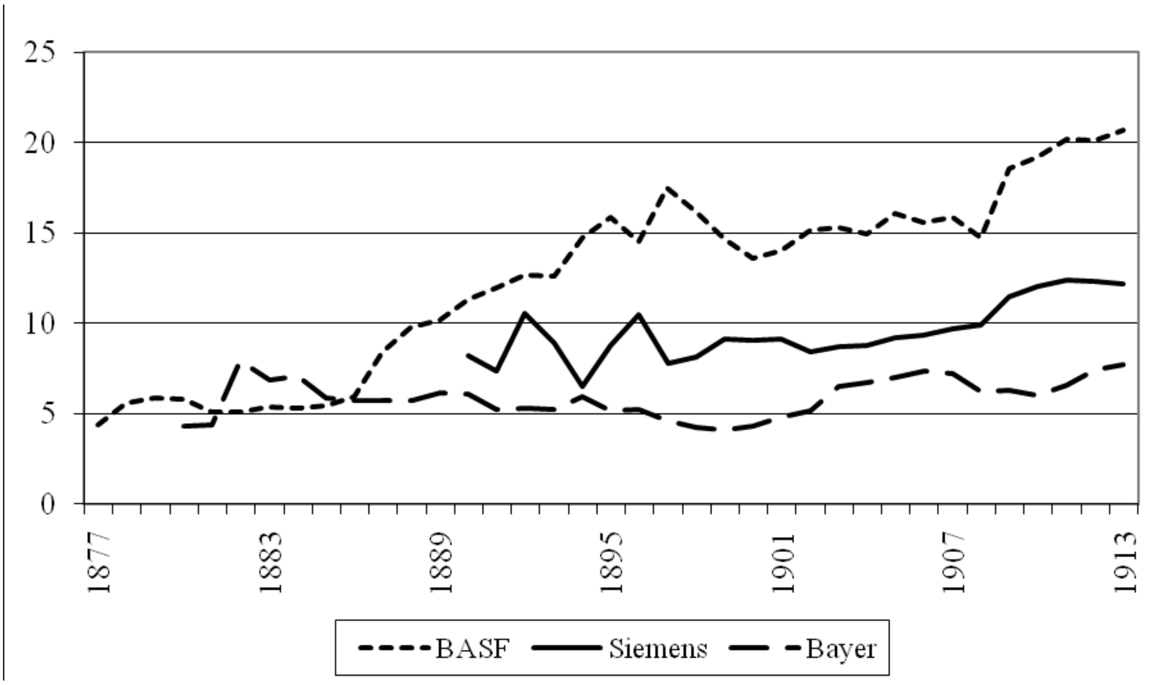

Figure 4
Average total income of researchers as multiples of the average income of an industrial worker.

In Figure 4, we compare the total income of researchers at Bayer, BASF, and Siemens to the average income of industrial workers between 1877 and 1913.[25] First of all, researchers were much better paid than the average worker and the relative income position of researchers improved over time. Until the mid-1880s, the average remuneration of researchers employed by BASF, Bayer, and Siemens was about five times the income of a typical worker. The compensation of researchers at Bayer remained on this level throughout the late 19th and early 20th century. Researchers at BASF, on the other hand, experienced a significant increase of their relative income position over time. From the mid-1890s onwards, BASF's researchers earned an income of about 15 times a worker's income. Finally, our data suggest that Siemens took an intermediate position and paid about ten times the average worker's income to its researchers and engineers.

V. Econometric evaluation

In this section, we investigate the relationship between researcher's remuneration and innovative output of the three companies. Our proxies of innovative output are the number of patents and the number of long-living patents granted to the firms between 1890 and 1913. Following Streb et al. (2006), a valuable patent is a patent that was in force for at least ten years. Measured by the total number of patents granted between 1890 and 1913, Siemens was the most innovative firm, followed by Bayer, and BASF. Taking the number of valuable patents as a measure, the order changes. According to this criterion, Bayer is the most innovative firm, followed by BASF, and

25 The wage data are taken from Hoffmann (1965: 492-494, col. 3).

Siemens. Thus, the average quality of Bayer's patents is higher than the average quality of the two other firms patents; this might be a result of the explicit incentive schemes offered by Bayer.

TABLE 2: INNOVATIVE ACTIVITY OF THE FIRMS, 1890-1913

	BASF	Bayer	Siemens
Number of patents granted	1,445	1,987	2,111
Number of valuable patents granted	563	752	397

Sources: Number of patents granted: Kaiserliches Patentamt (various years); number of valuable patents: Streb et al. (2006).

Explanatory variables are the average total compensation paid by firm i during period t to the researcher in our sample; the average share of variable compensation in total compensation in the compensation of the researchers at firm i during period t; the aggregate innovative activity, i.e. the total number of patents granted in the technology classes chemicals, dyestuffs, and electrical engineering during period t; and firm fixed effects. To account for possible dynamic effects, the lagged dependent variable is included in all regressions and some of the regressions also include the lagged explanatory variables as regressor. Thus, we estimate autoregressive distributed lag (ARDL) models with one autoregressive parameter and zero or one lagged explanatory variables, i.e. we estimate ARDL (1,0) or ARDL (1,1) models, see equations (1) to (4).[26]

(1) $\text{Patents}_{i,t} = c + \lambda \text{Patents}_{i,t-1} + \beta_0 X_t$

(2) $\text{Patents}_{i,t} = c + \lambda \text{Patents}_{i,t-1} + \beta_0 X_t + \beta_1 X_{t-1}$

(3) $\text{Valuable Patents}_{i,t} = c + \lambda \text{Valuable Patents}_{i,t-1} + \beta_0 X_t$

(4) $\text{Valuable Patents}_{i,t} = c + \lambda \text{Valuable Patents}_{i,t-1} + \beta_0 X_t + \beta_1 X_{t-1}$

$$X_t = \left\{ \text{Bonusshare}_{i,t}, \text{Compensation}_{i,t}, \text{Innovation}_t, \text{Bayer}, \text{BASF}, \text{Siemens} \right\}$$

$$X_{t-1} = \left\{ \text{Bonusshare}_{i,t-1}, \text{Compensation}_{i,t-1}, \text{Innovation}_{t-1} \right\}$$

Equations (1) and (3) are ARDL (1,0) models explaining the number of patents (valuable patents) granted to firm i during period t using the lagged dependent variable and a set of contemporaneous explanatory variables X_t. Equations (2) and (4) are ARDL (1,1) models, which also include the lagged explanatory variables X_{t-1}. The β_0-coefficients measure the contemporaneous effects of an explanatory variable, whereas the ratio $(\beta_0+\beta_1) / (1-\lambda)$ equals the long-run effect of an explanatory variable on the dependent variable.

From an econometric point of view, it is well-known that ARDL models yield efficient, but downward biased results (Nickel, 1981) and several dynamic panel estimators have been proposed to estimate unbiased and efficient models. However, these more recent dynamic panel es-

26 See Greene (2003: 571-576) for a technical exposition of ARDL models.

timators perform only in relatively large samples better than the established ARDL model. More specifically, dynamic panel estimators usually yield less biased, but inefficient results in small samples (see, e.g., Kiviet, 1995; Judson and Owen, 1999). Given the time and cross-sectional dimension of our data set, the formula derived by Kiviet (1995) suggest that the bias is close to zero in our data set.[27] Thus, we prefer the slightly biased, but efficient ARDL estimator over unbiased, but inefficient dynamic panel estimators.

Table 3 presents the baseline regression results for the ARDL (1,0) and ARDL (1,1) models. The only variable with a significant impact on the innovative activity of the three firms in our sample is the aggregate number of patents granted in chemicals, dyestuffs, and electrical engineering, i.e., the aggregate innovative activity. Moreover, the lagged dependent variables show substantial persistence in innovative activity over time. The variables of interest – the total compensation and the share of bonus payments in total compensation – are statistically insignificant. Neither the contemporaneous nor the long-run effects of total compensation or the bonus share in total compensation are significant from a statistical point of view. Thus, compensation schemes for researchers did not affect the innovative activity of German high-tech firms during the late 19th and early 20th century. Moreover, the firm fixed effects are all insignificant. This indicates that differences in the management of innovation – e.g., the type of working contracts offered to researchers – did not influence the innovative activity. Yet, the overall innovative activity in the economy had a significant impact on the innovative activity of the three firms. The long-run effects indicate that a one percent increase in aggregate innovative activity increased the number of patents by about 0.9 percent and the number of valuable patents by about 1.3 percent.

27 Kiviet (1995) demonstrates that the bias in ARDL (1,0) models is N-1T-3/2, with N denoting the cross-section dimension and T denoting the time series dimension. Our data set contains 24 years of observations for three firms. This implies a bias of 0.0028.

TABLE 3: COMPENSATION AND INNOVATION - BASELINE REGRESSION

	Log (Number of patents)		Log (Number of valuable patents)	
	(1)	(2)	(3)	(4)
Log (Share of bonus in total compensation)	0.004	-0.014	-0.041	-0.067
Log (Total compensation)	-0.042	-0.190	-0.152	-0.088
Log (Aggregate innovative activity)	0.459***	0.918***	0.587**	1.313***
Bayer	-0.575	-0.099	-1.471	-1.043
BASF	-0.165*	-0.148	0.084	0.040
Siemens	0.093	0.149	0.422	0.330
Log (Share of bonus in total compensation in t-1)		0.068		0.108
Log (Total compensation in t-1)		0.104		-0.051
Log (Aggregate innovative activity in t-1)		-0.520*		-0.822**
Log (Number of patents in t-1)	0.488***	0.573***		
Log (Number of valuable patents in t-1)			0.552***	0.614***
Long-run effects				
Share of bonus in total compensation		0.127		0.104
Total compensation		-0.201		-0.361
Aggregate innovative activity		0.933***		1.274***
Number of observations	69	69	69	69
Autocorrelation of residuals	0.296	0.181	0.167	0.039
F-Test (p-value)	0.000	0.000	0.000	0.000
adjusted R^2	0.808	0.820	0.638	0.648

*Method: Ordinary least squares (OLS). Standard errors corrected for heteroscedasticity. *, **, *** indicates significance on 10, 5, and 1 percent level, respectively.*

Table 4 presents the first set of stability checks. It might be the case that the variables have a trend and that standard OLS regressions of the level series yield spurious results. Thus, we re-estimated the regression from Table 3 using first differences. Indeed, the autocorrelation of residuals and the coefficients of the lagged dependent variable are much smaller if first differences are employed. However, the main results still holds: only the aggregate innovative activity influenced the innovative performance of the three firms in our sample. Compensation schemes or firm specific effects are insignificant.

TABLE 4: COMPENSATION AND INNOVATION - STABILITY CHECK I

	Δ Log (Number of patents)		Δ Log (Number of valuable patents)	
	(1)	(2)	(3)	(4)
Δ Log (Share of bonus in total compensation)	0.041	-0.039	-0.063	-0.161
Δ Log (Total compensation)	-0.403	-0.213	0.116	0.293
Δ Log (Aggregate innovative activity)	1.251***	1.158***	1.503***	1.286**
Bayer	-0.036	-0.075	-0.043	-0.072
BASF	0.019	0.017	0.146	0.155
Siemens	0.142	0.152	-0.019	-0.083
Δ Log (Share of bonus in total compensation in t-1)		0.013		-0.140
Δ Log (Total compensation in t-1)		-0.195		0.803*
Δ Log (Aggregate innovative activity in t-1)		0.788**		0.201
Δ Log (Number of patents in t-1)	0.035	-0.116		
Δ Log (Number of valuable patents in t-1)			-0.106	-0.137
Long-run effects				
Share of bonus in total compensation		-0.024		-0.265*
Total compensation		-0.365		0.965
Aggregate innovative activity		1.743***		1.308**
Number of observations	69	69	69	69
Autocorrelation of residuals	0.034	0.167	-0.028	-0.036
F-Test (p-value)	0.002	0.003	0.120	0.095
adjusted R^2	0.203	0.230	0.064	0.092

*Method: Ordinary least squares (OLS). Standard errors corrected for heteroscedasticity. *, **, *** indicates significance on 10, 5, and 1 percent level, respectively.*

Our second stability check accounts for the fact that the number of patents and the number of valuable patents are non-negative by definition. Thus, a Tobit model might be the appropriate estimator. Indeed, the null hypothesis that a Tobit model is the correct econometric specification cannot be rejected. Yet, the key result is not affected by the choice of the estimator: the aggregate innovative activity has a positive and significant impact on the innovative activity of the three firms in our sample, whereas compensation schemes have, from an economic or statistical point of view, a small impact on innovativeness.

TABLE 5: COMPENSATION AND INNOVATION - STABILITY CHECK II

	Number of patents		Number of valuable patents	
	(1)	(2)	(3)	(4)
Share of bonus in total compensation	12.653	-18.850	1.403	23.792
Total compensation	-0.000	0.000	-0.000	-0.002***
Aggregate innovative activity	0.022***	0.049**	0.014**	0.024*
Bayer	5.394	4.102	-3.787	-5.276
BASF	-12.363	-12.163	1.437	5.905
Siemens	5.068	3.043	7.644	13.092**
Share of bonus in total compensation in t-1		33.194		-35.059*
Total compensation in t-1		-0.001		0.002***
Aggregate innovative activity in t-1		-0.030		-0.007
Number of patents in t-1	0.645***	0.698***		
Number of valuable patents in t-1			0.513***	0.460***
Long-run effects				
Share of bonus in total compensation		47.483		-20.869
Total compensation		-0.001		0.000
Aggregate innovative activity		0.060***		0.031***
Number of observations	69	69	69	69
Sigma	17.547***	17.139***	12.142***	11.015***
LM-Test for Tobit (p-value)	0.998	0.999	0.138	0.379
LM-Test for normality (p-value)	0.064	0.029	0.000	0.000
ANOVA pseudo R^2	0.796	0.807	0.488	0.568

*Method: Tobit. *, **, *** indicates significance on 10, 5, and 1 percent level, respectively.*

VI. Conclusion

In Germany, the late 19th and early 20th century was a period of rapid technological transformation and of fast economic growth. One key force behind this development was the rise of new industries, especially chemical, pharmaceuticals, and electrical engineering. In turn, the new industries were driven by new technologies, which were – at least in part – developed in the recently established corporate research units. The appearance of research laboratories has been investigated for various firms in Germany and other countries. In particular, the impact of government policy – e.g. in the fields of intellectual property rights and higher education – on corporate R&D and the effect of new industries on aggregate economic growth has been evaluated. In contrast, the management of the new R&D units has not been investigated in detail. Nonetheless, the management of R&D is an important topic for many national histories, since, for example, German as well as U.S. patent law allocated patent rights to the firms employing inventors, and not to the inventors themselves and a successful management strategy might have to address this principal-agent problem. More specifically, we investigate if incentive or reward schemes were set up by industrial firms and if such schemes had a measurable impact on innovative activity.

It turns out that only one of the leading firms of Germany's chemical and electrical engineering industries investigated in this paper – Bayer – addressed the potential principal-agent problem by offering explicit ex-ante contracted bonus payments to the employed inventors. This firm connected bonus payments to the profits made with a specified innovation. BASF and Siemens, on the other hand, did not use explicit bonus schemes, but implemented discretionary reward schemes. At all three firms, variable compensation was important and its relative size was comparable to incentive schemes in modern corporations. However, modern incentives mostly base on stock options, whereas only bonuses were in use a century ago.

Furthermore, we show that compensation packages for researchers were unimportant for the innovative activity during the late 19^{th} and early 20^{th} century: a high share of bonus payments in total compensation or a high total compensation was not related to the number of patents granted to a firm or to the number of long-living patents granted to a firm. Moreover, we could not detect systematic difference among the first. This implies that the explicit bonus schemes used by Bayer were not systematically superior to the discretionary reward schemes implemented by Siemens and BASF. Finally, our econometric results show that the aggregate innovative activity on the industry level positively influenced the innovative activity of single firms.

References

Aghion, P. and Tirole, T. (1994)
The management of innovation
Quarterly Journal of Economics, 109, 1185-1209

Anton, J.J. and Yao, D.A. (1994)
Expropriation and inventions: Appropriable rents in the absence of property rights
American Economic Review, 84, 190-209

Anton, J.J. and Yao, D.A. (1995)
Start-ups, spin-offs, and internal projects
Journal of Law, Economics, and Organization, 11, 362-378

Bartenbach, K. and Volz, F.-E. (1982)
Geschichtliche Entwicklung und Grundlagen des Arbeitnehmererfindungsrechts – 25 Jahre ArbEG
Gewerblicher Rechtsschutz und Urheberrecht, 84, 693-702

Beer, J.J. (1959)
The emergence of the Germany dye industry
The University of Illinois Press, Urbana

Borscheid, P. (1976)
Naturwissenschaft, Staat und Industrie in Baden (1848-1914)
Ernst Klett Verlag, Stuttgart

Cameron, R. and Neal, L. (2003)
A concise economic history of the World
4th Edition, Oxford University Press, Oxford

Chandler, A.D. (2005)
Shaping the industrial century: The remarkable story of the evolution of the modern chemical and pharmaceutical industries
Harvard University Press, Cambridge / Mass.

Church, R. and Tansey, E.M. (2007)
Burroughs, Wellcome & Co.: Knowledge, trust, profit and the transformation of the British pharmaceutical industry, 1880-1940
Crucible Books, Lancaster

Conrad, C. (1986)
Erfolgsbeteiligung und Vermögensbildung der Arbeitnehmer bei Siemens (1847-1945)
Steiner, Stuttgart

Erker, P. (1990)
Die Verwissenschaftlichung der Industrie: Zur Geschichte der Industrieforschung in den europäischen und amerikanischen Elektrokonzernen, 1890-1930
Zeitschrift für Unternehmensgeschichte, 35, 73-94

Feldenkirchen, W. and Posner, E. (2005)
Die Siemens Unternehmer
Piper, München

Fisk, C.L. (1998)
Removing the ‘Fuel of interest’ from the ‘Fire of Genius’: Law and the employee inventor, 1830-1930
University of Chicago Law Review, 65, 1127-1198

Flechtner, H.J. (1959)
Carl Duisberg: Vom Chemiker zum Wirtschaftsführer
Econ Verlag, Düsseldorf

Galambos, L. and Sewell, J.E. (1995)
Networks of innovation: Vaccine development at Merck, Sharp & Dohme, and Mulford, 1895- 1995
Cambridge University Press, Cambridge
Gareis, C. von (1879)
Über das Erfinderrecht von Beamten, Angestellten und Arbeitern
Carl Heymann: Berlin
Gesellschaft für soziale Reform (1919)
Erfinderschutz: Sozialpolitische Forderungen einzelner Berufsgruppen. Verhandlungsbericht der außerordentlichen Hauptversammlung der Gesellschaft für soziale Reform, Berlin, 9. Mai 1914
Verlag von Gustav Fischer, Berlin
Greene, W.H. (2003)
Econometric Analysis
5th Edition, Pearson Education International, Upper Saddle River
Griliches, Z. (1990)
Patent statistics as economic indicators: A survey
Journal of Economic Literature, 28, 1661-1707
Grupp, H., Dominguez-Lacase, I., and Friedrich-Nishio, M. (2002)
Das deutsche Innovationssystem seit der Reichsgründung
Physica Verlag, Heidelberg
Hoffmann, W.G. (1965)
Das Wachstum der deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts
Springer, Berlin
Holmstrom, B. and Milgrom, R. (1991)
Multitask principal agent analyses: Incentive contracts, asset ownership, and job design
Journal of Law, Economics, and Organization, 7, 24-52
Honig-Haftel, S. and Martin, L.R. (1993)
The effectiveness of reward systems on innovative output: An empirical analysis
Small Business Economics, 5, 261-269
Hounshell, D.A. and Smith, J.K. (1988)
Science and corporate strategy: Du Pont R&D, 1902-1980
Cambridge University Press, Cambridge 1988
Johnson, J.A. (1985)
Academic chemistry in Imperial Germany
Isis, 76, 500-524
Johnson, J.A. (1989)
Hierarchy and creativity in Chemistry, 1871-1914
Osiris, 5, 214-240
Judson, R.A. and Own, A.L. (1999)
Estimating dynamic panel data models: a guide for macroeconomists
Economics Letters, 65, 9-15
Kaiserliches Patentamt (various years)
Verzeichnis der von dem Kaiserlichen Patentamt im Jahre […] erteilten Patente
Carl Heymann, Berlin
Kiviet, J.F. (1995)
On bias, inconsistency, and efficiency of various estimators in dynamic panel data models
Journal of Econometrics, 68, 53-78

Kocka, J. (1969)
Unternehmensverwaltung und Angestelltenschaft am Beispiel Siemens 1847-1914
Ernst Klett, Stuttgart
König, W. (1995)
Technikwissenschaften: Die Entstehung der Elektrotechnik aus Industrie und Wissenschaft zwischen 1880 und 1914
Fakultas: Chur
König, W. (1996)
Science-based industry or industry-based science? Electrical engineering in Germany before World War I
Technology and Culture, 37, 70-101
Kurz, P. (1997)
Geschichte des Arbeitnehmererfindungsrechts
Shaker Verlag, Aachen
Labuske, K. and Streb, J. (2008)
Technological creativity and cheap labour? Explaining the growing international competiveness of German mechanical engineering before World War I
German Economic Review, 9, 65-86
Landes, D.S. (1999)
The wealth and poverty of nations
W.W. Norton & Co., New York
Lerner, J. and Wulf, J. (2007)
Innovation and incentives: Evidence from Corporate R&D
Review of Economics and Statistics, 89, 634-644
MacLeod, C. (1999)
Negotiating the rewards of invention: The shop-floor inventor in Victorian Britain
Business History, 41, 17-36
Metz, R. and Wattleder, O. (2002)
Historische Innovationsindikatoren: Ergebnisse einer Pilotstudie
Historical Social Research, 27, 4-129
Meyer-Thurow, G. (1983)
The industrialization of invention: A case study from the German chemical industry
Isis, 73, 363-381
Murmann, J.P. (2006)
Knowledge and competitive advantage
Cambridge University Press, Cambridge
Nickel, S. (1981)
Biases in dynamic models with fixed effects
Econometrica, 49, 1417-1426
Reinhardt, C. (1997)
Forschung in der chemischen Industrie: Die Entwicklung chemischer Farbstoffe bei BASF und Hoechst, 1863-1914
Technische Akademie der Bergakademie
Seckelmann, M. (2006)
Industrialisierung, Internationalisierung und Patentrecht im Deutschen Reich, 1871-1914
Vittorio Klostermann, Frankfurt / Main
Streb, J., Baten, J., and Yin, S. (2006)
Technological and geographical knowledge spillover in the German Empire, 1877-1918
Economic History Review, 59, 347-373

Streb, J., Wallusch, J., and Yin, S. (2007)
Knowledge spill-over from new to old industries: The case of German synthetic dyes and textiles (1878-1913)
Explorations in Economic History, 44, 203-223
Travis, A.S. (1998)
Ambitious and glory hunting…impractical and fantastic: Heinrich Caro at BASF
Technology and Culture, 39, 105-115
Wetzel, W. (1991)
Naturwissenschaften und chemische Industrie in Deutschland
Franz Steiner Verlag, Stuttgart
Wimmer, W. (1994)
„Wir haben immer was Neues“: Gesundheitswesen und Innovationen in der Pharma-Industrie in Deutschland, 1880-1935
Duncker & Humblot, Berlin

Archival Records

BASF Record Office
Personnel files

Bayer Record Office
271-1

Siemens Record Office
4/Lk 78
13/Li 64
13/Lk 764
Personnel files