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Formal and Informal Technology Transfer from Academia to Industry: Complementarity Effects and Innovation Performance

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Non-technical summary

Knowledge produced in the public sector has been found to be an important ingredient of economic growth and technological progress. Close links to academic research have further been shown to be beneficial for innovation performance of the individual firm. As there are many different channels through which academic science reaches the private sector, most prominently licensing contracts, joint research and academic consulting, it is important for the decision making of policy makers and managers to assess their effectiveness. Most of the existing research has focused on formal university technology transfer mechanisms, i.e. those that embody or directly lead to a legal instrument like a patent, license or royalty agreement. Only a few authors have investigated informal university technology transfer mechanisms. Informal technology transfer focuses on non-contractual interactions of the agents involved, i.e. on university scientists and industry personnel. Research suggests that formal and informal technology transfer may go well together in that informal contacts improve the quality of a formal relationship or that formal contracts are accompanied by an informal relation of mutual exchange on technology-related aspects.

In this paper, we analyze whether these activities are mutually reinforcing, i.e. complementary. Our analysis is based on a comprehensive dataset of more than 2,000 German manufacturing firms. We perform direct and indirect tests for the complementarity of formal and informal technology transfer. Our results confirm a complementary relationship: using both transfer channels contributes to higher innovation performance. The management of the firm should therefore strive to maintain close informal relationships with universities to realize the full potential of formal technology transfer.

Das Wichtigste in Kürze

Universitäten und außeruniversitäre Forschungseinrichtungen besitzen eine zentrale Bedeutung für die Innovationsaktivitäten von Industrieunternehmen. Wissen, das unter Mitwirkung von öffentlichen Forschungseinrichtungen generiert wird, kann dabei durch grundsätzlich zwei Kanäle an Unternehmen übertragen werden. Dabei handelt es sich zum einen um formellen Technologietransfer, beispielsweise durch einen Vertrag über eine lizenzierte Technologie, gemeinsame Forschungsaktivitäten oder durch universitäre Beratungsdienstleistungen, zum anderen um informellen Technologietransfer. Dieser bezeichnet den Transfer technologischen Wissens durch nicht-vertragliche Interaktionen von Universitäts- und Industriepersonal. Nur wenige Autoren haben bislang die Determinanten und Effekte informeller Technologietransfers untersucht. Vieles spricht allerdings dafür, dass sich beide Formen des Technologietransfers wechselseitig beeinflussen, in anderen Worten komplementär zueinander sind. Beispielsweise können informelle Kontakte die Qualität eines formellen Technologietransfers unterstützen.

Wir untersuchen in diesem Beitrag die Komplementarität beider Formen des Technologietransfers. Unsere Analyse basiert auf einem umfassenden Datensatz, der mehr als 2.000 deutsche Unternehmen im verarbeitenden Gewerbes umfasst. Im Rahmen der Analyse verwenden wir direkte und indirekte Komplementaritätstests. Unsere Ergebnisse zeigen, dass beide Formen zueinander komplementär sind, d.h. die Nutzung beider Transferkanäle führt zu einem höheren Innovationserfolg. Für das Management von Unternehmen ist es daher bedeutsam, enge informelle Beziehungen zu öffentlichen Forschungseinrichtungen zu unterhalten, um das volle Potenzial eines formellen Technologietransfers zu realisieren.

Formal and Informal Technology Transfer from Academia to Industry: Complementarity Effects and Innovation Performance

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Abstract

Literature has identified formal and informal channels in university technology transfer. While formal technology transfer typically involves a legal contract on a patent or on collaborative research activities, informal transfer channels refer to personal contacts and hence to the tacit dimension of knowledge transfer. Research is, however, scarce regarding the interaction of formal and informal transfer mechanisms. In this paper, we analyze whether these activities are mutually reinforcing, i.e. complementary. Our analysis is based on a comprehensive dataset of more than 2,000 German manufacturing firms. We perform direct and indirect tests for the complementarity of formal and informal technology transfer. Our results confirm a complementary relationship: using both transfer channels contributes to higher innovation performance. The management of the firm should therefore strive to maintain close informal relationships with universities to realize the full potential of formal technology transfer.

Keywords: University technology transfer, complementarity, innovation performance

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1 Introduction

Knowledge produced in the public sector has been found to be an important ingredient of economic growth and technological progress (Jaffe, 1989; Adams, 1990). Close links to academic research have further been shown to be beneficial for innovation performance of the individual firm (Cockburn and Henderson, 1998; Cassiman et al., 2007). As there are many different channels through which academic science reaches the private sector, most prominently licensing contracts (Jensen and Thursby, 2001; Thursby and Kemp, 2002), joint research (Cockburn and Henderson, 1998) and academic consulting (Thursby et al., 2007), it is important for the decision making of policy makers and managers to assess their effectiveness (D'Este and Patel, 2007).

Recent patterns of evidence for university technology transfer focus on the institutions (e.g. technology transfer offices), the agents involved in technology commercialization, academic spin-offs, university-industry cooperative research centers or science parks and incubators (Bozeman, 2000; Rothaermel et al., 2007; Aerts et al., 2007). Most of the existing research has focused on formal university technology transfer mechanisms, i.e. those that embody or directly lead to a legal instrument like a patent, license or royalty agreement (Bozeman, 2000; Siegel and Phan, 2005; Feldman et al., 2002; Thursby and Thursby, 2002). Only a few authors have investigated informal university technology transfer mechanisms (e.g. Link et al., 2007). Informal technology transfer focuses on primarily non-contractual interactions of the agents involved, i.e. on university scientists and industry personnel.[1]

The differences between formal and informal technology transfer have not always been defined in a mutually exclusive way. Link et al. (2007), for example, define informal technology transfer as a mechanism facilitating the flow of technology knowledge through informal communication processes which could comprise technical assistance, consulting or collaborative research. In contrast to formal technology transfer mechanisms which often aim at transferring a specified research outcome like a patent, informal mechanisms do not, and there is usually no expectation that they will. In this sense, formal technology transfer is conceived as a way to allocate property rights whereas those are of much less importance in informal technology transfer. This definition is however not always without problems. Siegel

[1] In the following, we will use the term "university scientist" as shorthand for scientists employed at universities or other public research institutes.

et al. (2003) and Thursby et al. (2007) found that many university scientists in the US do not disclose their inventions to their university although prescribed by law. And even if university inventions are publicly disclosed some firms will try to contact scientists and arrange to work with them directly (Hall et al., 2003). While such a situation could be interpreted as an informal technology transfer, we can assume that in most cases there will at least be a contractual relationship between the scientist and the firm, governing the nature of the collaboration including duties and remuneration. The contract itself makes it hence a formal technology transfer. Consequently, in this paper we define informal technology transfer as a mechanism that does not involve any contractual relationship between the university scientist and the firm. Examples could be contacts between academics and industry personnel at conferences, or other informal contacts, talks and meetings.

The relationship between formal and informal technology transfer is not yet clear-cut. Research suggests that formal and informal technology transfer may go well together (Siegel et al., 2003; Link et al., 2007) in that informal contacts improve the quality of a formal relationship or that formal contracts are accompanied by an informal relation of mutual exchange on technology-related aspects. Each type of transfer mechanism has its unique advantages and shortcomings. It is therefore not surprising that both types may occur simultaneously in order to transfer codified knowledge in the form of a patent or license as well as tacit knowledge through the interaction between the university scientist and industry personnel (Perkmann and Walsh, 2007). In other words, it seems reasonable to assume a complementary relationship between formal and informal technology transfer.

Surprisingly, there has been little systematic research on the interaction between formal and informal technology transfer. The purpose of this paper is therefore to provide empirical evidence on the relationship between both transfer mechanisms. In contrast to other papers in the domain that focus on the individual scientist (e.g., Louis et al., 1989; Owen-Smith and Powell, 2001; 2003), we adopt the perspective of the firm engaging in university technology transfer. In fact, universities have frequently been regarded as a source of unique and valuable knowledge which has been characterized as the most important asset of a firm for achieving competitive advantage (Grant, 1996; Liebeskind, 1996). Using a comprehensive sample of more than 2,000 German firms, we conduct direct and indirect tests for complementarity and derive implications for managers and policy makers.

The remainder of the paper is organized as follows: The next section contains a discussion of the two transfer mechanisms, their interaction and the trajectories through which they may impact the innovation performance of firms. Section 3 describes our dataset and section 4 our empirical strategy. Section 5 presents our results and the final section outlines conclusions, implications of the empirical findings and limitations of our study.

2 Literature Background

Unique knowledge, be it internally or externally produced, has been characterized as the most valuable asset of a firm for achieving a competitive advantage (Liebeskind, 1996). This perspective is rooted in the resource and capability based view of the firm (Barney, 1991; Conner, 1991; Peteraf, 1993; Wernerfelt, 1984) and has eventually culminated in a knowledge-based view of the firm (Grant, 1996). Knowledge is critical for a firm's success as it provides the basis for decisions on which resources and capabilities to deploy, develop or discard when the environment changes (Ndofor and Levitas, 2004). However, using a competitive strategy that is built around knowledge is challenging. Knowledge is by its very nature a public good (Arrow, 1962; Jaffe, 1986) that could 'spill over' to competitors and allow them to free-ride on a firm's investments in knowledge production. Relying on research generated in the public sector to achieve a knowledge-based competitive advantage might be even riskier as academic research results typically diffuse fast, e.g. through scientific publications and conferences. Dissemination of scientific findings is a central element of the reward system in public science as academic scientists strive for money, but also for appraisal from their scientific community (Merton, 1973).

The strong incentives for firms to protect their unique knowledge against dissemination notwithstanding it has also been argued that opening up the innovation process and moving from 'research and develop' towards 'connect and develop' has its merits (Huston and Sakkab, 2006). It is particularly the 'open innovation' model by Chesbrough (2003) which develops this new perspective on how firms should innovate. Environmental changes which have become apparent in shorter product life cycles and the growing complexity of technologies and markets have forced firms to rely not exclusively on their own resources for the entire innovation process but on external sources of knowledge as well (Kogut and Zander, 1992). These developments motivate firms to reach out to actors beyond firm boundaries to maximize the benefits from inventions and ideas (Rosenkopf and Nerkar, 2001). Literature has provided evidence for positive innovation performance effects from incorporating external knowledge at various levels (e.g., Henderson and Cockburn, 1994; Cockburn and Henderson, 1998; Gambardella, 1995; Cassiman et al., 2007). Such effects center on the innovation success (Gemünden et al., 1992; Love and Roper, 2004), an increased novelty of innovations (Landry and Amara, 2002), and higher returns on R&D investments (Nadiri, 1993).

Against the background of increasing collaboration activities of the business sector (Hagedoorn, 2002), industry-science interactions play a particular role. Strongly supported by national policies, most prominently the US Bayh-Dole Act in 1980 and its European equivalents, industry-science collaborations have increased significantly over the recent past as becomes for instance visible in increased research joint ventures with university participation (Link, 1996; Link and Scott, 2005) and emerging joint industry-science R&D centres (Cohen et al., 2002). The nature of industry-science collaborations is presumably very different from intra-industry interactions. While within-industry R&D collaboration is mainly employed in order to internalize spillover effects (D'Aspremont and Jacquemin, 1988; De Bondt, 1996) and to benefit from complementarities (Hagedoorn, 2002), industry-science collaborations are targeting different goals as the R&D process in the business sector and in universities is quite different (Dasgupta and David, 1994). While business sector R&D is directed at commercial success, knowledge produced at universities is rather basic in nature (Trajtenberg et al., 1997). Technological knowledge generated by universities can be seen as the result of a dynamic development that is hard for firms to develop internally, since this process relies on a vivid discussion of earlier research results including a careful documentation of trial and error. Nevertheless or just because of that, university science and inventions are considered to be among the most important knowledge sources for innovation activities for the US business sector (Cohen et al., 2002) and Europe's largest firms (Arundel and Geuna, 2004). Due to its codification and careful documentation university research can further lead to efficiency enhancement in private research and to avoiding duplicated research (Dasgupta and David, 1994; Hall et al., 2003; Crespi et al., 2006). University involvement has been further found to be especially important in new technological areas, where business partners expect university scientists to translate and explain the nature of research being undertaken and to anticipate future research problems in those areas (Hall et al., 2003, for the US Advanced Technology Program).

Overall, there is a significant body of literature documenting that such industry-science links are fruitful. For example, Mansfield (1991) substantiates a research input from scientific institutions to be important for developing new products and processes. More precisely, without academic research 11 percent of new product innovations and 9 percent of process innovations would not have been developed, accounting for 3 percent and 1 percent of sales respectively. University collaborations are found to enhance the acquisition and assimilation of basic research in the firms and further lead to a sooner technology development and commercialization of the projects with university involvement (Hall et al., 2003). The benefits of university collaborations are not limited to co-invented technologies, but spill over to non-science related patented technologies of the firms as Cassiman et al. (2008) show based on an analysis of references to scientific literature in patents.

Accessing knowledge from universities can go through a wide variety of interaction modes (Arundel and Geuna, 2004; D'Este and Patel, 2007) including formal transfer mechanisms like licensing and the acquisition of patents (Jensen and Thursby, 2001; Thursby and Kemp, 2002), joint research (Cockburn and Henderson, 1998) or consulting (Thursby et al., 2007) – which involve a contract – as well as informal transfer mechanisms like informal contacts, meetings, conferences or citations in firm patents to scientific non-patent literature (Spence, 2003; Cassiman et al., 2007; Link et al., 2007).

Adopting the perspective of the firm, the choice of the technology transfer mode should primarily depend on the type of knowledge and its opportunities for exploitation. On the one hand, formal technology transfer provides the firm with a clearly-contoured research result or solution to a particular technological problem. Formal technology transfer through licensing for instance requires rather limited interaction. Similarly, other formal transfer modes like contract research or consulting allow firms to specify the desired research outcome which is subsequently transferred with all exploitation rights (Perkmann and Walsh, 2007). Through formal technology transfer firms gain access to complementary codified scientific knowledge, which they can exploit to create a unique combination of knowledge in order to enhance the quality of their inventions (Cassiman et al., 2008) or to realize efficiency gains for business R&D (Dasgupta and David, 1994; Crespi et al., 2006). The flipside of the coin is that university licenses and other types of contracts may be sold to competitors as well, which limits the potential for creating unique and valuable combinations of firm resources (Saviotti, 1998). Further, knowledge exchange might be limited to the stipulated amount.

On the other hand, informal technology transfer through contacts, meetings or conferences gives a firm the opportunity to browse for relevant technological knowledge without mobilizing substantial human or financial resources. Moreover, informal technology transfer enables firms to access tacit knowledge surrounding formalized technological knowledge that may actually be needed in order to integrate scientific knowledge into the firm's R&D

process. To achieve this, close interaction of personnel from the university and the firm is required. Moreover, informal technology transfer may facilitate the attraction of talented researchers from academia who may contribute both to the quality of internal research efforts and act as ‘gatekeepers’ to bridge the firm’s research activities with academic science (Rosenkopf and Nerkar, 2001). In this respect, Fabrizio (2006) illustrates the importance of absorptive capacity of the firm through an acquisition of scientific personnel, which leads to a better exploitation of scientific research and shorter time lags between knowledge acquisition and inventions. Although a lack of a formal collaboration framework might be considered a shortcoming of informal transfer in isolation, the knowledge gained from informal transfer limits competitor’s opportunities for imitation (Aschhoff and Sofka, 2008).

As suggested by the discussion of informal technology transfer above both modes of technology transfer may go well together (Siegel et al., 2003; Link et al., 2007). Informal contacts presumably improve the quality of a formal relationship or formal contracts may be accompanied by an informal relation of mutual exchange on technology-related aspects. It is therefore sensible to assume that both types occur simultaneously in order to transfer codified knowledge as well as tacit knowledge through the interaction between the university scientist and industry personnel (Perkmann and Walsh, 2007). Put differently, we hypothesize a complementary relationship between formal and informal technology transfer, i.e. that it is not an isolated transfer mode that provides firms with superior innovation performance but instead a combination of both transfer modes. The following section introduces the empirical part of our paper.

3 Data

The underlying database is the Mannheim Innovation Panel (MIP), a survey which has been conducted annually by the Centre for European Economic Research (ZEW) on behalf of the German Federal Ministry of Education and Research (BMBF) since 1992. The MIP is the German part of the Community Innovation Survey (CIS) of the European Commission. We restrict the sample to German manufacturing firms as technology transfer presumably has a different nature for services. This paper is based on the 2003 wave that asks firms whether they have collaborated with universities or public research institutes in the period from 2000-2002. Firms were asked to rate the importance of several technology transfer channels. In line with our definition of formal and informal technology transfer, we defined the following collaboration modes as being formal:

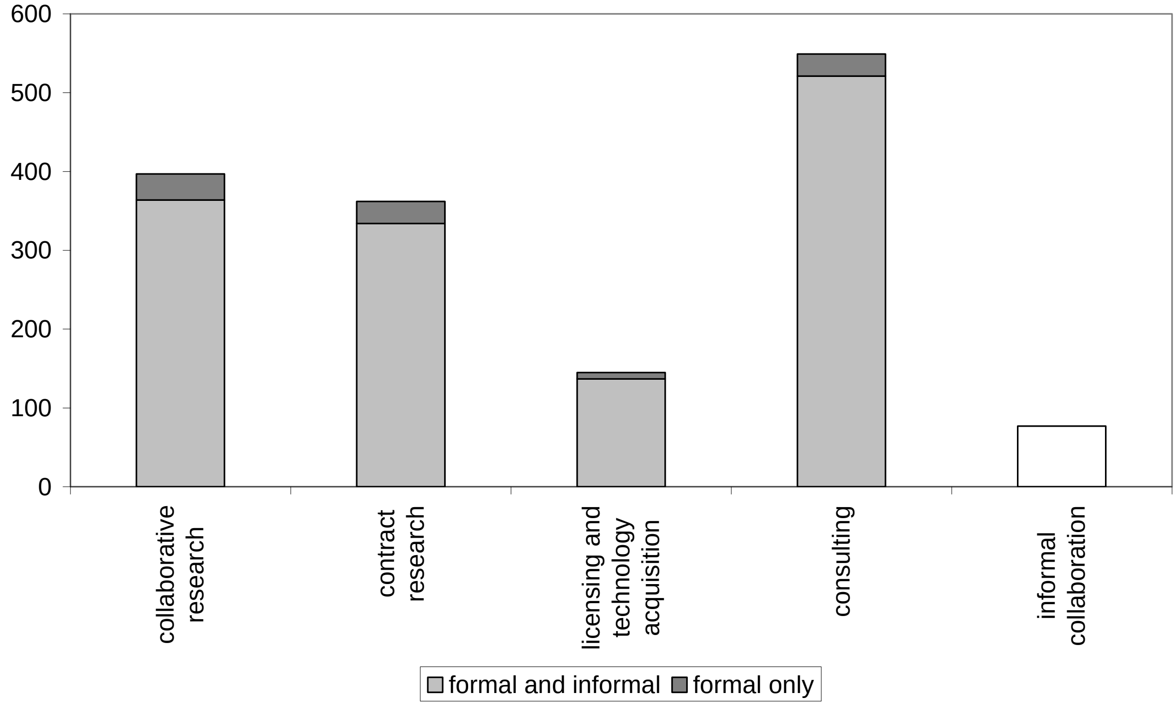
- collaborative research
- contract research
- technology consulting
- licensing and acquisition of technologies developed at universities

All four measures are based upon a contractual relationship. Moreover, they focus on a transfer of disembodied technology knowledge as they do not involve a transfer of personnel. These four measures exhibit common characteristics in that they involve a legal contract. Hence, we summarize them under one variable for formal technology transfer. Informal technology transfer is defined by the survey item 'informal contacts to universities and public research institutes'. Out of the 2,092 firms in our sample 691 collaborated with the scientific sector in a formal and 786 in an informal way. Of those, 614 firms used both forms of collaboration while 1,229 firms did not engage in any university technology transfer relationship.

Figure 1 shows the distribution of firms across the different formal university collaboration modes. The light grey area indicates the number of firms that also have informal links to the university. The dark grey area shows firms that rely on formal links only. It becomes apparent that all types of formal collaboration modes mostly coincide with informal links to the university. Focusing on the distribution of formal collaboration modes, it seems surprising that university licensing which is receiving much attention in the literature on industry-science links is used by relatively few German firms. A likely explanation for the relatively low rate of licensing agreements between firms and universities and the high frequency of informal links in Germany is that until 2002 the 'professor's privilege' ('Hochschullehrer-privileg') was in place. Once derived from Article 5 of the German constitution, which pertains to the freedom of science and research, the professor's privilege constituted that professors were the only occupational group in Germany that had the right to use their scientific results for private commercialization even if the underlying research was financed by the university (Kilger and Bartenbach, 2002). The professors' right to commercialize inventions privately before 2002 is reflected by a low number of German university patents (Czarnitzki et al., 2007; Czarnitzki et al., 2008), which translates into low university licensing activities in Germany as compared to the US, where the Bayh-Dole Act, which can be seen as the US counterpart of the German abolishment of the professors' privilege, took place already more than twenty years ago.

Figure 1 further shows that academic consulting is the most commonly used collaboration mode. Consulting to the business sector is an important way for scientists to increase their research budgets as has been found to be an important industry-science link for US universities as well (Link et al., 2007; Thursby et al., 2007).

Figure 1: Frequency of different formal and informal links to the university



We add 'supply-side factors' in university technology transfer by matching our firm-level dataset with regional data from the year 2000 on the number of university scientists in the NUTS-3 region where the firm is located. We did not restrict this number to any particular scientific discipline but normalized it by dividing it by the population of the region.

Table 1 shows some descriptive statistics distinguishing between the four groups of firms according to their involvement in collaboration with scientific institutions.[2] It becomes apparent that firms engaged in formal and informal technology transfer are the largest in terms of employment, R&D intensity, innovation sales over total sales[3], share of skilled workers, as defined by labor force with a university degree, and export sales. The high R&D intensity of firms using both modes of technology transfer suggests that firms require substantial absorptive capacity (Cohen and Levinthal, 1989; 1990) in order to reap the fruits

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[2] The definition of the industry classification can be found in Table 5 Table 1in the Appendix.

[3] Note that the percentage of innovation sales is derived from the last three years.

from formal and informal university collaboration. Skilled labor as defined by employees with a university degree might be essential not only for the exploitation of formal relationships but much more for the establishment of informal contacts to the university. The higher innovation sales of firms using both technology transfer modes are a first indication for the complementarity of formal and informal university links.

Note that for the continuous variables Table 1 shows the means and standard deviations for two different years. We use the continuous variables as firm size and R&D intensity with a one year lag in our later regression for the choice of the collaboration modes in order to limit endogeneity problems with respect to the regressors. For the same reason we linked the cross-section 2003 to the cross-section 2004. In the last part of the analysis we estimate the effect of the different transfer mechanisms on innovation sales. Using a lead of the dependent variable is again an attempt to limit endogeneity problems. Unfortunately, only a subsample of 884 firms responded to the sample in both years, which reduces the number of observation in the last part of the analysis.

Table 1: Descriptive statistics

	Formal collaboration only			Informal collaboration only			Formal and informal collaboration			No collaboration		
	# obs.	mean	std. dev.	# obs.	mean	std. dev.	# obs.	mean	std. dev.	# obs.	mean	std. dev.
R&D/employment$_{2002}$	77	0.01	0.03	172	0.01	0.01	613	0.02	0.03	1230	0.00	0.01
R&D/employment$_{2001}$	77	0.01	0.02	172	0.01	0.01	613	0.02	0.03	1230	0.00	0.01
Innovation sales/total sales$_{2003}$	40	18.45	29.14	84	16.12	22.62	297	25.29	27.18	568	9.44	18.67
Innovation sales/total sales$_{2002}$	77	16.77	25.61	172	17.81	23.70	613	23.10	26.53	1230	10.66	20.33
I(Innovation sales/employment$_{2003}$>0)	40	0.50	0.51	84	0.55	0.50	297	0.75	0.43	568	0.38	0.49
I(Innovation sales/employment$_{2002}$>0)	77	0.38	0.49	172	0.33	0.47	613	0.52	0.50	1230	0.20	0.40
Share of skilled labor force$_{2002}$	77	19.10	22.21	172	16.36	16.33	613	23.18	21.85	1230	12.55	12.24
No. of skilled workers$_{2002}$	77	0.04	0.19	172	0.05	0.21	613	0.02	0.15	1230	0.16	0.37
Skilled labor force/R&D$_{2002}$	77	28.60	43.53	172	24.04	34.64	613	33.93	230.13	1230	77.02	666.52
Share of skilled labor force$_{2001}$	77	17.58	22.05	172	16.28	16.47	613	22.45	21.85	1230	12.19	12.20
No. of skilled workers$_{2001}$	77	0.06	0.25	172	0.05	0.20	613	0.02	0.15	1230	0.17	0.37
Employment$_{2002}$	77	270.23	681.92	172	298.98	689.48	613	2941.44	21127.83	1230	250.66	1126.84
Employment$_{2001}$	77	293.59	715.46	172	334.88	695.37	613	3069.75	23108.83	1230	252.68	1011.77
Product innovator	77	0.62	0.49	172	0.65	0.48	613	0.85	0.36	1230	0.44	0.50
Process innovator	77	0.40	0.49	172	0.41	0.49	613	0.57	0.50	1230	0.30	0.46
Scientists per 1000 inhabitants in region$_{2000}$	77	2.29	5.15	172	2.58	5.16	613	3.55	5.65	1230	2.20	4.78
Export sales$_{2002}$	77	62.15	187.56	172	50.33	90.01	613	746.87	6946.96	1230	54.22	200.10
Export sales$_{2001}$	77	72.80	189.34	172	71.67	116.67	613	762.53	6937.55	1230	65.47	215.41
East Germany	77	0.31	0.47	172	0.32	0.47	613	0.31	0.46	1230	0.30	0.46
Firm age	77	14.57	13.28	172	18.48	15.34	613	25.35	83.76	1230	19.23	17.22
Part of a firm group	77	0.43	0.50	172	0.46	0.50	613	0.53	0.50	1230	0.51	0.50
… with a headquarter outside of Germany	77	0.16	0.37	172	0.13	0.34	613	0.15	0.36	1230	0.06	0.23
Industry 1	77	0.16	0.37	172	0.12	0.32	613	0.06	0.24	1230	0.16	0.36
Industry 2	77	0.04	0.19	172	0.03	0.17	613	0.01	0.11	1230	0.05	0.21
Industry 3	77	0.12	0.32	172	0.15	0.35	613	0.17	0.38	1230	0.13	0.34
Industry 4	77	0.08	0.27	172	0.03	0.18	613	0.06	0.24	1230	0.05	0.21
Industry 5	77	0.16	0.37	172	0.15	0.36	613	0.12	0.33	1230	0.17	0.38
Industry 6	77	0.16	0.37	172	0.16	0.36	613	0.18	0.38	1230	0.13	0.34
Industry 7	77	0.22	0.42	172	0.23	0.42	613	0.27	0.44	1230	0.14	0.34
Industry 8	77	0.05	0.22	172	0.09	0.29	613	0.11	0.31	1230	0.12	0.32

4 Empirical Strategy: Testing for Complementarity

In order to test for complementarity of formal and informal links to the university we apply an empirical strategy that is based on the theory of supermodularity (Milgrom and Roberts, 1995; Arora, 1996; Athey and Stern, 1998; Lokshin et al., 2004) which has been used in the field of industrial organization and management in recent years (e.g., Mohnen and Röller, 2005; Cassiman and Veugelers, 2006; Kaiser, 2003; Lokshin et al., 2004; Catozzella and Vivarelli, 2007). In these contexts, complementarity is defined as the increase in marginal or incremental return to one practice if other practices are in use as well. In our application we are interested in testing whether the use of informal university technology transfer increases the returns of formal technology transfer or vice-versa. Intuitively, this means that using the second channel of collaboration if the other one is in place has a higher incremental impact on innovation performance than using one of the modes more intense in isolation. Analogously, we would find that informal and formal technology transfer are substitutes if one of the links would decrease the marginal or incremental returns from one to the other collaboration mode. Two tests have been derived from the concept of supermodularity (Arora, 1996; Athey and Stern, 1998): an indirect test and a direct test on complementarity. Both will be applied in the empirical section.

4.1 The Indirect Approach

The indirect approach tests for a positive correlation between different practices conditional on a vector of covariates X (Arora, 1996; Athey and Stern, 1998). The indirect approach gives an indication of complementarity based on the assumption that the actual choice of the chosen practice(s) maps the firm's optimal decision. It has the advantage that it can be used if performance effects of the chosen practices cannot be observed.

In order to account for unobserved firm heterogeneity that can bias the test results (i.e. if unobserved factors drive the benefits from the application of the single or combined practices so that complementarity would be falsely rejected or falsely not rejected (Athey and Stern, 1998), it is recommended to use an exclusion restriction that directly impacts one of the practices, but not the other. If there is complementarity between two different practices there will be a positive effect on the combined use of the those (Arora, 1996; Athey and Stern, 1998; Cassiman and Veugelers, 2006; Catozzella and Vivarelli, 2007). Athey and Stern (1998) label this procedure the 'reduced-form test' for complementarity. Note that this test is only useful if there are not more than two practices to be tested as for more options a strong indirect effect might outweigh a substitution effect of the pair of practices. We implement this test as a multinomial logit model for the mutually exclusive collaboration modes: formal, informal technology transfer, both, and none.

4.2 The Direct Approach

The direct approach tests whether the simultaneous adoption of different practices, formal and informal technology transfer, has a positive impact on innovation performance. If the joint use of both collaboration modes has the highest impact as compared to using one of the channels in isolation they are complements (Arora, 1996; Athey and Stern, 1998; Mohnen and Röller, 2005; Cassiman and Veugelers, 2006; Catozzella and Vivarelli, 2007; Lokshin et al., 2004).

In our empirical application we have hence three different possible collaboration patterns for each firm *i*, formal collaboration (*A1*), informal collaboration (*A2*), and both informal and formal collaboration (*A1*A2*), entering our empirical model for the innovation performance at the firm level:

$$I(A1_i, A2_i, X_i) = A1_i * b_{10} + A2_i * b_{01} + A1_i * A2_i * b_{11} + X_i \beta + u_i \qquad (1)$$

The direct test derives directly from the inequality defined by the theory on supermodularity (Milgrom and Roberts, 1995). In case of complementarity we should find:

$$b_{11} \geq b_{10} + b_{01}. \qquad (2)$$

5 Empirical Results

As outlined above, we apply the indirect and direct test in order to investigate whether there is complementarity between formal and informal technology transfer. We start with an investigation of the correlation between both collaboration modes conditional on absorptive capacity and other characteristics of the firm. Formal and informal technology transfer are defined as non-exclusive activities of the firms, i.e. it is possible that the firms have used both. We estimate the following bivariate probit model:

$$formal_i = Z_i\beta + u_{i1}, formal_i = \begin{cases} 1 & if\ formal_i^* > 0 \\ 0 & otherwise \end{cases}$$

$$informal_i = Z_i\beta + u_{i2}, informal_i = \begin{cases} 1 & if\ formal_i^* > 0 \\ 0 & otherwise \end{cases} \quad , \qquad (3)$$

$$E[u_{i1}] = E[u_{i2}] = 0, Var[u_{i1}] = Var[u_{i2}] = 1, Cov[u_{i1}, u_{i2}] = \rho$$

where Z_i is a vector of firm characteristics.

The results are presented in Table 2. The most important finding is that there is a significant positive relationship between formal and informal technology transfer as indicated by the positive and significant correlation coefficient ρ. This finding suggests that formal and informal links are likely to occur in combination and is hence a first indication of complementarity. The estimation results further show that there is no substantial heterogeneity in firm characteristics predicting formal and informal technology transfer. In line with our expectations, firm size and absorptive capacity as is reflected by R&D intensity are important to engage in any technology transfer from the university. Moreover, skilled workers (normalized by R&D) matter significantly and having no employees with a university degree significantly lowers the probability of using either one technology transfer mode from the university. Employees with a university degree are supposed to be essential for establishing and maintaining contacts to the university. Further, the density of scientists in the region is an important determinant for technology transfer from the university. This variable is supposed to be especially important for informal technology transfer independent on whether formal transfer is in place or not because the chance of informal knowledge transfer is supposed to increase by the likelihood to meet scientists in daily life. Moreover, firms being part of a firm group are less engaged in university collaboration be it formal or informal. This effect is less strong for firm groups with a foreign headquarter. A likely explanation is that firm groups give priority to collaboration within the group and that firm groups with a foreign headquarter might be more interested in learning about local technologies than domestically led firm groups. Lastly, Eastern German firms turn out to be more likely to collaborate with universities.

The only difference for the predictors of using formal versus informal links to the university is found in the age of firms. While the likelihood of formal technology transfer decreases in firm age there is no significant effect for the use of informal technology transfer.

Table 2: Bivariate probit estimation for the choice of formal and informal technology transfer

	Formal technology transfer			Informal technology transfer		
	coefficient		std. err.	coefficient		std. err.
Log(employment$_{2001}$)	0.15	***	0.03	0.13	***	0.03
East Germany$_{2002}$	0.14	**	0.07	0.15	**	0.07
Log(firm age$_{2002}$)	-0.08	**	0.04	-0.03		0.04
Log(export$_{2001}$)	0.04	**	0.02	0.05	***	0.02
R&D/employment$_{2001}$	10.46	***	2.07	9.08	***	2.08
No skilled workers	-0.38	***	0.14	-0.52	***	0.14
Log(Skilled workers/R&D$_{2001}$)	0.03	***	0.00	0.03	***	0.00
Product innovator$_{2002}$	0.40	***	0.08	0.38	***	0.08
Process innovator$_{2002}$	0.16	**	0.07	0.15	**	0.07
Log(scientists per capita$_{2000}$)	0.01	***	0.01	0.01	***	0.01
Part of a firm group$_{2002}$	-0.64	***	0.08	-0.64	*	0.08
… with a headquarter outside of Germany$_{2002}$	0.58	***	0.11	0.59	***	0.11
Industry 1	-0.01		0.13	-0.13		0.12
Industry 2	-0.08		0.21	-0.18		0.20
Industry 3	0.23	*	0.12	0.18		0.12
Industry 4	0.66	***	0.16	0.42	***	0.16
Industry 5	0.18		0.12	0.09		0.11
Industry 6	0.23	*	0.12	0.14		0.11
Industry 7	0.31	***	0.11	0.25	**	0.11
constant	-1.09	***	0.19	-0.85	***	0.19
ρ	0.88	***	0.14			
Number of observations	2092					
Wald-X^2	609.27	***				

In the next step, we dig deeper into the firms' choice for a particular collaboration mode. In order to do so we apply the indirect structural test for complementarity that was described in the previous section. Under the assumption that firms make the best choice in terms of collaboration modes we estimate a multinomial logit model for their actual choices: formal, informal technology transfer, both and none:

$$\text{Prob}(Y = j) = \frac{e^{Z_i \beta}}{\sum_{k=1}^{4} e^{Z_i \beta}}; j \in \{formal, informal, formal \,\&\, informal, none\}, \quad (4)$$

where Z_i is a vector of firm characteristics. Firms without university collaboration serve as the reference case. Notice that in contrast to model (3) the alternatives are exclusive now, i.e. each firm can only belong to one of the four groups.

As outlined in the previous section the indirect test relies on an exclusion restriction that affects the use of one of the transfer modes in isolation as well as the combined use of both practices while not the use of the other transfer mode in isolation, i.e. a variable that shows that the marginal return from one technology transfer type is increased by the other. The literature on absorptive capacity (Cohen and Levinthal, 1989; 1990) provides us with a theoretical argument for an instrumental variable with a focus on formal technology transfer modes. Absorptive capacity encompasses three major components: the identification of valuable external knowledge, its assimilation with existing knowledge resources and finally its exploitation in the innovation process. Hence, it provides a firm with more options reacting to opportunities that arise in the environment (Bowman and Hurry, 1993; March, 1991). Accordingly, firms with a higher absorptive capacity are likely to better exploit incoming technology transfers (Cassiman and Veugelers, 2006). In line with these arguments, we suggest that a high absorptive capacity should increase the expected marginal returns from formal links in isolation as it reflects superior exploitation capabilities. Further, absorptive capacity should increase the marginal returns from informal links in the presence of formal links making the collaboration more effective. We do not expect an effect of absorptive capacity on the expected returns from informal technology transfer in isolation because informal university links are supposed to rather depend on the research personnel in the firm and the university in the local area. In order to measure absorptive capacity we use the firms' past R&D intensity as a proxy because absorptive capacity is typically developed as a by-product of internal R&D activities (Cohen and Levinthal, 1989). Past R&D should increase the awareness of what is needed to optimally exploit collaboration opportunities with the university (Fabrizio, 2006).

Two further exclusion restrictions are used that center around informal links. As stated above we expect that informal links mainly depend on the education of the R&D personnel involved in the firm. While the R&D intensity is considered as a measure of the firm's R&D capacity skilled R&D workers and the number of scientists in the same region are expected to be the main predictors of the establishment of informal links. We do not expect an effect of those variables on formal links as such links are more likely to be established by the head of the R&D department or the R&D manager, but we expect that informal links to enhance the effectiveness of such formal links.

Table 3 presents the estimation results for model (4). Most important, our exclusion restrictions for the indirect test work: R&D intensity as a proxy for absorptive capacity impacts the choice of formal links in isolation as well as the joint use of formal and informal technology transfer, while there is no impact on the choice of informal technology transfer. Hence, we can conclude that absorptive capacity increases the expected marginal returns from informal links in the presence of formal links. The second set of exclusion restrictions that builds on the importance of the education of the firm's R&D personnel and the availability of scientists in the geographical region shows that the abilities of firm personnel are indeed very important for informal technology transfers and that the marginal gains from those informal links are higher if formal links are in place. Having no employee with a university degree turns out to hinder informal transfers and also the expected outcome of the joint use of formal and informal technology transfer is lower for such firms. Having employees with a university education does not matter for formal transfers as was hypothesized. The concentration of scientists in the region has no significant impact on the establishment of formal or informal links to the university in isolation. Hence, this exclusion restriction does not turn out to be valid for our data. A likely explanation is that technology markets are by no means regional and that firms are carefully screening global markets for technologies and collaborators that fit best to their innovation activities. A high concentration of scientists increases however the expected gains from using informal and formal technology transfer in combination as the last column of Table 3 shows.

The results further show that the opportunities of firms for any kind of university collaboration increase with firm size. Moreover, firms that are part of a group of firms are less likely to engage with the university in a formal or informal way. They might exploit opportunities for collaboration within the firm group first. In line with the estimation results for model (3), Table 3 shows that firms which are a member of a firm group with a foreign headquarter are more involved in university collaboration than other firms that are part of a firm group. International firm groups might be more interested in absorbing academic knowledge in a foreign country (Sofka and Teichert, 2006) to exploit a variety of different innovation sources providing stimuli for innovation activities in the home country (Kuemmerle, 1998). A significant difference for the choice of technology transfer modes lies in the age of the firm as was already suggested by model (3). While the use of informal technology transfer and the use of both transfer modes are independent of firm age, the use of formal technology transfer decreases as firms get older. A likely explanation is that younger firms might have more formal ties with a university, particularly as they could be the result of a university spin-off which is based on a research result subsequently exploited for example by means of a licensing agreement.

Table 3 further shows that there are many variables predicting the combined use of both technology transfer mechanisms but not the use of either one in isolation. Firms located in

Eastern Germany are for instance more likely to rely on both collaboration channels. A reason for this might be the structure of the economy in Eastern Germany where the former state combines were split up and many people employed in the R&D unit of the state combine became part of the public research sector. As a consequence, a lot of informal contacts between former colleagues were still in place and were accompanying a formal technology transfer. Also exporting firms are more likely to rely on formal and informal links to the university than on a single technology transfer mode. Lastly, product and process innovators are more in favour of the combined use of formal and informal technology transfers from the university.

Table 3: Multinomial logit estimation for the choice of collaboration modes

	Formal technology transfer			**Informal technology transfer**			**Formal and informal technology transfer**		
	coefficient		std. err.	coefficient		std. err.	coefficient		std. err
Log(employment$_{2001}$)	0.22	**	0.10	0.12	*	0.07	0.26	***	0.05
East Germany$_{2002}$	0.01		0.27	0.09		0.19	0.35	***	0.14
Log(age$_{2002}$)	-0.42	***	0.13	-0.12		0.10	-0.10		0.07
Log(export$_{2001}$)	-0.01		0.07	0.06		0.05	0.11	***	0.03
R&D/employment$_{2001}$	13.87	*	8.36	6.52		7.13	19.77	***	4.61
No skilled workers	-0.79		0.51	-1.24	***	0.42	-0.84	***	0.31
Log(Skilled workers/ R&D$_{2001}$)	0.02		0.02	0.04	***	0.01	0.06	***	0.01
Product innovator$_{2002}$	0.32		0.31	0.31		0.22	0.88	***	0.16
Process innovator$_{2002}$	0.13		0.27	0.08		0.19	0.31	**	0.13
Log(scientists per capita$_{2002}$)	0.02		0.02	0.00		0.01	0.03	***	0.01
Part of a firm group$_{2002}$	-1.26	***	0.31	-1.01	***	0.20	-1.12	***	0.15
… with a headquarter outside of Germany$_{2002}$	1.57	***	0.40	1.19	***	0.29	1.12	***	0.21
Industry 1	0.96	*	0.52	0.02		0.33	-0.25		0.25
Industry 2	0.96		0.74	0.05		0.53	-0.52	*	0.47
Industry 3	0.57		0.55	0.19		0.31	0.41	*	0.22
Industry 4	1.59	***	0.61	0.15		0.49	1.03	***	0.30
Industry 5	0.82		0.52	0.15		0.31	0.28		0.22
Industry 6	0.83		0.52	0.17		0.31	0.32		0.22
Industry 7	1.07	**	0.51	0.47		0.30	0.58	***	0.21
Constant	-3.07	***	0.76	-1.87	***	0.51	-2.01	***	0.36
Number of observations	2092								
LR X^2	751.65	***							
Pseudo R^2	0.18								

We have seen that the correlation test as well as the indirect test provide evidence for complementarity with respect to the expected returns from informal and formal university collaboration. In the next step we conduct the direct test for complementarity of both technology transfer modes. We test whether the combined use of both translates into superior innovation performance. Our R&D performance measure is sales with innovative products, defined as market novelties over total sales. We use the dependent variable with a one-year lead to limit endogeneity problems. As not all firms responded to the survey in the following year we have to conduct the test based on a reduced number of observations. The test is implemented using a tobit model to account for the fact that many firms have no sales with innovative products at all and others that have all their sales with innovative products. The estimated model can be written as:

$$\frac{innovation\ sales_i}{total\ sales_i}^* = b_{10} informal_i + b_{01} formal_i + b_{11}(informal_i * formal_i) + \beta X_i + u_i, \qquad (5)$$

where $\frac{innovation\ sales_i}{total\ sales_i}^*$ is the unobserved latent variable. The observed dependent variable is equal to:

$$\frac{innovation\ sales_i}{total\ sales_i} = \begin{cases} 1 & \text{if } \frac{innovation\ sales_i}{total\ sales_i}^* \geq 1 \\ \frac{innovation\ sales_i}{total\ sales_i}^* & \text{if } 0 < \frac{innovation\ sales_i}{total\ sales_i}^* < 1 \\ 0 & \text{if } \frac{innovation\ sales_i}{total\ sales_i}^* \leq 0 \end{cases} \qquad (6)$$

Most important the coefficients for the *informal* and *formal* variable and the interaction term of those variables as they allow to directly test equation (2). X_i is a vector of covariates and u_i the error term of the model.

In addition, we estimate a probit model in search of complementarity of both technology transfer modes for the likelihood of having any innovation sales as a robustness check. The dependent variable is now a binary variable that equals one if innovation sales are larger than zero and zero otherwise. The model can be written as:

$$I[innovation\ sales_i > 0]^* = b_{10} informal_i + b_{01} formal_i + b_{11}(informal_i * formal_i) + \beta X_i + u_i$$

$$I[innovation\ sales_i > 0] = \begin{cases} 1 & \text{if } I[innovation\ sales_i^* > 0] \geq 0 \\ 0 & \text{otherwise} \end{cases} \qquad (7)$$

Table 4 shows the estimation results. The results of both models show that using formal and informal technology transfer in combination contributes to firms' innovation performance, while there is no performance effect of using one technology transfer mode in isolation. This is a strong indication for complementarity of formal and informal technology transfer. We can further confirm this result based on one-sided tests on the null hypothesis of no complementarity (derived from equation (2)) at the 10% level of statistical significance (see bottom of Table 4). This confirms our findings from the previous sections.

With respect to the control variables, it turns out that the major part of innovation sales over total sales is explained by innovation sales over total sales in the previous period. This is not surprising as the lagged dependent variable can be seen as an attempt to control for fixed effects in innovation performance. A few other variables have an effect on innovation sales. One is the indicator for R&D collaborations with firms. Like industry-science linkages, inter-firm collaborations have a positive effect on innovation sales confirming prior findings (see Hagedoorn, 2002, for an overview). Further, the share of workers with a university degree and being a process innovator are predictors of innovation sales. SMEs and firms in firm groups with a foreign headquarter are less successful in terms of innovation output than others.

Table 4: Tobit and probit models for the effects of different university collaboration modes on innovation sales

	% of Innovation sales$_{2003}$ Tobit model			Innovation sales > 0 Probit model		
	coefficient		std. err.	coefficient		std. err.
Formal collaboration$_{2002}$	4.39		6.06	0.12		0.27
Informal collaboration$_{2002}$	1.60		3.95	0.10		0.18
Formal and informal collaboration$_{2002}$	16.02	***	2.090	0.58	***	0.13
Collaboration with firms$_{2002}$	13.95	***	3.86	0.78	***	0.20
% Innovation sales/Employment$_{2002}$	0.79	***	0.05	1.01	***	0.12
Log(R&D$_{2002}$)	0.40		1.31	-0.01		0.06
Share of high skilled workers$_{2002}$	12.30	*	7.14	0.94	***	0.36
Log(employment$_{2002}$)	-1.00		1.12	0.04		0.05
SME$_{2002}$	-6.33	*	3.59	-0.30	*	0.16
Log(export$_{2002}$)	-0.37		0.54	-0.02		0.02
East Germany$_{2002}$	0.05		5.50	-0.00		0.11
Log(age$_{2002}$)	-0.51		1.29	-0.04		0.06
Process innovator$_{2002}$	6.07	***	2.42	0.42	***	0.11
Part of a firm group$_{2002}$	6.55	***	2.59	0.16		0.12
… with a headquarter outside of Germany$_{2002}$	-7.05	*	3.85	-0.32	*	0.18
Industry 1	4.99		4.44	0.11		0.19
Industry 2	-2.49		6.74	0.17		0.28
Industry 3	5.79		4.18	0.22		0.18
Industry 4	-1.00		5.90	-0.11		0.26
Industry 5	1.07		4.14	0.07		0.18
Industry 6	3.82		4.26	0.14		0.19
Industry 7	8.31	**	4.02	0.50	***	0.18
constant	-17.09	**	7.90	-0.83	**	0.35
Complementarity test:	F-statistic:			X^2-statistic:		
Formal & informal > formal + informal	1.97	*		2.04	*	
Number of observations	884			884		
Number of left-censored observations	441					
Number of right-censored observations	10					
LR-X^2	483.54	***		348.41	***	
Pseudo R^2	0.10			0.28		

6 Conclusion and future research

In this paper, we have analyzed the interplay of formal and informal university technology transfer modes and their importance for innovation performance of the firm. We defined informal technology transfer as a mechanism that does not involve any contractual relationship between the university scientist and the firm while formal technology transfer should be based on such a contract. Our analysis reveals that the use of formal and informal technology transfer with the university mostly coincide. Based on different types of complementarity tests, our empirical results have shown that formal and informal technology transfer are complements, i.e. the use of informal technology transfer increases the marginal return of formal technology transfer.

For an appropriate interpretation of the empirical findings it is important to pay attention to the environment the industry-science links take place in. Our analysis reveals, for instance, that university licensing is not as prominent in Germany as previous literature suggests for the US. The reason is that until 2002 professors owned the inventions they produced at German universities ('professor's privilege'). Hence, we observe only a few technologies that are patented through German universities, which leads to little opportunities for university licensing. In 2003, the professor's privilege was abolished and since then universities own the inventions made in-house and have, hence, only since then been in charge of technology transfer. For the German university system, this means a significant change as universities mostly did not maintain professional technology transfer offices like US universities (Debackere and Veugelers, 2005). As a consequence, technology transfer offices just emerged in Germany in recent years. Against this background our empirical analysis suggests that universities should keep in mind the significant informal transfer which is already in place when designing technology transfer policies and commercialization incentive schemes for scientists. It can be a challenge to establish efficient centralized technology transfer offices at universities in the presence of existing technology transfer routines from science and industry although this change promises a significant reduction in transaction costs in the long run.

Our results also have important management implications. First, firms interested in setting up a relationship with a university to transfer technology should be aware that the full potential of such a transfer can only be realized if both transfer channels are used. The reasons for this are twofold: Firms do not only require the codified knowledge, e.g. in a licensed patent, but also the tacit knowledge surrounding a particular technology. In this sense, establishing a permanent relationship with a university with varying degrees of formality or informality seems to be key in benefiting from knowledge developed externally at universities. Moreover, our empirical analysis highlights the importance of absorptive capacity for technology transfer and its exploitation within the firm.

Further research should try to generate more insights on how formal and informal technology transfer mechanisms can be combined such that both sides benefit most. In this respect, it would particularly be interesting, on the one hand, to get insights on the evolution of technology transfer relationships, whether both channels can be observed at the same time or whether one channel stimulates the other. On the other hand, it would be interesting for the case of Germany to conduct a similar analysis in a couple of years in order to evaluate the effect of the abolishment of the professor's privilege on formal and informal technology transfer.

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Appendix

Table 5: Industry classification

Abbreviation	**Industry**	**NACE2 code**
Industry 1	Manufacture of food, tobacco and textiles, clothing	15, 16, 17, 18, 19
Industry 2	Manufacture wood, cork, straw and plaiting materials, publishing, printing and reproduction of recorded media	20, 21, 22
Industry 3	Manufacture chemicals and plastics	23, 24, 25
Industry 4	Manufacture of other non-metallic mineral products	26
Industry 5	Manufacture of basic metals and fabricated metal products	27, 28
Industry 6	Manufacture of machinery and equipment	29
Industry 7	Manufacture of office machinery, electrical machinery, communication equipment and instruments	30, 31, 32, 33
Industry 8	Manufacture of transport equipment and manufacture n.e.c.	34, 35, 36, 37