Discussion Paper No. 11-010

R&D Collaboration with Uncertain Intellectual Property Rights

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Centre for European
Economic Research

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Non-technical Summary

Research and development (R&D) collaborations allow firms to combine their resources, exploit complementary know-how and internalize R&D externalities. Hence, R&D collaborations may spur innovation activities in the private sector. Firms can, however, be reluctant to engage in R&D collaboration if they fear unwanted knowledge spillovers to partners. Losing highly valuable knowledge to potential competitors through collaborations poses a direct threat of a firm's market position. A means to control outgoing spillovers are formal intellectual property rights, such as patents.

This paper focuses on the interplay between intellectual property rights and R&D collaboration. We investigate the impact of uncertain intellectual property rights on firms' collaborative R&D activities. Our study is motivated by recent trends in the European patent system. While the patent examination process at the European Patent Office (EPO) takes relatively longer than at the United States Patent and Trade Mark Office, the duration of the patent examination at the EPO further increased significantly after a surge in patent applications in the mid 1990s. In response, firms face higher uncertainty about their certified intellectual property rights in Europe, in general, and especially since the 1990s.

In this study, we argue that patent pendencies create uncertainty and shape the relative return of R&D collaboration agreements. We show that, depending on the type of partner, uncertain intellectual property rights reduce R&D collaboration which may hinder the production of knowledge in the economy. Empirical results from a sample of almost 3,000 firms engaged in product and/or process innovations in German manufacturing indicate that collaboration between competitors is most sensitive to uncertain intellectual property rights as compared to collaborations with universities, suppliers or customers.

Our findings have important implications for technology policy. Governments have long understood the virtues of R&D collaboration by exempting R&D partnerships from anti-trust legislation and implementing several policies to encourage R&D collaborations. Our results show that a functional intellectual property rights system is needed for successful utilization of this policy: patent examination should be of high quality, but should also be performed in a timely manner.

Das Wichtigste in Kürze (Summary in German)

Kollaboration im Bereich Forschung und Entwicklung (FuE) ermöglicht es Unternehmen, ihre Ressourcen zu kombinieren, von Komplementaritäten zu profitieren und Externalitäten zu internalisieren. Das führt dazu, dass FuE-Kollaborationen die Innovationsaktivität der Privatwirtschaft fördern. Unternehmen können FuE-Kollaborationen jedoch skeptisch gegenüberstehen, wenn sie einen unbeabsichtigten Abfluss von Know-How an Kollaborationspartner befürchten. Der Abfluss von wichtigem Wissen an potenzielle Wettbewerber kann die Marktstellung eines Unternehmens gefährden. Einen Mechanismus, der verhindert, dass Kollaborationspartner unternehmensspezifisches Wissen nutzen können, stellt die Nutzung geistiger Eigentumsrechte wie beispielsweise Patente dar.

In dieser Studie untersuchen wir den Einfluss von unsicheren geistigen Eigentumsrechten auf das Kollaborationsverhalten von Unternehmen. Unsere Untersuchung ist durch kürzlich Entwicklungen am Europäischen Patentsystem (EPA) motiviert. Der Patentprüfungsprozess am EPA dauert im Vergleich zum amerikanischen Patentamt relativ lange. Insbesondere in den 1990er Jahren hat sich die Dauer des Patentprüfungsprozesses am EPA nach einem signifikanten Anstieg der Patentanmeldungen verlängert, was dazu führt, dass Patentanmelder sich einer größeren Unsicherheit bezüglich ihrer geistigen Eigentumsrechte gegenübersehen.

In dieser Studie argumentieren wir, dass die Dauer des Patentprüfungsprozesses Unsicherheiten für Patentanmelder generiert, welche die Kollaborationsbereitschaft von Akteuren der Privatwirtschaft negativ beeinflusst. Wir stellen die Hypothese auf, dass dabei der Typ des Kollaborationspartners eine Rolle spielt. Anhand einer empirischen Analyse basierend auf einer Stichprobe von ca. 3000 innovativen Unternehmen im Verarbeitenden Gewerbe zeigen wir, dass Unsicherheit über geistige Eigentumsrechte insbesondere dazu führt, dass Unternehmen FuE-Kollaboration mit Wettbewerbern meiden. FuE-Kollaboration mit Universitäten, Zulieferern und Kunden werden hingegen nicht von solchen Untersicherheiten beeinflusst.

Unsere Ergebnisse haben wichtige Implikationen für die Technologiepolitik. Da es hinlänglich akzeptiert ist, dass FuE-Kollaborationen die Innovationstätigkeit in der Privatwirtschaft stärken, erfahren FuE-Kollaborationen eine Sonderbehandlung vor dem Kartellgesetz und werden durch verschiedene weitere Politikmaßnahmen

stimuliert. Unsere Ergebnisse zeigen, dass ein funktionierendes Patentsystem notwendig ist, damit solche Initiativen greifen: die Patentprüfung sollte nicht nur von hoher Qualität sein, sondern auch zeitnah erfolgen.

R&D Collaboration with Uncertain Intellectual Property Rights[1]

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January 2011

Abstract

Patent pendencies create uncertainty in research and development (R&D) collaboration agreements, resulting in a threat of expropriation of unprotected knowledge by potential partners, reduced bargaining power and enhanced search costs. In this paper, we show that - depending of the type of partner - uncertain intellectual property rights (IPR) lead to reduced collaboration between firms and may hinder the production of knowledge. This has implications for technology policy as R&D collaborations are exempt from anti-trust legislation in order to increase R&D in the economy. We argue that a functional IPR system is needed for successful utilization of this policy.

Keywords: R&D collaboration, intellectual property, uncertainty, patents

JEL-Classification: O31, O38

[1] We are grateful to the MIP team of the ZEW Mannheim for providing the survey data and to Thorsten Doherr for his help in data processing and for providing his text field search engine. Further, we acknowledge helpful comments and discussions at the Intertic Conference on Competition Policy and Property Rights (Milan), the Pacific Rim Innovation Conference (Melbourne) and the EARIE 2010 (Istanbul).

1 Introduction

Confronted with intense technology competition and an increased complexity of technological inventions, successful creation of new knowledge often depends on the ability of firms to establish cooperative research and development (R&D) agreements in order to combine their resources, exploit complementary know-how and internalize R&D externalities (Katz, 1986; d'Aspremont and Jacquemin, 1988; Kamien et al., 1992).

R&D collaborations allow firms to internalize knowledge spillovers, thus eliminating the free rider problem in the market for ideas and to benefit from economies of scale and scope. Often only a consortium of firms has the necessary resources both financially and physically to undertake the ever larger, more complex, and more expensive research projects. Synergetic effects and risk pooling may also broaden the research horizon of cooperating firms. Hence, it can be expected that sustaining R&D cooperatives leads to an increase in private R&D activity (see Veugelers, 1998, for a survey of theoretical and empirical literature).

Unwanted knowledge spillovers to collaboration partners that go beyond the contracted research project are clear drawbacks of engaging in R&D collaborations. Losing highly valuable knowledge to potential competitors through direct collaborations or collaboration agreements with common customers or suppliers places a direct threat of a firm's market position. In order to control outgoing spillovers through collaboration, firms seek formal intellectual property protection before engaging in partnerships (Brouwer and Kleinknecht, 1999).

This paper focuses on the interplay between intellectual property rights and R&D collaboration. In particular, we investigate the impact of uncertain intellectual property rights on firms' collaborative R&D activities. Our study is motivated by recent trends in the European patent system. While the patent examination process at the European Patent Office (EPO) takes relatively longer than at the United States Patent and Trade Mark Office (Popp et al., 2004, Harhoff and Wagner, 2009) the duration of patent examination at the EPO further increased significantly after a surge in patent applications in the mid 1990s (OECD, 2008) due to an insufficient expansion of the workforce at the EPO (Harhoff and Wagner, 2009). Thus, firms face higher uncertainty about their certified intellectual property rights in Europe, in general, and especially since the 1990s.

In this paper, we argue that patent pendencies create uncertainty and shape the relative returns of R&D collaboration agreements. High levels of uncertainty in R&D partnerships result in a threat of expropriation of unprotected knowledge by potential partners, reduced bargaining power, enhanced search costs and asymmetric information. We show that, depending on the type of partner, uncertain intellectual property rights reduce R&D collaboration which may hinder the production of knowledge in the economy.

We argue that collaboration between competitors is more sensitive to uncertain intellectual property rights than collaborations between a firm and universities, suppliers or customers. Empirical evidence from a sample of almost 3,000 firms engaged in product and/or process innovations in German manufacturing confirm our hypotheses: firms are less likely to engage in R&D collaboration with competitors in response to uncertain patents, while collaborations with universities, customers and suppliers are unaffected.

This has important implications for technology policy. Governments have long understood the virtues of R&D collaboration and have exempted R&D partnerships from anti-trust legislation. In the European Union, for instance, the Treaty of Rome already contained a notice in article 85(3) that collaborating in R&D is permitted as long as post-innovation competition is not hampered. In 1984, the European Commission approved a block exemption for R&D collaborations that also allows joint exploitation of results (see Martin, 1997 for an overview on policy practices in the U.S., Japan and Europe). Our results show that a functional intellectual property rights (IPR) system is needed for successful utilization of this policy: patent examination should be of high quality, but should also be performed in a timely manner.

The remainder of this paper is organized as follows. Section 2 describes the conceptual background of patent pendencies and their involved legal uncertainty as well as the implications for R&D collaboration in more detail. The third section introduces the data and variables for our empirical test, and the fourth section presents the econometric results. Section 5 concludes.

2 Background

The theoretical and empirical literature on R&D collaboration emphasizes the importance of incoming spillovers, appropriability and absorptive capacity for the decision to enter collaborative R&D agreements (d'Aspremont and Jacquemin, 1988; Kamien and Zang, 2000; Cassiman and Veugelers, 2002). Firms aim at maximizing the inflow of information from collaboration partners and other market participants (incoming spillovers) while trying to minimize the outflow of information (appropriability). To manage incoming information flows, firms invest in "absorptive capacity" defined as the ability to recognize, assimilate and utilize external knowledge (Cohen and Levinthal, 1989). To control leakage of valuable intellectual assets, however, firms aim at protecting their proprietary knowledge through formal means such as patents.

Our empirical model builds on this stream of research by analyzing the occurrence of R&D collaboration with uncertain IPRs. Formal IPRs reduce the threat of expropriation between partners but also transaction costs of bargaining. Because of the threat of expropriation, innovators with pending patents (applications that are still under review at the patent office) might be reluctant to enter cooperative agreements. At the same time, pending patents reduce the bargaining power of a firm when contracting over R&D outside its boundaries and enhances its search costs.

We first discuss the types of uncertainty generated by the patent system and then detail their implications for collaborative R&D.

2.1 Patent pendencies and uncertainty

Patent pendencies create legal and economic uncertainty. Gans et al. (2008) review the distinct types of uncertainty over patent rights.

1. *Patent grant uncertainty*: the first source of uncertainty arises from the outcome of the application procedure. Uncertainty over patent rights is resolved once a final decision on the status of the application is reached. A patent can be formally awarded by the patent office (PTO), but applications can also be refused a grant by the examiner or can be terminated by the applicant. Harhoff and Wagner (2009) show that about 2/3 of all applications are eventually approved at the EPO. Innovators may therefore be reluctant to enter

collaborative agreements and disclose unprotected information before the patenting process is completed.

2. *Patent scope uncertainty*: Examiners may require the applicant to change the specification of the patent and narrow the scope of the claimed invention in the course of the examination procedure. If the examiner and the applicant find an agreement, the patent might be awarded to the applicant. If no such agreement is found, the application may be withdrawn by the applicant or refused a grant by the PTO. Until a final decision is taken by either party, considerable uncertainty exists over the scope of the (potential) patent award.
3. *Pendency uncertainty*: The duration of patent examination varies substantially across technological areas, patent and applicants characteristics (Harhoff and Wagner, 2006; Popp et al., 2004; Regibeau and Rockett, 2007). Innovators may face substantial opportunity costs if they delay commercialization, new projects or cooperative agreements as a consequence of patent pendencies.
4. *Economic and strategic uncertainty*: In addition to the legal uncertainty, there is substantial uncertainty associated with the economic and strategic value of the invention. The value of (patented) inventions is highly skewed with most patents having no or little economic value (Harhoff et al., 1999). The value of the underlying invention may only become apparent to the applicant, to competitors and potential partners and licensees once the uncertainty of patent rights is resolved.

In the next subsection, we explore the implication of these uncertainties on the occurrence of R&D collaboration.

2.2 Implications of uncertain IPRs on R&D collaboration.

The theoretical literature emphasizes that R&D partners attempt to manage spillovers, trying to minimize knowledge leakages (Cassiman et al., 2002; Martin, 2002; Amir et al., 2003). In addition, imperfect appropriability may increase the incentives of firms to free-ride on each other's R&D investment (Shapiro and Willig, 1990; Kesteloot and Veugelers, 1995; Eaton and Eswaran, 1997). The empirical literature confirms the critical importance of appropriability for successful collaboration (Cassiman and Veugelers, 2002; Gans et al., 2002).

We argue that uncertain IPRs exacerbate these effects for several reasons. First, an innovator with patent applications under review at the PTO is under the threat of expropriation. Even though patent applications are usually made publicly available when the formal examination starts, an applicant is likely to have detailed information beyond the mere technical description of the claimed invention (Teece, 1981; Arora, 1995). Therefore patent pendencies may have an impact on the risk of expropriation and on the willingness of the applicant to disclose unprotected information.

Appropriation concerns are prevalent in horizontal cooperative agreements (with competitors). Minimizing opportunistic partner behavior in cooperative contracts will be more pronounced when the existing research portfolio of a firm is characterized by a large amount of uncertainty. By contrast, the threat of expropriation is lower in vertical cooperation (with customers or suppliers) that is directed at cost reduction or customer acceptance of new products, or institutional collaboration (with universities) that covers more generic knowledge production (Belderbos et al. 2004).

Second, uncertain property rights decrease the bargaining power of firms seeking to collaborate. The literature suggests that the rational for collaboration is to combine the firms' existing resources to exploit complementarities (Kogut, 1998; Roeller et al., 2007). Because formal IPRs such as patents can serve as a vehicle for the formalisation of technology exchange arrangements between partners (Brouwer and Kleinknecht, 1999) and as a bargaining chip in negotiation with potential partners (Blind et al., 2006), firms with uncertain patents may be at a comparative disadvantage when negotiating the terms of the agreement and the division of rents.

Third, uncertain patents increase search costs. The greater a firm's stock of resources, the greater the firm's attractiveness to partners, and the greater the firm's collaboration opportunities (Ahuja, 2000). Therefore, the incentives to engage in costly search for partners may only be sufficient once the uncertainty over IPRs is resolved (Gans et al. 2008; Hellmann, 2007).

3 Data and Variables

3.1 Firm level and patent data

The main data source is the Mannheim Innovation Panel (MIP), a survey that 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.

In 1992 and 1996 firms reported their involvement in collaborative R&D.[2] Innovation collaborations are defined as "active participation in joint innovation projects with other organizations. These may either be other enterprises or non-commercial institutions. The partners need not derive immediate benefit from the venture. Pure contracting out of work, where there is no active collaboration, is not regarded as co-operation. Co-operation is distinct from open information sources and acquisition of knowledge and technology in that all parties take an active part in the work" (OECD, 2005).

The questionnaire asked respondents to distinguish between different types of collaboration: horizontal collaboration (with competitors), institutional collaboration (with universities and public research institutions) and vertical collaboration (with suppliers and customers). In addition, the MIP provides comprehensive information on the firms' innovation activities. The MIP survey years 1992 and 1996 constitute a pooled cross-sectional database for our empirical analysis.[3] We restrict the sample to manufacturing firms only and exclude firms that were not engaged in process and/or product innovations. This leaves us with a total of 2,795 sample firms.

Table 1 shows descriptive statistics for the variables used for the empirical analysis. It shows that about a quarter of the innovative firms in German manufacturing are involved in some kind of R&D collaboration. About 17% of the firms collaborated with universities, 18% with suppliers or customers (vertical collaboration) and a much smaller share of 6% collaborated with competitors.

Information on the patenting activity of firms is taken from the patent database of the EPO. Firm and patent information were linked based on firms' names and addresses. The match between firms and their EPO patent applications was conducted using a

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[2] This question was also part of the MIP survey in 2000 and 2004. However, we abstain from using this more recent data because the information on pending patents is added from EPO data and we want to avoid that our results are driven by reporting lags of the outcome of patent decisions, i.e. right-censoring of the patent data (see e.g. Harhoff and Wagner, 2009).

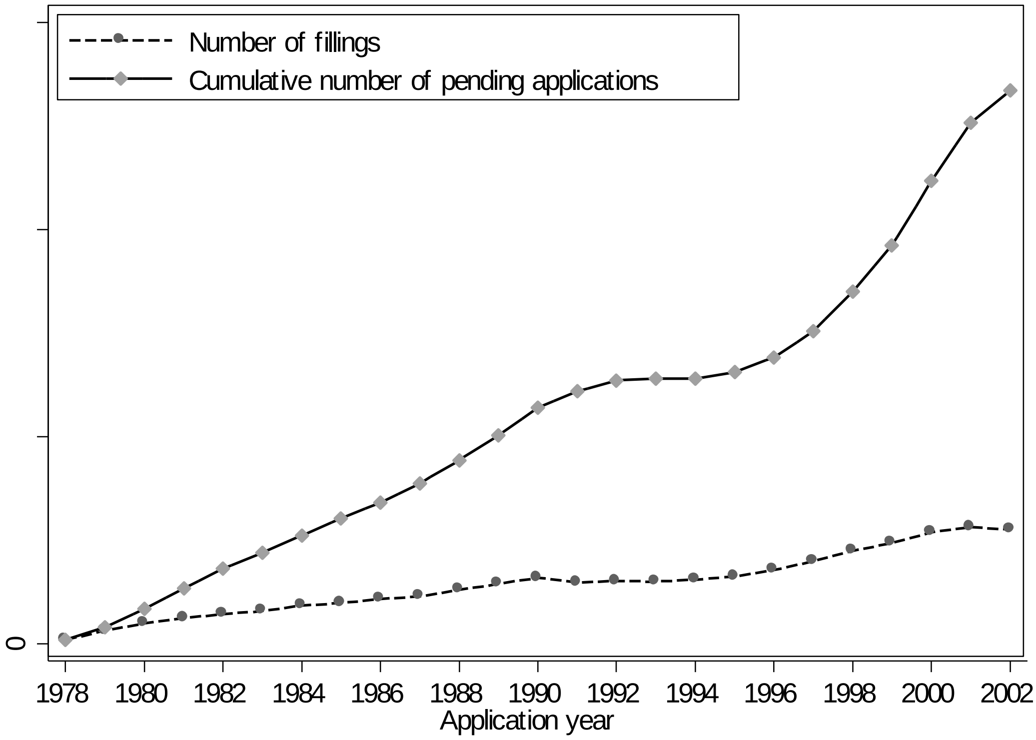
[3] Only 15.5% of the firms in our sample of innovative firms in German manufacturing responded to the survey in both years.

computer-assisted text-based search algorithm. All potential hits were checked manually. In total, 27% of the sample firms applied for at least one patent at EPO since its inception in 1978.

3.2 Pending Patents at the EPO

The number of pending patents at the EPO has risen sharply over time. Figure 1 shows the evolution of the number of applications and the number of pending applications at the EPO. The surge in patenting observed at the EPO lead to a backlog of pending cases, amounting to more than 500,000 in the beginning of the year 2001.

Figure 1: Applications and pendencies at the EPO



Source: Espace Bulletin (EPO). Authors' own calculations.

Harhoff and Wagner (2009) report that in the period 1978-2000, it took on average 4.3 years from the initial filling to the grant decision. Popp et al. (2004) show that in the period 1976-1996, the average grant lag for utility patents awarded by the United States Patent and Trademark Office (USPTO) was about 2.3 years. It appears that the average grant lag at the EPO is longer than at the USPTO and that this gap has been increasing significantly over time (Harhoff and Wagner, 2009). This difference can be explained by the divergent practices adopted by both patent offices in the wake of increasing inflows of applications. The USPTO granted patents of dubious merit in order to deliver patent awards in a timely manner (Lemley, 2001), whereas the EPO attempted to maintain high quality in examination, creating enormous backlogs of applications (Guellec and van Pottelsberghe de la Potterie, 2007, Harhoff and Wagner, 2009).

We make use of the EPO information to define our measure of uncertain IPRs as the number of pending patent applications. Pending applications are defined as filings that are still under review at the EPO in the year of interest.[4] Table 1 shows that the average firm in our sample has more than two pending patent applications at the EPO. The ratio of pending applications over the total application stock is 0.15. The latter measure is used in the empirical analysis to account for the fact that the patent stock and the number of pending patents are highly correlated.

3.3 Control variables

In addition to our main variable of interest, we use a rich set of control variables that were identified as determinants of R&D collaboration in the previous literature. We include proxy variables for appropriability, incoming R&D spillovers, absorptive capacity as well as indicators for the cost and risk of innovation, following the definitions proposed by Cassiman and Veugelers (2002).

Appropriability describes the ability of firms to appropriate the returns from their innovations. Our measures for appropriability capture the effectiveness of different protection mechanisms. Following Cassiman and Veugelers (2002), we distinguish between legal and strategic protection tools. The legal protection measure maps the extent to which patents, trademarks and copyrights are effective for the protection of product and process inventions. Strategic protection is measured by the effectiveness of secrecy, complexity and lead time for the protection of product and process inventions. In the survey, respondents were asked to rate the effectiveness of the particular protection mechanisms on a Likert scale from one (unimportant) to five (highly important). The questions about the effectiveness of different protection tools

[4] The patent application and review procedure at EPO involves several steps, which are briefly described in Appendix 1.

is only included in the 1992 survey wave. Therefore, we use the industry average of both strategic and legal protection (rescaled between 0 and 1) in 1992 at the 3-digit NACE level for both waves.

Furthermore, we control for incoming spillovers. Again, we use particular questions from the MIP survey, namely the questions on the importance of different sources of information for firms' innovation activities. In line with Cassiman and Veugelers (2002), we focus on public spillovers which include the importance of patent information, specialized conferences, meetings and publications as wells as trade shows and seminars. For these questions too, firms were asked to rank the different information sources on a scale from unimportant to highly important. As for the appropriability measure, we rescale the variable between 0 and 1 and use the industry average at the 3-digit NACE level.

The theoretical literature underscores the importance of cost and risk constraints as motives to establish R&D collaboration agreements (Katz, 1986, d'Aspremont and Jacquemin, 1988, Kamien et al., 1992). The previous empirical literature has found some evidence for the cost-sharing motive behind R&D collaborations (Cassiman and Veugelers, 2002, Schmidt, 2005, Roeller et al., 2007), while there is typically no effect for the risk-sharing motive (Cassiman and Veugelers, 2002; Schmidt, 2005).

The survey allows us to proxy both the cost and risk constraints. Both survey years contain information about different obstacles to innovation, among them the costs of innovating and the risks and uncertainties of the innovation process. Firms for which the costs and risks of innovating are perceived to be high are more likely to be involved in R&D collaborations. Again, the obstacles were ranked on a scale between unimportant and highly important. We defined two binary variables, COST and RISK, which take the value one if costs or risks respectively were indicated as very important obstacles to innovation and zero otherwise.

In addition, we use a range of further firm characteristics as control variables. First, we use firm size and R&D intensity. Larger and more R&D intensive firms are more likely to possess the necessary absorptive capacity to benefit from R&D cooperation and are therefore expected to have a positive impact on the likelihood to observe such agreements. Firm size is measured as the total number of employees, EMPL. We use the logarithm of this number to account for the skewness of the distribution. R&D

intensity is measured as R&D expenses over total sales. Table 1 shows that the average firm in our sample has 691 employees and an R&D intensity of 2%.

The patent application stock accounts for the importance of the ownership of IP for collaboration. The patent applications stock is measured as:

$$PS_t = PS_{t-1}(1-\delta) + patent\ \ applications_t ,$$

where δ represents the constant knowledge depreciation rate, which is set to 15 percent as it is standard in the literature (e.g. Griliches and Mairesse, 1984, or Hall, 1990). The patent stock enters our specification with a one year lag to avoid endogeneity. In order to avoid collinearity with firm size, we divide the patent stock by employment. On average, the firms in our sample have a patent stock over employment of 0.004. As the sample includes a large fraction of firms that never applied for a patent we also include a binary variable that takes on the value one for firms with no patent application and zero otherwise.

In addition, we control for industry affiliation using eleven industry dummies and a dummy for complex technology industries. Complex technology industries capture sectors characterized by technologies that enclose a large number of complementary patentable elements. Firms operating in complex industries face a higher density of patent applications, which decreases transparency in technology markets and therefore increases the threat of patent thickets and blocking patents (Cohen et al., 2000). It has been shown that technology licensing is one method to overcome hold-up problems in complex industries (Siebert and von Graeventiz, 2010, Grimpe and Hussinger, 2009). R&D collaboration may constitute an alternative solution.

By including a dummy, EAST, for firms located in the Eastern part of the country, we take the turbulent past of Germany into account. East Germany was a planned economy until the fall of the Berlin wall in 1989. Since then, East Germany has been undergoing a transition process into a market economy. Recent studies have shown that East German firms still lag behind their West German counterparts in terms of innovativeness (Czarnitzki and Kraft, 2006) and productivity (Czarnitzki, 2005).

Finally, we include the Hirschman-Herfindahl index (HHI) to control for product market competition. We also use a dummy indicating firms that were founded in the recent two years, as start-up companies may be more like to rely on collaboration than other firms. In contrast, it may also be the case that they are not collaborating as they may not be attractive partners for more established companies. Last but not least, we include a time dummy, Y1992, to capture macroeconomic shocks across the two time periods.

Table 1: Descriptive statistics (2,794 observations)

Variable	Mean	Std. dev.	Min.	Max.
Collaboration	0.24	0.43	0	1
… with competitors	0.06	0.24	0	1
… with universities	0.17	0.37	0	1
… vertical	0.18	0.38	0	1
R&D (in million DM)	7.50	83.30	0	2302
R&D/sales	0.02	0.05	0	0.57
Patent stock	2.90	55.37	0	2866.50
Patent stock / EMPL	0.004	0.01	0	0.27
No patents	0.73	0.45	0	1
Complex industry	0.43	0.50	0	1
Pending patents	2.29	42.01	0	2121
Pending patents/ patent stock	0.15	0.36	0	2.25
EMPL	691.31	5279.51	1	177183
Newly founded	0.18	0.39	0	1
HHI	44.73	64.30	3.32	444.95
EAST	0.31	0.46	0	1
COST	0.40	0.49	0	1
RISK	0.43	0.49	0	1
Incoming spillovers	0.64	0.07	0.44	0.79
Strategic appropriability	0.71	0.05	0.60	0.80
Legal appropriability	0.49	0.07	0.29	0.67
Y1992	0.58	0.49	0	1

Note: Industry dummies omitted.

4 Empirical Results

In a first step, we investigate the effects of pending patent applications on all forms of collaboration. Then, we distinguish between different types of collaboration, i.e. horizontal collaborations, institutional collaborations and vertical collaborations. We present probit models for each type of collaboration and for two different specifications. The first specification includes a set of standard control variables along with the pending applications over the patent application stock. The control variables are R&D intensity, the patent application stock per employee, the binary variable indicating whether a firm never applied for a patent, the log of firm size, the dummy for complex industries and the other industry dummies as well as the dummy for firm location in Eastern Germany and the time dummy. The second specification adds the survey proxies for spillovers, the effectiveness of legal and strategic knowledge protection and the two dummy variables for cost and risk constraints. Further, the dummy for newly founded firms and the logarithm of the Hirschman-Herfindahl Index are included.

In addition to the standard probit models, we report results where we instrument R&D intensity by estimating Full Information Maximum Likelihood Probit instrumental variable models. R&D intensity is a potential source of endogeneity in our model, as the firms' collaboration activities and their R&D intensity are likely to depend on some unobservable firm-specific factors like, for instance, the managerial skills that are used to optimize firms' innovation activities. We use the share of R&D employment at the 3-digit NACE level as an instrument for R&D intensity. The industry variable defines the R&D environment in which the firms operate and the key assumption behind industry level instruments is that the unobserved firm characteristics do not significantly affect the industry variables (Jaffe, 1986).

Endogeneity of R&D intensity with regard to all collaboration variables cannot be rejected based on Rivers and Vuong (1988) tests. This test requires a first step regression of R&D intensity on all regressors and the instrument. The predicted residuals of this model are included in a second regression of the collaboration variables on all regressors. The estimated coefficient for the residual is the test statistic for the null hypothesis of exogeneity of R&D intensity (Wooldridge, 2002, p.474). Exogeneity is rejected at the 1% level of statistical significance for all our models.

Stock and Staiger (1997) emphasize that endogeneity tests can be misleading in case of weak instruments. If instruments are weak the correlation between the endogenous variable and the instrument can be artificially high due to the presence of other control variables. Staiger and Stock (1997) propose evaluating the partial correlation of the endogenous variable and the instruments as a test for weak instruments. As a rule of thumb, the partial F-statistic for the instrument(s) should be larger than 10 to ensure that instruments are not weak. The F-statistic exceeds 10 for both specifications (F = 44.99 for the full specification; F = 49.13 for the baseline specification).

Tables 2 to 5 show the results for all types of collaboration, horizontal collaboration, institutional collaboration, and vertical collaborations. The first two columns show the results of the probit models for the baseline and full specifications. The next two columns show the results of the instrumental variable probit regressions for both specifications.

The regression results reveal that there is no impact of uncertain IPRs on collaboration in general (Table 2). Tables 3 to 5 show that pending patents are only significant for R&D collaborations with competitors. Uncertain IPRs decrease the likelihood of collaborating with competitors, while there is no effect of this variable on the likelihood of collaborating with scientific institutions or suppliers and customers. With regard to the marginal effect of pending patents we find a non-negligible magnitude. Among firms with patent applications the average probability to collaborate with a competitor amounts to 13%. The probability of collaborating with a competitor decreases by 3% points for these firms if the share of pending patents in the patent application stock increases by one standard deviation at the mean. Thus, the average probability of collaborating with firms in the same industry is reduced by about 23% (=3/13), which is a sizeable impact.

Concerning the control variables the estimation results reveal some significant predictors for R&D collaboration. As expected, large firms and firms with a high R&D intensity are more likely to collaborate with all types of partners. In line with the concept of absorptive capacity, firms need a sufficient level of in-house R&D in order to benefit from collaborations (Roeller et al., 2007, Cassiman and Veugelers, 2002).[5] Interestingly, the size of the patent application stock is not important for the collaboration decision. The patent stock is only significant for university collaborations and there is weak evidence for their importance for vertical collaboration agreements. A further interesting result is that vertical collaborations are in particular attractive in industries employing complex technologies. The further control variables do not exhibit any significant impact on the likelihood of R&D collaborations.

Focusing on the survey proxies suggested by Cassiman and Veugelers (2002) the regression results show that cost and risk sharing drive R&D collaborations. The effect of innovation costs however disappears if it is distinguished between the different types of collaboration. The risk sharing motive is strongest for vertical

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[5] However, the effect of R&D intensity disappears for collaborations with scientific institutions and vertical collaborations if endogeneity of R&D intensity is taken into account.

collaborations. This finding stands in contrast to the results of Cassiman and Veugelers (2002) and Schmidt (2005) who find evidence for the importance of cost sharing but not of risk-sharing. A potential explanation can be the difference in the definition of these variables. While Cassiman and Veugelers (2002) and Schmidt (2005) use a Likert scale variable describing the importance of costs and risks as obstacles for innovation we can only use a dummy variable for our sample.

We do not find any effect of the industry measures for appropriability and incoming spillovers either.

Table 2: Probit models on the likelihood to collaborate with any type of partner

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	4.00***	3.73***	10.23***	9.53**
	(0.70)	(0.70)	(3.62)	(3.97)
Patent stock / EMPL	2.73	2.67	1.66	1.64
	(2.03)	(2.07)	(2.15)	(2.20)
No patent dummy	-0.10	-0.12	-0.08	-0.07
	(0.09)	(0.10)	(0.09)	(0.10)
Complex technology	0.58***	0.51**	0.43**	0.39*
	(0.18)	(0.21)	(0.20)	(0.22)
Pending pat./pat. stock	0.08	0.08	0.02	0.03
	(0.10)	(0.10)	(0.11)	(0.11)
Ln(EMPL)	0.33***	0.34***	0.31***	0.32***
	(0.02)	(0.02)	(0.03)	(0.03)
Newly founded		-0.04		-0.04
		(0.10)		(0.10)
Ln(HHI)		0.02		0.02
		(0.03)		(0.03)
EAST		0.17*		0.07
		(0.09)		(0.11)
COST		0.16**		0.14*
		(0.08)		(0.08)
RISK		0.23***		0.20**
		(0.08)		(0.09)
Incoming spillovers		-0.08		-0.17
		(0.99)		(0.95)
Strategic appropriability		0.38		0.16
		(1.04)		(1.02)
Legal appropriability		0.46		0.40
		(0.70)		(0.69)
1992	0.23***	0.07	0.18**	0.05
	(0.06)	(0.11)	(0.07)	(0.11)
Intercept	-2.84***	-3.48***	-2.72***	-3.12***
	(0.23)	(0.78)	(0.26)	(0.84)
Industry dummies	X^2 = 40.65***	X^2 = 30.16***	X^2 = 29.65***	X^2 = 23.11***
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).

Table 3: Probit models on collaboration with competitors

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	2.46***	2.48***	12.18***	11.68***
	(0.61)	(0.62)	(3.67)	(4.04)
Patent stock / EMPL	-0.75	-1.12	-2.20	-2.45
	(3.52)	(3.68)	(3.24)	(3.42)
No patent dummy	-0.44***	-0.41***	-0.36***	-0.31**
	(0.12)	(0.13)	(0.12)	(0.13)
Complex technology	0.80**	0.67*	0.52	0.46
	(0.33)	(0.35)	(0.33)	(0.35)
Pending pat./ pat. stock	-0.31**	-0.30**	-0.36***	-0.34***
	(0.13)	(0.13)	(0.12)	(0.12)
Ln(EMPL)	0.25***	0.24***	0.21***	0.20***
	(0.03)	(0.03)	(0.04)	(0.04)
Newly founded		0.15		0.14
		(0.15)		(0.14)
Ln(HHI)		0.06		0.06
		(0.04)		(0.04)
EAST		-0.16		-0.28**
		(0.15)		(0.14)
COST		0.06		0.03
		(0.12)		(0.11)
RISK		0.25*		0.18
		(0.13)		(0.12)
Incoming spillovers		-0.38		-0.62
		(1.38)		(1.24)
Strategic appropriability		0.48		0.14
		(1.63)		(1.49)
Legal appropriability		1.21		0.92
		(0.95)		(0.89)
1992	-0.16*	-0.29*	-0.20***	-0.27*
	(0.08)	(0.15)	(0.08)	(0.14)
Intercept	-3.11***	-3.97***	-2.75***	-3.12**
	(0.37)	(1.27)	(0.43)	(1.26)
Industry dummies	X^2 = 36.71***	X^2 = 21.01**	X^2 = 13.80	X^2 = 10.96
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).

Table 4: Probit models on collaboration with universities

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	3.83***	3.73***	8.12*	7.13
	(0.65)	(0.66)	(4.28)	(4.57)
Patent stock / EMPL	5.14**	5.07**	4.38*	4.47*
	(2.09)	(2.11)	(2.27)	(2.30)
No patent dummy	-0.12	-0.12	-0.11	-0.09
	(0.10)	(0.10)	(0.10)	(0.11)
Complex technology	0.40*	0.35	0.31	0.29
	(0.20)	(0.23)	(0.23)	(0.25)
Pending pat. / pat. stock	0.07	0.07	0.03	0.04
	(0.11)	(0.11)	(0.11)	(0.11)
Ln(EMPL)	0.34***	0.33***	0.33***	0.33***
	(0.02)	(0.02)	(0.03)	(0.03)
Newly founded		-0.06		-0.05
		(0.11)		(0.11)
Ln(HHI)		0.03		0.04
		(0.03)		(0.03)
EAST		0.06		0.01
		(0.10)		(0.12)
COST		0.03		0.03
		(0.09)		(0.09)
RISK		0.16*		0.14
		(0.09)		(0.10)
Incoming spillovers		0.29		0.21
		(1.12)		(1.11)
Strategic appropriability		1.40		1.27
		(1.17)		(1.18)
Legal appropriability		0.21		0.17
		(0.79)		(0.78)
1992	0.21***	0.11	0.18**	0.11
	(0.07)	(0.12)	(0.08)	(0.12)
Intercept	-3.17***	-4.58***	-3.11***	-4.37***
	(0.26)	(0.91)	(0.28)	(0.96)
Industry dummies	X^2 = 44.42***	X^2 = 37.75***	X^2 = 30.88***	X^2 = 29.70***
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).

Table 5: Probit models on vertical collaboration (customers and suppliers)

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	2.78***	2.60***	0.94	0.13
	(0.63)	(0.64)	(4.40)	(4.66)
Patent stock / EMPL	3.46	3.49	3.72*	3.85*
	(2.12)	(2.15)	(2.19)	(2.23)
No patent dummy	-0.15	-0.15	-0.16	-0.16
	(0.10)	(0.10)	(0.10)	(0.10)
Complex technology	0.68***	0.67***	0.71***	0.71***
	(0.19)	(0.21)	(0.20)	(0.22)
Pending pat. / pat. stock	0.02	0.02	0.03	0.03
	(0.10)	(0.10)	(0.11)	(0.11)
Ln(EMPL)	0.26***	0.27***	0.26***	0.27***
	(0.02)	(0.02)	(0.02)	(0.02)
Newly founded		-0.04		-0.04
		(0.11)		(0.11)
Ln(HHI)		0.02		0.01
		(0.03)		(0.03)
EAST		0.08		0.11
		(0.10)		(0.12)
COST		0.14		0.14*
		(0.08)		(0.08)
RISK		0.28***		0.29***
		(0.09)		(0.09)
Incoming spillovers		0.34		0.39
		(1.05)		(1.05)
Strategic appropriability		0.68		0.75
		(1.11)		(1.12)
Legal appropriability		-0.69		-0.67
		(0.75)		(0.74)
1992	0.14**	-0.08	0.15**	-0.07
	(0.06)	(0.12)	(0.07)	(0.12)
Intercept	-2.71***	-3.25***	-2.70***	-3.33***
	(0.24)	(0.85)	(0.24)	(0.85)
Industry dummies	X^2 = 32.14***	X^2 = 29.67***	X^2 = 32.46***	X^2 = 30.82***
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).

Robustness checks

We show some robustness checks in Appendix 2 and Appendix 3. Table 6 in Appendix 2 presents results of multivariate probit models which take the correlation of the error terms of the collaboration equations into account. There is evidence for positive error term correlation. The results remain robust to the findings presented in Tables 3 to 5. Pending patents only affect collaborations with competitors.

Some readers may be concerned about a potential omitted variable bias. It may be the case that the collaboration decision is partly driven by the "technological position" of a firm. On the one hand, a firm possessing the leading technological portfolio in its market may not be interested in collaboration. In particular, it may not be willing to collaborate with rivals. On the other hand, firms holding key patents might be more likely to collaborate because they have more to offer to potential partners. We model the technological position of a firm by adding a quality indicator of a firm's patent stock. Therefore, we compute the stock of forward patent citations, i.e. all citations received in future patent applications. Patent forward citations are a well established measure for the "importance", the "quality" or the "significance" of a patented invention and have been used in different contexts in the literature on technological change (see Trajtenberg, 1990; Henderson et al., 1998; Harhoff et al., 1999; Trajtenberg, 2001; or Hall et al., 2005).

In order to avoid a right-hand censoring of the citation variables, we limit the citation time window to five years after the patent application. The variable enters the regression as all forward citations received divided by the number of total patent applications. On average, a patent receives 0.16 citations in the future five years in our sample (std. dev. = 0.5). In addition to the citations over patent applications we include a dummy variable indicating if a firm did not receive any citation within the five-year window. 33% of the patenting firms (and 82% of the firms in total) received no citations to their patents within five years after application.

Tables 7 to 10 in Appendix 3 show that the results are robust with regard to all earlier results. Pending patents only impact the likelihood to collaborate with competitors while they do not matter for other types of collaboration. There is no robust finding for the quality of patents influencing the likelihood to collaborate with any type of partner.[6] If at all, we find weak indications that the quality of the technological portfolio increases the likelihood to collaborate.

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[6] We also tested whether there is a nonlinear relationship between the citation variable and the likelihood of collaboration but did not find significant effects.

5 Conclusion

Against the background of an increased duration of the patent examination procedure at the European Patent Office (EPO) this paper investigates whether the so created uncertainty impacts firms' R&D collaborations. After a surge in patent applications in the mid 1990s the EPO suffered from a lack of qualified examiners. Rather than cutting back on patent quality the time for patent investigation at the EPO increased. The consequence is that firms face higher uncertainty about their certified intellectual property rights which might have important implications for their R&D activities.

Intellectual property rights are highly important for firms that engage in R&D collaborations in order to limit the threat of expropriation of unprotected knowledge by potential partners. Furthermore, uncertain intellectual property rights reduce the bargaining power of collaboration partners and enhance search costs and asymmetric information for potential collaborators. In this study, we show that uncertain intellectual property rights lead to less collaboration among firms in the same industry, which implies less knowledge production in the economy because complex R&D projects that demand a bundle of resources and different skills in order to be realized may not be conducted. In particular, our empirical results for a large sample of German manufacturing firms reveal that collaborations between competitors are most sensitive to uncertain intellectual property rights. Firm collaborations with universities, suppliers or customers are not affected by uncertain intellectual property rights because these collaboration partners do not compete in the same product markets.

Our findings have important implications for technology policy. Governments have long understood the virtues of R&D collaboration by exempting R&D partnerships from anti-trust legislation and implementing several policies to encourage R&D collaborations. Our results show that a functional intellectual property rights system is needed for successful utilization of this policy: patent examination should be of high quality, but should also be performed in a timely manner.

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Appendix 1: Application procedure at the EPO

A brief sketch of the steps from application to grant/refusal decision is given below:[7]

- After an application was filed, patent examiners prepare a search report describing the state of the art regarded as relevant for the patentability of the invention.[8]
- Eighteen months after the priority date of the patent application the patent application is made public along with the search report in the EPO Patent Bulletin.
- Within six months after publication, applicants can request for substantial examination of the application. If examination is not requested, the patent is deemed withdrawn.
- If examination is requested a decision on the patentability of the invention is made according to the EPO patentability criteria: novelty, inventive step and industrial applicability. The examination can end by a grant or refusal to grant.
- The applicant can voluntarily withdraw the application at each step of the procedure.

[7] A more detailed description can for example been found in Harhoff and Wagner (2009).

[8] Note that unlike in the U.S. patent applicants at the EPO are not required to supply a list of prior art themselves.

Appendix 2: Multivariate Probit Models

Table 6: Multivariate probit models for different types of collaboration

	Model I			Model II		
Collaboration type	Equation 1: competitor	Equation 2: university	Equation 3: vertical	Equation 1: competitor	Equation 2: university	Equation 3: vertical
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	2.82***	3.76***	2.79***	2.77***	3.61***	2.56***
	(0.70)	(0.57)	(0.57)	(0.73)	(0.58)	(0.58)
Patent stock / EMPL	-1.12	4.90**	3.44	-1.65	4.87**	3.48
	(3.08)	(2.31)	(2.16)	(3.12)	(2.33)	(2.20)
No patent dummy	-0.42***	-0.12	-0.15	-0.40***	-0.11	-0.15
	(0.12)	(0.10)	(0.10)	(0.13)	(0.10)	(0.10)
Complex technology	0.73**	0.34*	0.69***	0.54	0.30	0.68***
	(0.32)	(0.20)	(0.19)	(0.35)	(0.22)	(0.22)
Pending pat. / pat. stock	-0.29**	0.05	0.01	-0.29**	0.06	0.01
	(0.13)	(0.11)	(0.10)	(0.13)	(0.11)	(0.10)
Ln(EMPL)	0.28***	0.33***	0.26***	0.26***	0.33***	0.26***
	(0.03)	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)
Newly founded				0.10	-0.08	-0.07
				-0.11	(0.11)	(0.10)
East				-0.11	0.09	0.10
				(0.14)	(0.10)	(0.09)
Cost				0.07	0.03	0.13
				(0.11)	(0.09)	(0.08)
Risk				0.30**	0.19**	0.29***
				(0.12)	(0.09)	(0.09)
Incoming spillovers				-0.43	0.31	0.17
				(1.36)	(1.04)	(0.99)
Strategic appropriability				-0.14	1.25	0.48
				(1.50)	(1.07)	(1.03)
Legal appropriability				1.85*	0.18	-0.57
				(1.01)	(0.74)	(0.72)
Ln(HHI)				0.05	0.04	0.02
				(0.04)	(0.03)	(0.03)
1992	-0.14	0.24***	0.15**	-0.28*	0.13	-0.04
	(0.09)	(0.07)	(0.06)	(0.15)	(0.12)	(0.11)
Intercept	-3.29***	-3.16***	-2.71***	-3.90***	-4.49***	-3.09***
	(0.36)	(0.23)	(0.22)	(1.10)	(0.78)	(0.74)
Industry dummies	YES	YES	YES	YES	YES	YES
RHO21		0.66***			0.66***	
		(0.04)			(0.04)	
RHO31		0.63***			0.62***	
		(0.04)			(0.04)	
RHO32		0.84***			0.84***	
		(0.02)			(0.02)	
N		2794			2794	
Log-Likelihood		-2185.36			-2160.06	

*** (**, *) indicate a significance level of 1% (5%, 10%).

Appendix 3: Probit Models Taking Forward Citations into Account

Table 7: Probit models on the likelihood to collaborate with any type of partner

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	3.83***	3.56***	10.02**	9.21**
	(0.70)	(0.70)	(3.97)	(4.41)
Patent stock / EMPL	2.66	2.58	1.62	1.61
	(2.04)	(2.07)	(2.21)	(2.27)
Citations/ patents	0.14*	0.14*	0.02	0.03
	(0.07)	(0.08)	(0.11)	(0.12)
No patent dummy	0.01	-0.01	-0.06	-0.05
	(0.13)	(0.14)	(0.14)	(0.14)
No citation dummy	0.07	0.06	0.01	0.02
	(0.13)	(0.13)	(0.14)	(0.14)
Complex technology	0.58***	0.52**	0.44**	0.40*
	(0.18)	(0.21)	(0.20)	(0.22)
Pending pat./ pat. stock	0.09	0.09	0.03	0.04
	(0.10)	(0.10)	(0.11)	(0.11)
ln(EMPL)	0.33***	0.34***	0.31***	0.32***
	(0.02)	(0.02)	(0.03)	(0.03)
Newly founded		-0.04		-0.04
		(0.10)		(0.10)
ln(HHI)		0.02		0.02
		(0.03)		(0.03)
EAST		0.17*		0.08
		(0.09)		(0.12)
COST		0.16*		0.14*
		(0.08)		(0.08)
RISK		0.23***		0.20**
		(0.08)		(0.09)
Incoming spillovers		0.01		-0.11
		(0.99)		(0.97)
Strategic appropriability		0.44		0.20
		(1.05)		(1.03)
Legal appropriability		0.40		0.38
		(0.71)		(0.69)
Y1992	0.23***	0.06	0.18**	0.05
	(0.06)	(0.11)	(0.07)	(0.11)
Intercept	-2.96***	-3.67***	-2.75***	-3.22***
	(0.25)	(0.80)	(0.32)	(0.91)
Industry dummies	X^2 = 40.52***	X^2 = 03.16***	X^2 = 29.07***	X^2 = 22.65***
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).

Table 8: Probit models on collaboration with competitors

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	2.19***	2.23***	12.04***	11.44**
	(0.63)	(0.64)	(4.04)	(4.53)
Patent stock / EMPL	-0.92	-1.17	-2.34	-2.49
	(3.51)	(3.64)	(3.29)	(3.46)
Citations/ patents	0.16***	0.16**	-0.03	-0.02
	(0.06)	(0.07)	(0.11)	(0.12)
No patent dummy	-0.31*	-0.28*	-0.39***	-0.31**
	(0.16)	(0.16)	(0.15)	(0.16)
No citation dummy	0.06	0.08	-0.04	-0.01
	(0.16)	(0.16)	(0.15)	(0.16)
Complex technology	0.81**	0.69*	0.53	0.47
	(0.33)	(0.35)	(0.33)	(0.35)
Pending pat./ pat. stock	-0.30**	-0.29**	-0.36***	-0.34***
	(0.13)	(0.13)	(0.12)	(0.12)
ln(EMPL)	0.25***	0.24***	0.22***	0.21***
	(0.03)	(0.03)	(0.04)	(0.04)
Newly founded		0.15		0.14
		(0.15)		(0.14)
ln(HHI)		0.06		0.06
		(0.04)		(0.04)
EAST		-0.15		-0.27*
		(0.15)		(0.14)
COST		0.05		0.03
		(0.12)		(0.11)
RISK		0.25*		0.18
		(0.13)		(0.13)
Incoming spillovers		-0.19		-0.50
		(1.38)		(1.25)
Strategic appropriability		0.61		0.21
		(1.64)		(1.51)
Legal appropriability		1.05		0.85
		(0.94)		(0.88)
Y1992	-0.15*	-0.30*	-0.20***	-0.28*
	(0.08)	(0.15)	(0.08)	(0.14)
Intercept	-3.26***	-4.26***	-2.74***	-3.22**
	(0.39)	(1.28)	(0.51)	(1.36)
Industry dummies	X^2 = 36.22***	X^2 = 20.74***	X^2 = 13.41	X^2 = 10.67
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).

Table 9: Probit models on collaboration with universities

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	3.80***	3.69***	8.36*	7.29
	(0.66)	(0.67)	(4.61)	(4.99)
Patent stock / EMPL	5.02**	4.96**	4.23*	4.34*
	(2.13)	(2.15)	(2.36)	(2.39)
Citations/ patents	0.02	0.03	-0.06	-0.04
	(0.08)	(0.08)	(0.12)	(0.12)
No patent dummy	-0.12	-0.11	-0.16	-0.13
	(0.14)	(0.14)	(0.15)	(0.14)
No citation dummy	-0.02	-0.01	-0.06	-0.04
	(0.14)	(0.14)	(0.14)	(0.14)
Complex technology	0.40*	0.35	0.30	0.29
	(0.20)	(0.23)	(0.23)	(0.26)
Pending pat. / pat. stock	0.07	0.07	0.02	0.04
	(0.11)	(0.11)	(0.11)	(0.11)
ln(EMPL)	0.34***	0.33***	0.33***	0.32***
	(0.02)	(0.03)	(0.03)	(0.03)
Newly founded		-0.06		-0.05
		(0.11)		(0.11)
ln(HHI)		0.04		0.04
		(0.03)		(0.03)
EAST		0.06		0.00
		(0.10)		(0.13)
COST		0.03		0.03
		(0.09)		(0.09)
RISK		0.16*		0.14
		(0.09)		(0.10)
Incoming spillovers		0.31		0.20
		(1.12)		(1.11)
Strategic appropriability		1.41		1.25
		(1.17)		(1.19)
Legal appropriability		0.19		0.17
		(0.79)		(0.78)
1992	0.21***	0.11	0.18**	0.11
	(0.07)	(0.12)	(0.08)	(0.12)
Intercept	-3.17***	-4.60***	-3.04***	-4.31***
	(0.28)	(0.92)	(0.34)	(1.02)
Industry dummies	X^2 = 43.80***	X^2 = 37.41***	X^2 = 29.35***	X^2 = 28.30***
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).

Table 10: Probit models on vertical collaboration (customers and suppliers)

	Probit		IV Probit (R&D instrumented)	
	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)	Coeff. (Std. err.)
R&D intensity	2.66***	2.49***	0.14	-0.84
	(0.64)	(0.65)	(4.87)	(5.18)
Patent Stock / EMPL	3.20	3.24	3.55	3.71*
	(2.15)	(2.19)	(2.21)	(2.24)
Citations/ patents	0.08	0.08	0.12	0.13
	(0.05)	(0.05)	(0.10)	(0.10)
No patent dummy	-0.12	-0.11	-0.09	-0.09
	(0.13)	(0.13)	(0.14)	(0.13)
No citation dummy	-0.03	-0.02	-0.01	0.00
	(0.12)	(0.13)	(0.13)	(0.13)
Complex technology	0.68***	0.68***	0.72***	0.72***
	(0.19)	(0.21)	(0.20)	(0.22)
Pending pat. / pat. stock	0.01	0.01	0.03	0.04
	(0.10)	(0.10)	(0.11)	(0.11)
ln(EMPL)	0.26***	0.26***	0.26***	0.26***
	(0.02)	(0.02)	(0.02)	(0.02)
Newly founded		-0.04		-0.05
		(0.11)		(0.11)
ln(HHI)		0.02		0.01
		(0.03)		(0.03)
EAST		0.08		0.13
		(0.10)		(0.12)
COST		0.14		0.14*
		(0.08)		(0.08)
RISK		0.27***		0.29***
		(0.09)		(0.09)
Incoming spillovers		0.41		0.49
		(1.05)		(1.05)
Strategic appropriability		0.72		0.83
		(1.12)		(1.13)
Legal appropriability		-0.75		-0.73
		(0.75)		(0.74)
Y1992	0.14**	-0.08	0.16**	-0.07
	(0.06)	(0.12)	(0.07)	(0.12)
Intercept	-2.73***	-3.32***	-2.75***	-3.48***
	(0.26)	(0.86)	(0.26)	(0.88)
Industry dummies	X^2 = 32.66***	X^2 = 30.07***	X^2 = 33.38***	X^2 = 31.85***
N	2794			

*** (**, *) indicate a significance level of 1% (5%, 10%).