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Heterogeneity in R&D cooperation strategies

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Abstract

We explore heterogeneities in the determinants of innovating firms' decisions to engage in R&D cooperation, differentiating between four types of cooperation partners: competitors, suppliers, customers, and universities and research institutes (institutional cooperation). We use two matched waves of the Dutch Community Innovation Survey (in 1996 and 1998) and apply system probit estimation. We find that determinants of R&D cooperation differ significantly across cooperation types. The positive impact of firm size, R&D intensity, and incoming source-specific spillovers is weaker for competitor cooperation, reflecting greater appropriability concerns. Institutional spillovers are more generic in nature and positively impact all cooperation types. The results appear robust to potential simultaneity bias.

JEL classification: O30; O32; L13

Keywords: Heterogeneity; R&D cooperation; Innovating firms

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1. Introduction

The growing role of R&D collaboration in firms' innovative activities (Hagedoorn, 2002) has spurred research into the determinants of R&D cooperation and the effects of cooperative R&D. Two major strands of theoretical literature can be distinguished. The Industrial Organization (IO) literature has extensively examined the incentives and welfare effects of R&D cooperation among competing firms, focusing on the role of R&D investments and R&D spillovers. Theoretical contributions in the management literature have stressed that R&D collaboration aims at minimizing transaction costs and exploiting complementary know-how between partner firms (e.g. Kogut, 1988; Das and Teng, 2000). Empirical work on R&D cooperation has utilized micro-level survey data from the European Community Innovation Surveys (CIS), and has focused mainly on the impact of firm size and R&D intensity as determinants of cooperation (Becker and Dietz, 2002; Leiponen, 2001; Kaiser, 2002; Veugelers, 1997).

Most of the existing literature does not distinguish R&D cooperation by type of partner (e.g. competitors, suppliers, clients, universities) but instead aggregates over R&D cooperation types, with some notable recent exceptions. Kaiser (2002) distinguishes between vertical cooperation (cooperation with suppliers and customers) and a mix of other R&D partnerships in analyzing cooperative R&D by German service firms. Cassiman and Veugelers (2002), using CIS-I data on Belgian firms in 1994, distinguished between university–firm cooperation and cooperation with vertically related partners, but did not consider cooperation with competitors. Fritsch and Lukas (2001) differentiate cooperation by type of partner to focus on the impact of firm size and R&D intensity on the propensity to cooperate among German manufacturing firms. Tether (2002) distinguishes suppliers, customers, competitors, universities and consultants in his sample of UK CIS-II firms. Leiponen (2001) considers cooperation with competitors, customers, suppliers and universities using 1997 CIS data for Finnish manufacturing firms. These studies have in common that they only had cross-section data at their disposal and hence have grappled with the problem of a simultaneous relationship between R&D cooperation and R&D intensity and spillovers. Another feature of these studies is that they have treated the different cooperation strategies as independent, not taking into account possible correlations between the strategies that could be due to complementarities.

In this paper we consider heterogeneity in R&D cooperation by exploring differences in the determinants of innovating firms' decisions to establish different types of cooperation: with competitors (horizontal), with suppliers or customers (vertical), and with universities and research institutes ('institutional' cooperation). We take into account a broad set of possible explanatory variables, but we concentrate particularly on the impact of different types of spillovers, a central focus in the industrial organization literature. Furthermore, while previous studies have investigated the propensity to establish different types of R&D partnerships in separate models, we allow for possible correlations between R&D cooperation strategies, by applying a system method of estimation for dichotomous variables. In addition, we are able to limit simultaneity bias by employing lagged explanatory variables utilizing two waves of Dutch CIS surveys in 1996 and 1998. We further check the robustness of the results to potential simultaneity bias by estimating a model limiting the analysis to firms that had no R&D cooperation in 1996, examining the determinants of the propensity to establish new cooperation agreements in 1998.

The remainder of this paper is organized as follows. The next section provides a brief overview of the theoretical and empirical literature on R&D cooperation. Section 3 explains the empirical model used and describes the dataset. Section 4 presents the results and Section 5 concludes.

2. R&D cooperation: theoretical and empirical models

2.1. Theoretical models

Models that seek to answer the questions why and what kinds of firms seek to perform joint research activities are grounded in several theoretical approaches. We will first review the Industrial Organization (IO) literature, after which we briefly discuss relevant literature in the domains of management and technology (policy).

The IO literature has focused on the relationship between two kinds of spillovers and R&D cooperation. On the one hand, there are measures of the importance of external information flows for the firm's innovation process. These are *incoming spillovers*. On the other hand, firms attempt to appropriate the benefits of their innovations by controlling information flows out of the company. These are *outgoing spillovers*. Spillovers can refer to both involuntary leakage and voluntary transfers of knowledge between market participants. When spillovers are considered to be at least partly voluntary, firms that are partners in R&D cooperation can improve on incoming knowledge transfer through information sharing (Kamien et al., 1992; Katsoulacos and Ulph, 1998). In most theoretical models of R&D cooperation, incoming and outgoing spillovers are treated as symmetric and exogenous to the firm. When anticipated, voluntary or involuntary transfers of know-how complicate cooperative R&D strategies in a non-trivial way (e.g. Spence, 1984; Katz, 1986; D'Aspremont and Jacquemin, 1988; De Bondt and Veugelers, 1991; Kamien et al., 1992; Suzumura, 1992; Vonortas, 1994; De Bondt, 1996; Leahy and Neary, 1997; Katsoulacos and Ulph, 1998). A finding in most models is that spillovers increase the relative profitability of R&D cooperation once spillovers are sufficiently high, i.e. beyond a critical level (De Bondt and Veugelers, 1991). On the other hand, models considering free riding problems in joint ventures have found that higher spillovers also increase the incentives to cheat by partner firms and the profits from free-riding by outsiders to the cooperative agreement (Kesteloot and Veugelers, 1995; Eaton and Eswaran, 1997). These results emphasize a dual role of spillovers: outgoing spillovers may jeopardize the cooperative agreement while incoming spillovers increase the attractiveness of cooperation.

More recent IO models take into account that firms can attempt to manage spillovers, trying to minimize outgoing spillovers while at the same time maximizing incoming spillovers (Cassiman et al., 2002; Martin, 2002; Amir et al., 2003). Firms can increase the effectiveness of incoming spillovers by investing in "absorptive capacity". Cohen and Levinthal (1989) show that external knowledge is more effective for the innovation process when the firm engages in own R&D. Increased absorptive capacity through investments in internal R&D efforts thus increases the effectiveness of incoming information. In addition, the choice of research approach by the firm influences the appropriability conditions it faces and the extent of incoming spillovers it enjoys. Kamien and Zang (2000) derive a model in which firms that cooperatively choose their R&D expenditures seek to maximize information flows (their incoming spillovers) by choosing broader research directions for the research joint venture.

IO research on R&D cooperation has paid little attention to the different types of potential partners. It has typically considered horizontal cooperation, i.e. between competing firms, stressing the importance of the degree of product market competition. When firms are not direct competitors but market independent or complementary goods, cooperation is associated with higher R&D investment levels independent of any critical level of spillovers (De Bondt et al., 1992; Röller et al., 1997). In such a setting where firms are less direct competitors, joint R&D and possible cheating have no detrimental effect in terms of strengthening the product market position of the rival. A similar logic holds for inter-industry cooperation with firms in unrelated markets (Steurs, 1995) and vertical cooperation with suppliers (Atallah, 2002), although in the latter type of cooperation commercially sensitive information may also leak out to competitors through common suppliers or customers.

The management literature typically analyzes cooperation from a transaction costs and resource-based framework (Tyler and Steensma, 1995). The transaction cost approach describes alliances as a hybrid form of organization combining aspects of hierarchical transactions within the firm and arm's-length transactions in the market place. Cooperation may reduce transaction costs through a better control and monitoring of technology transfer than on arm's length markets, while the inherent reciprocal relationship and "hostage" exchange between partners with complementary capabilities can minimize opportunism (e.g. Pisano, 1990; Hennart, 1988). The resource-based view of the firm suggests that the rationale for partnerships is the value-creation potential of pooling firms' resource bases. Cooperation is viewed as a mechanism to maximize firm value through effectively combining the resources of the partners by exploiting complementarities (Kogut, 1988; Das and Teng, 2000; Hagedoorn et al., 2000).

The management literature further provides helpful insights to pinpoint different motives and problems for R&D cooperation with different types of partners. The importance of lead customers in helping to define innovations and, therefore, to reduce the risk associated with their market introduction, has already been long recognized (Von Hippel, 1988; Schmookler, 1966). This provides a major motive for cooperation with customers in the development of particularly novel or complex new products (Tether, 2002). The goal of vertical cooperation with suppliers has been linked more to cost reduction, related to the tendency of firms to focus on core competences, outsource activities to suppliers and/or develop close collaborative arrangements with suppliers to reduce costs.[1]

[1] See also Atallah (2002). Suzuki (1993) finds that collaboration with suppliers within Japanese vertical business groups has a significant impact on cost reduction.

Recent work on industry–science collaboration has shown that cooperation between universities and industry has intensified (e.g. Hall et al., 2000). Firms look for public science as one of the external sources for rapid and privileged access to new knowledge and to increase the firms' engineers understanding of scientific developments. Science is more important as source of information for innovation in those science-based technology fields where new breakthrough innovations can be achieved and transferred to applied research and translated into new products and processes (e.g. Klevorick et al., 1995). In particular, when coupled with the available public funding opportunities, cooperation arrangements with academia are increasingly seen as an inexpensive source of specialist knowledge. Furthermore, the more generic nature of research projects with universities and research institutes involves fewer appropriation issues as compared to the more commercially sensitive content when cooperating in later development stages with customers/suppliers and—a fortiori—competitors (Cassiman and Veugelers, 2002).

In summary, the IO literature suggests that spillovers increase incentives to cooperate in particular if cooperation allows firms to enhance knowledge transfers among the collaborating partners. However, if incoming spillovers are associated with outgoing spillovers they have a more ambiguous effect on competitor collaboration as collaborating product market rivals benefit more from a firm's R&D effort. These appropriability considerations are much less important for vertical (supplier, customer) and institutional collaboration. Firms that increase their absorptive capacity through larger R&D investments are more likely to benefit from cooperation. In case of competitor cooperation, higher R&D investments lead to a greater pool of know-how on which the partner firms can potentially free-ride. The management literature indicates that different R&D partnerships may be engaged in for different purposes, with customer cooperation more focused on bringing to market adapted or improved products, supplier cooperation more focused on cost reduction, and university cooperation focused on new generic technologies and product families in sectors with greater technological opportunities.

2.2. Empirical research

There is an expanding empirical literature on the determinants of R&D cooperation. Given the difficulties in empirically assessing the profitability of R&D cooperation, most studies indirectly focus on explaining the frequency of occurrence of R&D cooperation to assess which characteristics are more beneficial to R&D cooperation.[2] Product complementarities among partners are found to positively affect the likelihood of R&D cooperation (Röller et al., 1997). Sakakibara (1997) finds that access to complementary knowledge is one of the most important objectives of establishing government sponsored research cooperations in Japan. This is in line with Narula's (2002) finding that access to complementary technology has the highest importance among motives for R&D

[2] See e.g. Monjon and Waelbroeck (2003) for a cross section analysis of the impact of different types of R&D cooperation on firm innovativeness.

cooperation for European ICT firms. Tyler and Steensma (1995) find that the ability to share cost and risks is important for the success of R&D cooperation. Fritsch and Lukas (2001), Röller et al. (1997) and Colombo and Garrone (1996) show a positive impact of firm size and R&D intensity of firms on R&D cooperation. This is reminiscent of the absorptive capacity idea that stresses the need to have in-house (technological) knowledge to optimally benefit from R&D cooperation.[3] Another line of empirical research has specifically taken into account the simultaneous relationship between R&D cooperation and in-house R&D activities. These studies have generally confirmed that, controlling for this simultaneity, internal R&D investments still have a positive impact on the probability or intensity of cooperation (Colombo and Garrone, 1996; Veugelers, 1997; Cassiman and Veugelers, 2002; Becker and Dietz, 2002).

The relationship between R&D spillovers and R&D cooperation, as well as the potentially different determinants of alternative types of cooperation, have remained largely unexplored in empirical work. Empirical work on R&D cooperation distinguishing between the types of cooperation partner has often singled out specific types of partnerships, not taking into account the simultaneity among different types of cooperation. Cassiman and Veugelers (2002) analyzed the impact of spillovers on cooperation but could only distinguish between research institutes and vertically related partners. They found that higher incoming public spillovers (knowledge available from public sources) positively affect the probability of cooperating with research institutes and universities. Greater appropriability of results of the innovation process (lower outgoing spillovers) increased the probability of cooperating with customers or suppliers, but was unrelated to cooperative agreements with research institutes. Kaiser (2002) applied a nested logit framework to analyze firms' R&D cooperation in the German service sector, distinguishing between the decision whether or not to cooperate and the decision which type of cooperation to choose. Here a distinction could only be made between vertical cooperation and a mixed category of university and competitor cooperation. The cooperation model had weak explanatory power and neither measures of spillovers nor variables proxying the research base of the firm were found to have a statistically significant impact.

Tether (2002), using UK CIS data, investigated the patterns of cooperation between innovating firms and different potential collaboration partners in a series of independent logistic regressions. He found firm size to be most influential in cooperation with suppliers and universities, but less so for cooperation with customers. Engagement in own R&D had a clear positive effect on all types of cooperation. Leiponen (2001) used a classification into four types of cooperation: competitors, suppliers, customers, and universities. The probit results for cooperation suggested that R&D intensity, firm size and membership of a larger group generally had positive impacts on the four types of cooperation. The results also showed higher probabilities of cooperation with universities (customers) in industries where spillovers from universities (customers) were important, but generally lower probabilities in

[3] This parallels the argument in Veugelers (1997) for including a permanent R&D variable as facilitator of appropriation of external knowledge.

industries where suppliers were an important source of incoming spillovers.[4] The latter result is consistent with the notion that in 'supplier dominated' industries (Pavitt, 1984), firms are more dependent on technological development coming from their suppliers and are less likely to engage in major product innovations, focusing on incremental process improvements requiring little formal collaboration. The analysis did not include firm-specific data on the importance of incoming spillovers.

3. Empirical model, data, and estimation method

This paper contributes to the growing empirical literature on R&D cooperation by estimating a multivariate probit model that jointly determines the decision to engage in four types of R&D cooperation: competitor, customer, supplier and (research) institutional R&D partnerships. While the nested logit approach used in previous work (Kaiser, 2002) does not account for the fact that firms can engage simultaneously in multiple cooperation agreements, the multivariate probit specification allows for systematic correlations between choices for the different cooperation types. Such correlations may be due to complementarities (positive correlation) or substitutabilities (negative correlation) between different cooperation types, e.g. the benefit of horizontal cooperation may be larger if the firm also cooperates with universities or research institutes. Positive correlation also arises if there are unobservable firm-specific characteristics that affect several cooperation decisions but that are not easily captured by measurable proxies, such as the stock of tacit knowledge. The multivariate probit model takes these correlations into account, although it is not able to distinguish between the two sources of correlation. If correlation exists, the estimates of separate (probit) equations of the cooperation decisions are inefficient.

Our panel dataset is constructed from two consecutive CIS surveys performed by Statistics Netherlands in 1996 and 1998, which allows us to take past values of independent variables (in 1996) to explain the existence of R&D cooperation in 1997–1998. This setup reduces simultaneity bias inherent to cross section analysis in a single year. According to the theoretical IO literature, the two main explanatory variables that are most likely to be simultaneously determined with the cooperation decision are incoming spillovers and R&D intensity: R&D investments may increase if cooperation makes own R&D activities more effective, and incoming spillovers are likely to increase through cooperation if only because of information sharing among partners. In our model setup using 2-year lagged variables such bias will be reduced, but it will not be completely eliminated. If R&D partnerships last longer than 2–3 years, the R&D intensity and the importance of incoming spillovers in 1996 are still partly affected by those R&D partnerships that were formed in or before 1996 and still in existence in 1998. In order to further reduce such potential simultaneity bias we follow two routes. First, we correct the spillover measures for systematic impacts of past or existing cooperation. The 1996 spillover measures are also affected by purposeful informational exchanges in past R&D

[4] Fontana et al. (2004) find that in addition to size and R&D intensity, firm openness to the external environment (measured as reliance on publications for acquiring knowledge) affects the probability, but not the level, of cooperation with universities.

partnerships. We adjust the spillover measure by regressing the 1996 spillover variable on the corresponding cooperation variables in 1996 and a set of industry dummies. The residuals of these equations are then included as spillovers that are not due to past cooperation. Secondly, we examine the determinants of cooperation among a sub-sample of firms lacking any cooperative agreements in 1996. This model of new cooperation allows us to test for the robustness of the impact of 1996 R&D intensity and incoming spillovers on the possible establishment of new R&D partnerships in the 1997–1998 period. Although this approach reduces the potential simultaneity between R&D (cooperation) and spillovers to a minimum,[5] its results need to be interpreted with care. Restricting the sample to firms without any type of R&D cooperation in 1996 among the set of innovating firms in 1996 excludes persistently cooperating firms—those firms that are most likely to engage in R&D partnerships. This selection itself creates a sample selection bias and reduces the number of observations considerably, which is likely to bias standard errors upwards. However, if tests on this lower tail of firms inclined to cooperate replicate the results using the complete sample, we take this as a strong indication of the robustness of the results.

3.1. Data

The dataset used in this paper contains data at the establishment level (in this paper referred to as 'firms') from the CIS surveys in the Netherlands in 1996 and 1998. To create a panel data set, the 6315 innovating firms in the 1998 CIS survey are matched with the information on these firms in the 1996 survey: 2353 firms could be linked to the 1996 survey and were classified as innovating firms in that survey.[6] Due to missing values for some of the 1996 explanatory variables the number of observations used in the final sample is 2149. The distribution of cases for the four equations by the dependent variable is presented in Table 1. There were 627 firms with R&D cooperation of some type among the 2149 innovating firms in 1998. Vertical cooperation is most prominent: supplier only (68), customer only (64), combined (71) or both combined with institutional cooperation (66). A total of 72 firms have cooperative agreements of all four types. The model restricting the sample to firms with newly formed cooperative agreements or no R&D cooperation at all uses a smaller sample of 1484 firms, in which the number of firms with cooperation in 1998 is substantially reduced to 269.

3.2. Dependent and independent variables

The dependent variables of the model are four dummy variables equal to one if the firm was engaged in 1998 in an active R&D partnership with competitors, suppliers, clients, or

[5] The new cooperation model eliminates the potential reverse causality effect from R&D cooperation to spillovers and R&D, but it does not completely do away with unobserved heterogeneity bias: even among firms that are not cooperating in 1996, there may be a correlation between the profitability of cooperation, R&D intensity, and spillovers due to unobserved firm characteristics.

[6] Information on explanatory variables is only available in the survey if firms are classified as innovating firms. Since we did not correct for a possible sample selection bias on innovating firms, the results need to be interpreted as applicable to innovation active firms only.

Table 1
Distribution of cooperation cases

Cooperation type	Number of cases in full sample	Number of cases in new cooperation sample
None	1542	1215
Institutional only	39	19
Supplier only	68	38
Supplier and institutional	42	17
Customers only	64	32
Customers and institutional	27	4
Customers and suppliers	71	35
Customers, suppliers and institutional	66	20
Horizontal only	43	26
Horizontal and institutional	31	13
Horizontal and suppliers	8	5
Horizontal, suppliers, institutional	17	4
Horizontal and customers	8	4
Horizontal, customers, institutional	20	5
Horizontal, customers, suppliers	31	17
All four	72	30
Total	2149	1484

research institutes and/or universities (institutional cooperation), respectively. The model includes a range of explanatory variables supported by our review of theoretical work and previous empirical models, but remains rather explorative given the lack of straightforward theoretical predictions available. Since it is our interest to explore the varying determinants of R&D cooperation between the types, we include each explanatory variable in all four equations to test whether some variable impacts cooperation of one type but not another. The descriptive statistics for the samples are presented in Table 2. A detailed description of the variables is provided in Appendix A and a correlation table in Appendix D.

We include firm-specific and type-specific direct measures of the importance of *incoming spillovers*.[7] The firms are asked in the CIS survey to rate the importance of various external sources of information for the firm's innovation activities. We include the scores of importance of information from competitors, suppliers, customers, and the average of scores of information from universities and research institutions (institutional incoming spillovers). Our prediction is that R&D cooperation of a given type is more likely if incoming spillovers coming from the potential partners are more important. As noted supra, we estimate the impact of exogenous spillovers, i.e. not due to purposeful informational exchanges that arise through past cooperation. The adjusted spillovers are the residuals obtained from auxiliary regressions of the spillover variables in 1994–1996 on the corresponding cooperation variable and the set of industry dummies.[8] In addition,

[7] Several alternative indirect measures of spillovers have been used in previous empirical work, e.g. based on uncentered correlation (Jaffe, 1986; Adams, 1990), Euclidean distance, and geographic distance. According to a comparative study of various spillover measures by Kaiser (2002) both uncentered correlation and direct measures (used in our model) appear to capture spillovers quite accurately.

[8] The auxiliary results of the spillover variables in 1996 on the corresponding cooperation variable and the set of industry dummies are presented in Appendix C.

Table 2
Descriptive statistics

	Full sample			New cooperation sample		
	Sample mean (n=2149)	Mean non-cooperating firms (n=1542)	Mean cooperating firms (n=607)	Sample mean (n=1484)	Mean non-cooperating firms (n=1215)	Sample mean (n=269)
Competitor incoming spillovers	1.108	1.071	1.203	1.025	1.022	1.037
Customer incoming spillovers	1.358	1.316	1.247	1.244	1.239	1.268
Supplier incoming spillovers	1.179	1.152	1.247	1.135	1.117	1.219
Institutional incoming spillovers	0.444	0.361	0.655	0.341	0.314	0.462
Public incoming spillovers	0.631	0.584	0.760	0.556	0.544	0.611
Industry outgoing spillovers	0.711	0.704	0.729	0.705	0.703	0.714
R&D intensity	0.029	0.025	0.039	0.024	0.023	0.028
R&D intensity squared	0.004	0.003	0.005	0.003	0.003	0.003
Firm size	4.459	4.307	4.841	4.273	4.203	4.569
Industry average innovative firm size	0.080	0.077	0.088	0.076	0.075	0.079
Organizational capability constraint	0.042	0.032	0.067	0.033	0.030	0.050
Cost constraint	0.061	0.054	0.080	0.047	0.048	0.045
Risk constraint	0.101	0.081	0.151	0.075	0.069	0.100
Speed of technological change	0.501	0.491	0.526	0.495	0.493	0.506
Service dummy	0.350	0.359	0.328	0.351	0.344	0.383
Internal knowledge flows	0.539	0.564	0.474	0.576	0.592	0.505
Part of a domestic group	0.471	0.446	0.537	0.438	0.431	0.468
Foreign multinational	0.280	0.274	0.294	0.275	0.273	0.283
R&D subsidy	0.434	0.377	0.578	0.356	0.342	0.416

we control for other incoming spillovers that may affect cooperation decisions, by including a measure of the importance of spillovers stemming from public sources (*public incoming spillovers*): the average of scores of the importance of patents, databases, trade literature and fairs.[9]

A shortcoming of the Dutch version of the CIS questionnaire is the lack of a question to construct a measure of firm-specific outgoing spillovers or appropriability. Instead, we proxy outgoing spillovers through an industry level variable, taking the average of horizontal spillovers of firms in the same industry (cf. Leiponen, 2001). The variable *industry outgoing spillovers* is constructed at the two-digit industry level and measures the mean of average scores of information obtained from competitors and patents reported by

[9] The four spillover sources included in the model identify directly the *source* of the information in line with theoretical models and identify most relevant potential sources of information, regardless of the channel of information transfer. The public spillover measure, on the other hand, identifies the *channel* of the spillover (databases, trade fairs, patents) rather than the source and is likely to overlap with the direct measures (if information from competitors is important, it may reach the firm through patents or trade shows). Inclusion nevertheless controls for spillovers that may affect cooperation but are not covered by the direct source specific measures.

all competing firms in the industry. If firms in the industry report that they obtain important information from competitors and through published patents (filed among others by competitors), appropriability conditions in the industry are weak and this may negatively affect the propensity to cooperate. *Industry outgoing spillovers* is expected to impact horizontal cooperation negatively since it measures spillovers to same-industry competitors.

We include R&D *intensity* and R&D *intensity squared*, allowing for a non-linear impact of R&D (measured as the number of R&D personnel over total personnel) as explanatory variables. Increasing levels of R&D intensity up to a point will be closely correlated with absorptive capacity. Further increases may be less effective in expanding absorptive capacity due to diminishing scale economies or may be associated with the conduct of idiosyncratic in-house R&D efforts. Hence, we expect a concave relationship, with the marginal effect of R&D intensity declining. Following previous theoretical and empirical work, we also expect the relationship between R&D intensity and R&D cooperation to differ depending on the type of cooperation partner. In case of horizontal cooperation, the positive relationship is predicted to be weaker than in case of vertical or institutional cooperation. A large R&D base is likely to be associated with stronger proprietary knowledge and greater risks for the firm of leakage of information in cooperation with competitors. This risk is less important in case of cooperation with research institutes and suppliers and customers.

In line with the existing literature, we also include *firm size* (the logarithm of the number of the firm's employees) as an explanatory variable. We expect that the larger the firm, ceteris paribus, the more likely it is that it engages in R&D cooperation. For any given level of R&D intensity, larger firms perform more R&D and are more likely to possess the necessary absorptive capacity to benefit from R&D cooperation. Larger firms are also more likely to be engaged in multiple technologies that may require various R&D partnerships. The largest absorptive capacity and R&D intensity is likely to be required to absorb scientific knowledge stemming from universities (Leiponen, 2001).

The propensity to engage in cooperation is also affected by the presence or absence of partner firms with complementary resources in R&D, and the ease with which suitable partners can be located. Both are likely to be related to the presence of large innovating firms in the industry. We aim to control for this influence in case of horizontal cooperation by including the variable *industry average innovative firm size* (mean of turnover of all innovating firms in the two-digit industry). We expect a positive impact, but only on horizontal cooperation.[10]

We include three firm-specific measures that aim to capture factors hampering the innovation process of the firm, potentially pushing the firm to search for cooperation partners. This follows the perspective of the management literature on R&D alliances on

[10] The average size of innovative firms in the industry is correlated with market concentration, such that its impact may also pick up an effect of industry concentration on cooperation (see e.g. Katsoulacos and Ulph (1998) on the potential anti-competitive effects of research joint-ventures). However, including a C4 concentration ratio in the model in addition to the innovative firm size variable did not change the latter's significance while the impact of the C4 variable was not significantly different from zero for any of the cooperation types.

the various motivations for partnerships. *Cost constraint* captures bottlenecks caused by lack of financial resources or high costs of new innovation projects. *Risk constraint* captures bottlenecks caused by financial uncertainty (profitability) or uncertain market conditions. *Organizational capability constraint* is an average of ranked scores of the bottlenecks that relate to the firm's shortage of (R&D) personnel, lack of knowledge, and organizational rigidity that cause the delay or abandonment of new innovation projects or the failure to start these. These constraints are expected to provide an incentive for firms to cooperate to reduce the costs, risks, and organizational constraints of R&D.

In case of rapid technological developments it is likely that firms want to be active in multiple technological trajectories which buys them options to expand in the technology directions that eventually prevails (e.g. Tyler and Steensma, 1995). Such rapid technological developments are most likely to be a feature of 'science based' industries characterized by strong technological opportunities and relying on scientific developments in scientific institutions (Leiponen, 2001; Klevorick et al., 1995; Pavitt, 1984). To proxy for *the speed of technological change* we take the ratio of the number of firms in the two-digit industry that reported that they had introduced products new to the industry to the number of firms that did not introduce new products, weighted by firm size. We expect that firms operating in industries characterized by rapid introduction of completely new products have a higher incentive to engage in cooperation, but primarily with research institutions. One problem with this measure is that the question on new products may not adequately pick up technological change in the services sector. To get an unbiased impact of speed of technological change we include a *service dummy*. If service sectors are more technologically active than the speed of technological change proxy suggests, the service dummy will have a positive sign correcting for this bias in the variable. Naturally, the service dummy in addition will pick up any systematic differences in cooperation between manufacturing and service sectors beyond this bias.[11]

We also control for the relative importance of information used in the innovation process coming from other establishments that are part of the same firm group. *Internal knowledge flows* is the ratio of the score on the importance of information from other firms within the group to the importance of external spillovers (sum of scores of all external sources of information). We expect a negative impact on cooperation, as firms that rely more on internally generated know-how, perhaps because of unique innovation processes or technologies, are less likely to see benefit in cooperation with external partners. Table 1

[11] One may expect more differences between sectors in the propensity to cooperate due to the divergent technological trajectories (e.g. Pavitt, 1984; Leiponen, 2001). We ran separate models for manufacturing and services firms only but found remarkably little differences in explanatory factors. To check the consistency of the estimation results further, we estimated an alternative model including a full set of industry dummies. Since performing this test within the multivariate probit framework (a four-equation model with 17 dummies) is exceedingly burdensome computationally, we could only run tests for the individual probit equations. In three out of four cases (the exception was supplier cooperation), the LR test did not reject the industry variable model (the LR tests were 17.6, 27.6, 20.1 and 12.2 for competitor, supplier, customer and institutional cooperation, respectively). With the exception of a higher estimated standard error for supplier spillovers, the spillover and R&D variables remained robust. We therefore present the more informative industry variable model.

indeed shows that the mean of the internal knowledge flow variable is lower for cooperating firms than for non-cooperating firms, while the means for the incoming spillover variables are higher for cooperating firms.

We include a dummy for firms that are *part of a domestic group*. It takes the value 1 if an establishment is part of a larger firm grouping. Firms that are part of a larger group may draw on group financial and technological resources that make them more attractive as cooperation partners, but at the same time such firms may have fewer incentives to cooperate with outside partners.[12] In addition, we include a dummy variable *multinational firm*, taking the value 1 if the headquarters of the group to which the firm belongs is located outside the Netherlands.[13]

Finally, we control for the possible role of R&D subsidies, by including a dummy taking the value one if the firm stated that it received an R&D *subsidy*. On the one hand, R&D subsidies can moderate financial bottlenecks for the firm's R&D activities and hence reduce the need to cooperate to share costs. On the other hand, given that a variety of R&D national and European subsidy schemes are aimed particularly at promoting R&D cooperation, the availability of R&D subsidies may make the difference in motivating firms to establish R&D partnerships. These schemes often target pre-competitive and basic R&D cooperation (e.g. with universities) but are less often aimed at R&D partnerships with competing firms. However, we cannot measure the availability of subsidy schemes but only the actual receipt of subsidies by the firms. If indeed R&D subsidies are conditional on cooperation, there will be a strong positive correlation between subsidies and cooperation but this is due to a simultaneous relationship between the two rather than a causal effect of subsidies. By comparing results of the full model with results of the new cooperation model we will be able to further examine the different effects of subsidies.

3.3. Model and estimation method

Our model consists of four binary choice equations. These choices are for horizontal (competitors), customer, supplier and institutional (universities, research centers) cooperation, respectively. We have four binary dependent variables y_1, y_2, y_3 and y_4 where

$$y_{i,k} = \begin{cases} 1 \text{ if } x_{i,k}\beta_k + \omega_{i,k} > 0 \\ 0 \text{ otherwise,} \end{cases} \qquad k = 1,\ldots,4; \quad i = 1,\ldots,N$$

and $(\omega_1\omega_2\omega_3\omega_4) \sim N\,(0, \Sigma)$ where Σ is the covariance matrix of the error terms. The error terms are likely to be correlated if only because of omitted variables in these choice processes. If one does not take this into account, for example with four separate probit

[12] Note that the internal spillover variable already corrects for a potential greater inclination towards intra-group rather than external R&D cooperation for firms.

[13] A sizeable proportion (27%) of the establishments are owned by foreign multinationals. The dependent variable includes a limited number of international R&D partnerships. We also ran the models limiting the analysis of R&D cooperation to domestic cooperation. As expected, we found a stronger negative impact of the multinational firm dummy, but no important changes in the overall results.

equations, inefficient estimators result. To capture the possible interdependence of yes-or-no decisions we employ a multivariate limited dependent variable (multivariate probit) model. The computation of the maximum likelihood function based on a multivariate normal distribution requires multidimensional integration. Simulation methods have been proposed (see Train, 2002, chapter 5) to approximate such a function. The GHK simulator (Geweke et al., 1997; Hajivassiliou et al., 1996) has been a particularly popular choice[14]. We will follow the GHK simulator approach and choose a simulated maximum likelihood estimator that also offers possibilities of cross-equation tests and restrictions in parameters.[15]

4. Empirical results

Table 3 reports the results of the multivariate probit model for the complete sample of 2149 observations. First of all, we note that the correlation coefficients of the error terms in the multivariate probit are positive, ranging from 0.636 to 0.834, and highly significant.[16] This supports the notion of interdependence between the different cooperation decisions, which may be due to complementarity in R&D cooperation strategies but also to omitted firm-specific factors affecting all types of cooperation. A second finding is that the estimated coefficients differ substantially across the equations, indicating the appropriateness of differentiating between cooperation types. In order to formally test this, we estimated a constrained specification with all slope coefficients forced to be equal. The likelihood ratio test statistic was 411.57 (76 degrees of freedom), decisively rejecting the null hypothesis of equal slope coefficients. This result strongly indicates the heterogeneity in cooperation strategies and, consequently, the unsuitability of aggregating them into one cooperation variable (cf. Fritsch and Lukas, 2001; Janz et al., 2003).

The hypothesis that source-specific incoming spillovers positively affect the probability of cooperation is confirmed. All spillover variables have significantly positive impacts on the respective cooperation type. The results suggest that firms tend to gravitate to the cooperation type that has the potentially highest value in terms of incoming knowledge. *Customer* and *supplier incoming spillovers* are significant the 5% level, while *competitor incoming spillovers* is significant at the 10% level (two-sided), but clearly smaller in impact. This finding is consistent with the theoretical literature on R&D cooperation which predict a weaker relationship between spillover levels and cooperation for competing firms

[14] Another possibility is to apply GMM along the lines of the estimator proposed by Bertschek and Lechner (1998). This estimator is shown to have good small sample properties and to have limited efficiency loss compared to maximum likelihood. Greene (2004), using the same data as Bertschek and Lechner (1998), shows that maximum likelihood estimates using the GHK simulator are very close to GMM estimates.

[15] The results are obtained with a Stata routine due to Cappellari and Jenkins (2003) and are based on 200 random draws. Hajivassiliou and Ruud (1994) prove that under regularity conditions the simulated maximum likelihood estimator is consistent when both the number of draws and observations goes to infinity. Gourieroux and Monfort (1996) show that it has the same limiting distribution as the (infeasible) maximum likelihood estimator if in addition the ratio of the square root of the number of observations over the number of draws approaches zero.

[16] For comparison we also report the results when using four independent univariate probits in Appendix B.1.

Table 3
Results of multivariate probit analysis of R&D cooperation

	Competitor cooperation	Customer cooperation	Supplier cooperation	Institutional cooperation
res. Competitor incoming spillovers	0.079 (0.047)*	−0.032 (0.042)	0.032 (0.042)	0.007 (0.046)
res. Customer incoming spillovers	0.015 (0.044)	0.209 (0.039)***	0.007 (0.039)	−0.000 (0.043)
res. Supplier incoming spillovers	−0.057 (0.046)	0.030 (0.041)	0.239 (0.040)***	−0.051 (0.045)
res. Institutional incoming spillovers	0.367 (0.070)***	0.223 (0.064)***	0.211 (0.065)***	0.722 (0.065)***
Public incoming spillovers	0.010 (0.076)	0.000 (0.069)	−0.013 (0.069)	0.104 (0.073)
Industry outgoing spillovers	−0.476 (0.305)	0.402 (0.285)	−0.007 (0.281)	−0.199 (0.301)
R&D intensity	2.117 (1.649)	4.179 (1.530)***	3.219 (1.606)**	4.588 (1.599)***
R&D intensity squared	−3.860 (5.108)	−12.440 (5.159)**	−11.729 (5.669)**	−11.714 (5.229)**
Firm size	0.145 (0.031)***	0.137 (0.029)***	0.153 (0.029)***	0.215 (0.032)***
Industry average innovative firm size	1.070 (0.394)***	0.299 (0.409)	0.372 (0.387)	0.778 (0.420)*
Organizational capability constraint	−0.163 (0.259)	0.103 (0.222)	0.730 (0.214)***	0.428 (0.228)*
Cost constraint	0.171 (0.341)	0.247 (0.304)	−0.525 (0.314)*	0.683 (0.324)**
Risk constraint	0.351 (0.153)**	0.188 (0.139)	0.328 (0.138)**	−0.060 (0.150)
Speed of technological change	0.547 (0.242)**	0.605 (0.227)***	0.169 (0.224)	1.067 (0.251)***
Service dummy	0.238 (0.093)**	0.187 (0.086)**	0.095 (0.086)	0.031 (0.094)
Internal knowledge flows	−0.023 (0.070)	−0.031 (0.066)	−0.156 (0.071)**	−0.109 (0.077)
Part of a domestic group	−0.034 (0.080)	0.144 (0.072)**	0.192 (0.072)***	0.048 (0.078)
Foreign multinational	−0.231 (0.092)**	−0.033 (0.079)	0.030 (0.078)	−0.084 (0.086)
R&D subsidy	0.021 (0.087)	0.174 (0.078)**	0.220 (0.078)***	0.236 (0.083)***
Constant	−2.090 (0.264)***	−2.584 (0.250)***	−2.049 (0.240)***	−2.949 (0.271)***

	Rho1	Rho2	Rho3
Rho/2	0.649 (0.035)***		
Rho/3	0.636 (0.036)***	0.834 (0.020)***	
Rho/4	0.744 (0.031)***	0.735 (0.029)***	0.784 (0.026)***
Observations	2149		
LL	−2536.12		
Wald χ^2 (76)	521.67		
LL_0 (10)[a]	−2843.826		
LR χ^2 (76)[b]	615.41		

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: $\chi^2(6) = 1234$, Prob>$\chi^2 = 0.0000$.
Standard errors in parentheses.

[a] Denotes log-likelihood value (*df*) of the "naïve" model, containing only the intercepts.

[b] LR test is between the full model and the "naïve" model.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

compared with vertically related or unrelated firms (e.g. Atallah, 2002). This result holds when incoming and outgoing spillovers are not separately identified. We may measure this weaker impact on competitor cooperation because the model may not sufficiently correct for outgoing spillovers at the firm level.[17] *Institutional incoming spillovers* have a positive and strongly significant effect in all four cooperation equations, and, as expected, the largest impact on institutional cooperation. The impact on vertical (both customer and supplier) cooperation and horizontal cooperation suggests that institutional incoming spillovers are more generic in nature, improving the general effectiveness of the firm's R&D activities and stimulating vertical and horizontal cooperation as well. This is consistent with the notion that for firms for which science is more important as a source of knowledge, there exist greater technological opportunities, enhancing the effectiveness of various innovation strategies (Klevorick et al., 1995; Leiponen, 2001). Also, the importance of this type of incoming spillovers may reflect that the firms are engaged in basic R&D, such that information sharing within R&D cooperation is more effective (Katsoulacos and Ulph, 1998).

Industry outgoing spillovers has the expected negative impact on horizontal cooperation, but it just fails to reach conventional two-sided significance levels.[18] With the source-specific spillovers included, there is no additional impact discernable of *incoming public spillovers*, perhaps because these measure partly the channel through which spillovers of various sources reach the firm and do not constitute new sources of information.

The effect of R&D *intensity* on the probability of cooperation is positive and concave as expected, with the linear term positive and the quadratic term negative, but there are differences between cooperation types. A robust concave relationship is estimated for supplier, customer, and institutional cooperation, with the maximum impact reached at rather high levels between 0.137 and 0.196 (percentage of R&D employees over total employees). For competitor cooperation both terms are insignificant with the coefficients substantially smaller than in the other cooperation equations. On the other hand, the F-test on removing both R&D intensity terms from the horizontal cooperation equation is rejected and a specification in which the quadratic term is dropped renders a significantly positive coefficient on the linear term (not reported here). Overall, these findings suggest a positive but weaker impact of R&D intensity on competitor cooperation. This is consistent with the notion that R&D-intensive firms in horizontal partnerships also face greater risks of leakage of their proprietary knowledge, which may outweigh the potential benefits of knowledge transfers due to cooperation.

Firm size is positive and significant in each of the equations, with the coefficient highest in case of institutional cooperation. Larger firms are more likely to have the critical size and absorptive capacity required to engage in R&D cooperation, and this effect is strongest for cooperation with universities. The *industry average innovative firm size* variable is positive and significant in the horizontal cooperation equation as hypothesized, and also marginally (10%) in the institutional cooperation equation. The availability of

[17] The outgoing spillovers variable is measured at the industry level and hence not fully representative for the specific appropriability conditions for individual firms within the industry. An alternative explanation may be that firms rating horizontal incoming spillovers as important are more likely to be technology followers rather than leaders and are as such less attractive R&D partners.

[18] The coefficient does reach significance in the univariate probit model reported in Appendix B.1.

large innovating potential partners (nearby) appear to stimulate horizontal cooperative R&D.[19]

The *organizational capability constraint* is significantly positive in the supplier and institutional cooperation equations. The *risk constraint* variable is significant and positive for both the competitor and supplier cooperation decisions, while the *cost constraint* variable has a positive and significant impact on institutional cooperation but a negative impact on supplier cooperation. Overall, the results confirm that the various types of constraints induce R&D cooperation strategies, while commercial risk sharing and access to complementary knowledge when faced with internal resource constraints appear to be the most consistent motivation for firms to seek R&D partners. The various constraints do not affect customer cooperation, perhaps because the goal of this type of cooperation is often to improve market acceptance or design features of new products, rather than to alleviate internal constraints.

The *speed of technological change* variable is found to have a positive and significant effect for the horizontal, customer and institutional cooperation decisions, but not for supplier cooperation. Firms in industries with shorter product life cycles and rapid technological developments are more inclined to cooperate with rivals or/and customers or to cooperate in generic technologies with research institutes and universities. The largest impact is estimated for institutional cooperation, consistent with the notion that for firms facing rapid technological developments and greater technological opportunities, collaboration with universities and research institutes is essential for innovative success. The *speed of technological change* variable may have been less adequately measured for the service industries and, therefore, we incorporated a *service dummy* expecting a positive impact if this dummy corrects for under-reported speed of technological change. The service dummy has the expected positive effect in the customer and competitor cooperation equations.

The effect of the *internal knowledge flow* variable is negative as expected in each of the four equations, but is only significant in the supplier equation. Firms that are *part of a group* are more likely to cooperate with suppliers and customers, but not with competitors or research institutions. The dummy for a *multinational firm* is negative and significant in the competitor cooperation equation: affiliates of multinationals are less likely to cooperate with local rivals, but are not less inclined to engage in vertical or institutional types of cooperation. Finally, the R&D *subsidy* variable has a positive and significant impact on vertical (both customers and suppliers) and institutional cooperation, which may suggest that subsidies promote pro-competitive R&D partnerships.

4.1. New R&D cooperation

The multivariate probit results obtained on the sub-sample of firms not (yet) cooperating in 1996 are presented in Table 4.[20] The results are broadly in line with

[19] Since the Netherlands is a small country, the majority of potential partners is in geographical proximity: The large majority of firms is located in a circle of less than 100 km around Utrecht. Perhaps in industries in which the average innovative firm size is larger, there is also a greater probability of R&D consortia involving large firms and universities.

[20] For comparison, the results from the four binary probits on this sample are reported in Appendix B.2.

Table 4
Multivariate probit results for new R&D cooperation

	Competitor cooperation	Customer cooperation	Supplier cooperation	Institutional cooperation
res. Competitor incoming spillovers	0.105 (0.062)*	−0.033 (0.057)	0.024 (0.055)	0.015 (0.064)
res. Customer incoming spillovers	0.031 (0.058)	0.181 (0.052)***	0.012 (0.050)	−0.032 (0.058)
res. Supplier incoming spillovers	−0.033 (0.061)	−0.018 (0.056)	0.212 (0.053)***	0.009 (0.062)
res. Institutional incoming spillovers	0.266 (0.100)***	0.186 (0.090)**	0.128 (0.089)	0.671 (0.088)***
Public incoming spillovers	−0.192 (0.117)	−0.131 (0.099)	−0.040 (0.095)	−0.116 (0.110)
Industry outgoing spillovers	−0.039 (0.428)	0.457 (0.414)	0.154 (0.404)	0.132 (0.431)
R&D intensity	2.471 (2.736)	3.874 (2.247)*	5.865 (2.492)**	7.299 (2.882)**
R&D intensity squared	−8.693 (9.920)	−10.665 (7.684)	−21.333 (10.376)**	−29.678 (12.981)**
Firm size	0.104 (0.046)**	0.180 (0.043)***	0.174 (0.042)***	0.195 (0.049)***
Industry average innovative firm size	0.913 (0.546)*	−0.694 (0.695)	−0.718 (0.669)	0.495 (0.661)
Organizational capability constraint	−0.591 (0.430)	−0.010 (0.325)	0.802 (0.296)***	0.570 (0.325)*
Cost constraint	−0.405 (0.572)	−0.501 (0.500)	−0.819 (0.502)	−0.723 (0.569)
Risk constraint	0.400 (0.236)*	0.194 (0.216)	0.253 (0.201)	−0.136 (0.244)
Speed of technological change	0.044 (0.336)	0.548 (0.307)*	0.213 (0.296)	1.213 (0.351)***
Service dummy	0.179 (0.125)	0.283 (0.114)**	0.279 (0.111)**	0.113 (0.129)
Internal knowledge flows	−0.052 (0.091)	−0.080 (0.087)	−0.211 (0.096)**	−0.355 (0.130)***
Part of a domestic group	−0.202 (0.108)*	0.086 (0.097)	0.138 (0.095)	−0.032 (0.107)
Foreign multinational	−0.233 (0.127)*	−0.071 (0.107)	−0.091 (0.105)	0.074 (0.118)
R&D subsidy	−0.184 (0.123)	0.057 (0.106)	0.016 (0.105)	−0.051 (0.118)
Constant	−1.789 (0.346)***	−2.745 (0.336)***	−2.303 (0.320)***	−3.010

	Rho1	Rho2	Rho3
Rho/2	0.728 (0.043)***		
Rho/3	0.745 (0.040)***	0.890 (0.022)***	
Rho/4	0.834 (0.034)***	0.747 (0.042)***	0.811 (0.033)***
Observations	1484		
LL	−1234.62		
Wald χ^2 (76)	235.03		
LL_0 (10)[a]	−1379.33		
LR χ^2 (76)[b]	289.40		

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: $\chi^2(6) = 735.639$, Prob>$\chi^2 = 0.0000$.
Standard errors in parentheses.

[a] Denotes log-likelihood value (*df*) of the “naïve” model, containing only the intercepts.

[b] LR test is between the full model and the “naïve” model.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

results for the complete sample. The standard errors are generally somewhat larger, which is likely to be due to a smaller sample (1488 observations) and the exclusion of consistently cooperating firms resulting in a much smaller percentage of cooperating firms.

The source specific spillovers remain significant in their respective cooperation equations, while only the 'generic' effect of institutional spillovers on supplier cooperation appears less robust. The results for R&D intensity are by and large replicated, with the exception that the quadratic term for customer cooperation falls just below conventional significance levels. Overall, the findings indicate the robustness of results in the presence of potential simultaneity bias.

A number of differences are also worth noting in the new cooperation equations. Firms that rate *internal knowledge flows* as relatively important appear less likely to form new supplier and research institutional links, an effect that was not identified significantly in the full sample model. The average size of innovative firm maintains its expected positive impact on competitor cooperation, while the positive impact on institutional cooperation disappears. The speed of technological change variable looses its significance in the competitor cooperation equation but remains robust in the institutional and customer cooperation equations. Group membership now loses its positive effect on cooperation and instead has a significantly negative impact on competitor cooperation. The greatest change in the results compared those for the full sample model occurs for the R&D *subsidy* dummy, as expected. For the new cooperation sample, the coefficient of the R&D subsidy dummy no longer includes the effects of R&D subsidies that were granted conditional on R&D cooperation. Hence the results cannot be affected by simultaneity between subsidies and cooperation but reflect the effect of *existing* R&D subsidies on *new* R&D cooperation. While the estimated effect in the full model was significantly positive in supplier, customer, and institutional cooperation, these effects are now insignificant. The results suggest that the positive impact found for the full sample may indeed be biased upward by simultaneity between cooperation and subsidies.[21]

5. Conclusion

This paper has explored the heterogeneity in the determinants of firms' decisions to engage in vertical (suppliers, customers), horizontal (competitors) and research institutional (universities and research labs) R&D cooperation. We took into account a broad set of determinants but paid particular attention to the effects of different types of spillovers, a central focus in the industrial organization literature on R&D cooperation. We limited potential problems of simultaneity bias between cooperation and its determinants (notably R&D intensity and incoming spillovers) by utilizing a two-period dataset on innovating firms, which allowed us to employ lagged variables.

[21] Such bias may be caused by a positive impact of R&D subsidies in 1996 effectively allocated to joint R&D projects set up around that time but still in existence in 1998. The individual probit result for the impact of R&D subsidies on horizontal cooperation, as reported in Appendix B.2, is even found to be significantly negative. This could point to an alternative impact of subsidies in alleviating financial constraints: R&D subsidies moderate financial bottlenecks for the firm's R&D activities and hence reduce the need to cooperate. Non-cooperating firms that have received subsidies would be more likely to find it optimal to rely on internal R&D efforts instead of sharing funds and research results with competitors.

In addition, we considered a sample of firms that had not cooperated in the first period, further minimizing potential simultaneity problems. We used a multivariate probit model to reflect that firms consider simultaneously the decisions to cooperate with various partners. We found significantly positive correlations between the equations, which might indicate that the various cooperation decisions tend to be viewed by the firms as complementary rather than substitutes, but could also be due unobserved firm heterogeneity.

Our results confirmed that incoming source-specific spillovers are an important determinant of R&D cooperation: cooperation with a type or partner is significantly more likely if incoming spillovers from that type of partner are more important for the firms' innovation process. We found a smaller impact of competitor spillovers on horizontal cooperation, consistent with stylized results from theoretical industrial organization models of R&D cooperation, where spillover levels have a less unambiguously positive impact on R&D cooperation with competing firms than on cooperation with vertically or unrelated firms. Another finding was that incoming spillovers from universities and research institutes stimulate cooperation of all types, suggesting that this knowledge is more generic in nature and improves the technological opportunities and general effectiveness of the firm's R&D activities and R&D cooperation strategies.

R&D intensity has a positive impact on vertical and institutional cooperation, with a decreasing marginal impact for highly R&D intensive firms. A weaker positive impact was found for horizontal R&D cooperation with competing firms, consistent with the notion that firms in horizontal partnerships also face greater risks of leakage of proprietary knowledge. Firm size has a positive impact on all four types of cooperation, as larger firms are more likely to have the critical size and absorptive capacity required to engage in R&D cooperation. The largest firms were more likely to cooperate with universities and research institutes, suggesting that small and medium sized firms often do not have the critical size to cooperate effectively with science institutions. Risk and organizational constraints in the firm's innovation process generally had a positive impact on R&D cooperation, with the most robust results for the commercial risk factor being on horizontal cooperation and for organizational constraints on supplier and institutional cooperation. R&D cooperation with institutions, customers, and competitors were found to be more likely in case of a greater speed of technological change in terms of new product introductions in the industry. Foreign multinationals were found to have a lower propensity to engage in horizontal cooperation, but were not less inclined to cooperate vertically or with universities and research institutes. The estimated impact of R&D subsidies proved to be sample sensitive: received subsidies had a positive effect on R&D cooperation in the full sample model, but not in the model for new cooperation, suggesting that the positive impact is not generic but stems from those subsidies that are granted conditional on cooperation.

The results show that there is merit in disaggregating R&D cooperation by type of partner and that there are substantial differences in the motives and determinants of the different types of cooperation. Further empirical work in this area would greatly benefit from an extension of theoretical models to other types of R&D

partnerships than horizontal cooperation. High on the agenda of future empirical work is analysis of potential complementarities between cooperation types, i.e. the choice of multiple R&D partnerships, and the effects of these on innovative performance.

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Appendix A. Description of variables

Variable name	Definition
Competitor incoming spillovers*	Importance of competitors as source of knowledge for the firm's innovation process.
Customer incoming spillovers*	Importance of customers as source of knowledge for the firm's innovation process.
Supplier incoming spillovers*	Importance of suppliers as source of knowledge for the firm's innovation process.
Institutional incoming spillovers*	Average of importance of universities, innovation centers, and research institutions as source of knowledge for the firm's innovation process.
Public incoming spillover	Average of importance of patents, databases, trade literature and fairs as source of knowledge for the firm's innovation process.
Industry outgoing spillovers	Mean of scores of importance of information received from competitors and patents for all firms operating in the (two-digit) industry.
R&D intensity	R&D employees/total employees
R&D intensity squared	R&D employees/total employees squared
Firm size	Logarithm of number of employees
Industry average innovative firm size	Mean of sales by all innovating firms operating in the two-digit industry.

(continued on next page)

Appendix A (*continued*)

Variable name	Definition
Organizational capability constraint	Average of scores on the following responses: innovation project not started due to short of staff not started due short of knowledge not started due to rigid organization
Risk constraint	Average of scores on the following responses: innovation project not started due to economic risks not started due to uncertain markets
Cost constraint	Average of scores on the following responses: innovation project not started or delayed or abandoned due to short of financing not started or delayed or abandoned due to high costs
Speed of technological change	Sum of sales of firms in the two-digit industry that stated that they had introduced products new to the industry, divided by sum of sales of all firms in the industry
Service dummy	1 if business unit belongs to the services sector, else 0
Internal knowledge flows	Importance of other group firms as source of knowledge for the firm's innovation process, divided by the total of importance scores of all external sources of knowledge
Part of a domestic group	1 if the firm is part of a domestic corporate group, else 0
Foreign multinational	1 if headquarters of the firm is located outside the Netherlands, else 0
R&D subsidy	1 if firm received subsidy for innovation activities, else 0

All independent variables are derived from the 1996 CIS survey.

* In the full sample analysis, the source-specific incoming spillovers are substituted by the error terms of regressions of the 1996 spillovers on the 1994–1996 cooperation dummies and the set of industry dummies.

Appendix B.1. Individual probit results for the full sample

	Competitor cooperation	Customer cooperation	Supplier cooperation	Institutional cooperation
res. Competitor incoming spillovers	0.085 (0.048)*	−0.022 (0.043)	0.038 (0.043)	0.020 (0.048)
res. Customer incoming spillovers	0.022 (0.045)	0.224 (0.040)***	0.021 (0.039)	0.016 (0.045)
res. Supplier incoming spillovers	−0.055 (0.047)	0.044 (0.042)	0.248 (0.041)***	−0.053 (0.047)
res. Institutional incoming spillovers	0.375 (0.069)***	0.227 (0.063)***	0.221 (0.063)***	0.722 (0.066)***
Public incoming spillovers	−0.001 (0.077)	0.007 (0.069)	−0.004 (0.069)	0.091 (0.075)
Industry outgoing spillover	−0.557 (0.312)*	0.395 (0.292)	0.105 (0.286)	−0.203 (0.309)
R&D intensity	2.184 (1.684)	4.370 (1.578)***	3.421 (1.690)**	4.684 (1.656)***
R&D intensity squared	−4.182 (5.286)	−13.289 (5.465)**	−12.479 (6.294)**	−2.016 (5.488)**
Firm size	0.139 (0.032)***	0.138 (0.029)***	0.157 (0.030)***	0.240 (0.033)***
Cost constraint	−0.262 (0.580)	−0.291 (0.505)	−0.585 (0.509)	−0.468 (0.608)

Appendix B1 (*continued*)

	Competitor cooperation	Customer cooperation	Supplier cooperation	Institutional cooperation
Industry average innovative firm size	1.004 (0.395)**	0.329 (0.411)	0.323 (0.394)	0.796 (0.417)*
Organizational capability constraint	−0.169 (0.270)	0.008 (0.236)	0.732 (0.224)***	0.412 (0.242)*
Cost constraint	0.164 (0.350)	0.347 (0.308)	−0.427 (0.323)	0.794 (0.334)**
Risk constraint	0.371 (0.156)**	0.207 (0.142)	0.302 (0.143)**	−0.050 (0.158)
Speed of technological change	0.621 (0.246)**	0.612 (0.231)***	0.147 (0.230)	1.115 (0.265)***
Service dummy	0.217 (0.094)**	0.166 (0.088)*	0.067 (0.088)	−0.033 (0.097)
Internal knowledge flows	−0.013 (0.069)	−0.027 (0.065)	−0.127 (0.071)*	−0.103 (0.080)
Part of a domestic group	−0.053 (0.082)	0.156 (0.073)**	0.190 (0.073)***	0.058 (0.081)
Foreign multinational	−0.241 (0.095)**	−0.064 (0.080)	0.011 (0.079)	−0.137 (0.090)
R&D subsidy	−0.008 (0.089)	0.153 (0.079)*	0.177 (0.079)**	0.201 (0.086)**
Constant	−2.004 (0.271)***	−2.585 (0.255)***	−2.119 (0.246)***	−3.044 (0.287)***
Observations	2149	2149	2149	2149
Ll	−673.26	−876.62	−892.62	−710.62
χ^2	115.88	185.95	204.52	366.34

Standard errors in parentheses.
* Significant at 10%.
** significant at 5%.
*** significant at 1%.

Appendix B.2. Individual probit results for the new cooperation sample

	Competitor cooperation	Customer cooperation	Supplier cooperation	Institutional cooperation
res. Competitor incoming spillovers	0.102 (0.064)	−0.026 (0.059)	0.022 (0.057)	0.019 (0.069)
res. Customer incoming spillovers	0.044 (0.059)	0.209 (0.054)***	0.046 (0.052)	0.002 (0.064)
res. Supplier incoming spillovers	−0.047 (0.064)	−0.018 (0.059)	0.223 (0.055)***	−0.010 (0.068)
res. Institutional incoming spillovers	0.319 (0.097)***	0.232 (0.089)***	0.178 (0.088)**	0.694 (0.092)***
Public incoming spillovers	−0.194 (0.119)	−0.127 (0.103)	−0.014 (0.099)	−0.171 (0.119)
Industry outgoing spillovers	−0.099 (0.443)	0.403 (0.438)	0.207 (0.420)	0.023 (0.459)
R&D intensity	3.430 (2.803)	4.115 (2.316)*	6.790 (2.910)**	7.827 (3.085)**
R&D intensity squared	−11.218 (10.358)	−11.973 (8.070)	−28.871 (14.954)*	−31.620 (14.419)**
Firm size	0.113 (0.048)**	0.179 (0.044)***	0.190 (0.043)***	0.223 (0.052)***
Industry average innovative firm size	0.821 (0.552)	−0.513 (0.720)	−0.490 (0.651)	0.774 (0.643)
Organizational capability constraint	−0.730 (0.497)	−0.022 (0.357)	0.785 (0.306)**	0.544 (0.369)
Risk constraint	0.454 (0.246)*	0.228 (0.225)	0.233 (0.215)	−0.156 (0.275)

(continued on next page)

Appendix B2 (*continued*)

	Competitor cooperation	Customer cooperation	Supplier cooperation	Institutional cooperation
Speed of technological change	0.127 (0.350)	0.578 (0.323)*	0.172 (0.312)	1.381 (0.391)***
Service dummy	0.140 (0.130)	0.235 (0.118)**	0.230 (0.115)**	0.044 (0.140)
Internal knowledge flows	−0.029 (0.088)	−0.052 (0.085)	−0.151 (0.095)	−0.332 (0.162)**
Part of a domestic group	−0.207 (0.113)*	0.113 (0.101)	0.154 (0.098)	0.018 (0.117)
Foreign multinational	−0.217 (0.132)	−0.106 (0.112)	−0.086 (0.108)	0.079 (0.125)
R&D subsidy	−0.288 (0.130)**	−0.008 (0.109)	−0.054 (0.109)	−0.150 (0.126)
Constant	−1.807 (0.359)***	−2.740 (0.349)***	−2.443 (0.333)***	−3.169 (0.414)***
Observations	1484	1484	1484	1484
Ll	−353.19	−444.86	−473.67	−330.73
χ^2	47.04	68.95	92.61	132.69

Standard errors in parentheses.
* Significant at 10%.
** significant at 5%.
*** significant at 1%.

Appendix C. Auxiliary regression to remove the effect of past cooperation on incoming spillovers

	Competitor spillovers	Customer spillovers	Supplier spillovers	Institutional spillovers
Competitor cooperation	0.169*** (0.060)			
Customer cooperation		0.391*** (0.053)		
Supplier cooperation			0.204*** (0.048)	
Institutional cooperation				0.393*** (0.033)
Industry dummies	Yes	Yes	Yes	Yes
R^2	0.02	0.07	0.03	0.10

Notes to Appendix D:
(1) Competitor incoming spillovers.
(2) Customer incoming spillovers.
(3) Supplier incoming spillovers.
(4) Institutional incoming spillovers.
(5) Public incoming spillovers.
(6) Industry outgoing spillovers.
(7) R&D intensity.
(8) R&D intensity squared.
(9) Firm size.
(10) Industry average innovative firm size.
(11) Organizational cap. Constraint.
(12) Cost constraint.
(13) Risk constraint.
(14) Speed of technological change.
(15) Services.
(16) Internal knowledge flows.
(17) Part of a domestic group.
(18) Foreign Multinational.
(19) R&D Subsidy.

Appendix D. Correlations

(N=1949)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1	0.3928																	
2	0.3145	0.2837																
3	0.2308	0.1686	0.1694															
4	0.1521	0.0614	0.0290	0.1454														
5	0.0078	0.0030	−0.0004	0.0023	0.1183													
6	0.0300	0.0682	−0.0495	0.1236	0.1824	0.2616												
7	0.0306	0.0475	−0.0422	0.1023	0.1033	0.1366	0.8871											
8	0.1111	0.0517	0.0217	0.1024	0.1885	0.0250	−0.0054	−0.0157										
9	−0.0087	0.0058	0.0051	0.0031	0.0485	0.0854	−0.0124	−0.0188	0.1574									
10	0.0490	0.0257	0.0071	0.0665	0.1115	0.0543	0.0700	0.0373	0.0323	0.0089								
11	0.0418	0.0480	−0.0241	0.0400	0.1551	0.0988	0.1747	0.1072	0.0348	0.0189	0.3266							
12	0.0619	0.0703	0.0303	0.0893	0.1717	0.1018	0.1384	0.0807	0.0894	0.0273	0.3640	0.4617						
13	0.0075	0.0022	−0.0056	−0.0010	0.0840	0.4860	0.2106	0.1339	−0.0049	−0.2481	0.0450	0.0756	0.0832					
14	0.0001	0.0017	−0.0068	−0.0057	0.0057	−0.3719	−0.0915	−0.0177	−0.0132	−0.0359	−0.0141	−0.0563	−0.0639	−0.5080				
15	−0.0947	−0.0831	−0.0931	−0.1096	−0.3329	−0.0458	−0.0240	−0.0097	0.0492	0.0126	−0.0279	−0.0020	−0.0466	−0.0885	0.0801			
16	0.0184	0.0172	−0.0011	−0.0036	0.0899	0.1056	0.0312	0.0005	0.2446	−0.0017	−0.0002	0.0250	0.0340	−0.0023	−0.0031	0.0961		
17	0.0031	−0.0087	−0.0353	−0.0039	0.0466	0.1498	0.0415	0.0107	0.1627	0.0482	−0.0028	0.0237	0.0101	0.0114	−0.0303	0.0918	0.3083	
18	0.0978	0.0904	0.0319	0.1670	0.1792	0.2868	0.3277	0.1832	0.1723	0.0306	0.1071	0.1884	0.1778	0.2342	−0.2773	−0.0712	0.1140	0.0202

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