The Determinants of R&D Cooperation: Evidence from Dutch CIS Data 1996-1998

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René Belderbos[a], Martin Carree[b], Bert Diederen[c], Boris Lokshin[d], and Reinhilde Veugelers[e]

Corresponding Author
Boris Lokshin
Department of Organization and Strategy
Faculty of Economics and Business Administration
Universiteit Maastricht
PO Box 616
6200 MD Maastricht
The Netherlands
Phone: +31 43 388 3697
Fax: +31 43 325 4893
B.Lokshin@os.unimaas.nl

[a]Katholieke Universiteit Leuven and Universiteit Maastricht
[b]Universiteit Maastricht and Erasmus Universiteit Rotterdam
[c]Statistics Netherlands, Heerlen
[d]Universiteit Maastricht[e]
[e]Katholieke Universiteit Leuven and CEPR

ABSTRACT

We explore the determinants of firms' decisions to engage in R&D cooperation, differentiating between three types of cooperation partners: suppliers and customers (vertical cooperation), competitors (horizontal cooperation), and universities and research laboratories (institutional cooperation). Using panel data from Dutch CIS surveys in 1996 and 1998 we reduce simultaneity bias between cooperation and its determinants, in particular R&D intensity and spillovers, by employing lagged explanatory variables and further check the robustness of results by estimating a model limiting the analysis to R&D cooperation initiated in the 1996-1998 period. For the latter sub-sample the simultaneity bias can be assumed absent. Applying a system method estimator for probit equations we find cooperation decisions to be positively correlated, suggesting complementarities between cooperation types. While firm size and incoming institutional spillovers significantly impact all types of cooperation, the results also show major differences between determinants.

1. Introduction

The growing role of R&D collaboration in firms' innovative activities (Hagedoorn, 2002) has spurned research into the determinant of such R&D cooperation and the performance of cooperative R&D. While the management literature concentrates on the search for complementary know-how, most of the theoretical Industrial Organization literature has focused on the role of spillovers. Empirical work has used micro-level survey data, such as from the European Community Innovation Surveys (CIS). Central variables considered in these empirical studies to determine R&D cooperation are firm size and R&D intensity (Kleinknecht and Reijnen, 1992; Kaiser (2002); Becker and Dietz (2002); Veugelers (1997). While these studies aggregated over all potential types of cooperation, only a limited number of studies have attempted to differentiate between cooperation partners. Fritsch and Lukas (2001) identify factors that increase the propensity to cooperate among German manufacturing firms but limit their analysis to firm size and R&D intensity. Theter (2000) characterizes different types of cooperating innovators based on the UK data. Cassiman and Veugelers (2002a), using 1994 data on Belgian firms distinguished between university-firm cooperation and cooperation with vertically related partners, but could not distinguish cooperation with competitors. Recent work by Mohnen (2002) and Cassiman and Veugelers (2002b) has focused exclusively on the determinants of university-firm cooperation in R&D.

In this paper we explore the determinants of firms' decisions for vertical (suppliers, customers), horizontal (competitors) and research institutional (universities, research labs) cooperation taking into account a broad set of possible explanatory variables among which spillovers and R&D intensity. The contribution of the paper compared to previous work in this area is three-fold. First, while most previous studies have not been able to disaggregate R&D cooperation over different types of partners, we explicitly differentiate between the determinants of different types of cooperation. Second, while most previous studies have investigated different R&D partnerships in separate models, we apply a system method of estimation for limited dependent variables allowing for correlated decisions between cooperation types and cross-equation tests. Third, previous studies only had a cross-section data at their disposal, and hence have grappled with the problem of a simultaneous relationship between R&D cooperation on the one hand, and major determinants R&D intensity and spillovers on the other. Using panel data from Dutch CIS surveys in 1996 and 1998, we can link lagged determining variables from CIS 1996 to R&D cooperation activities from CIS 1998. We can hence reduce simultaneity bias between cooperation and its determinants, in particular R&D intensity and spillovers, by employing lagged explanatory variables. We further check the robustness of results by estimating a model limiting the analysis to firms initiating new R&D cooperation in the 1996-1998 period. For this specific sub-sample the problem of simultaneity can be assumed to be absent.

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

Theoretical Models

Models that seek to answer the questions of why and what kinds of firms seek to perform joint research activities are grounded in several theoretical strands. The management literature typically analyzes cooperation from a transaction costs framework (Pisano, 1990; Robertson & Gatignon, 1998; Oxley, 1997) or uses resource-based theories (Tyler & Steensma, 1995; Doz & Hamel, 1997). Pisano (1990) describes alliances as a hybrid form of organisation between hierarchical transactions within the firm and arm's-length transactions in the market place. Collaboration allows for a transfer of technology at lower transaction costs as compared to arm's length. It not only allows for a better control and monitoring of technology transfers, but also the inherent reciprocal relationship and "hostage" exchange between complementary partners minimizes opportunism. The resource-based view of the firm suggests that the rationale for partnerships is the value-creation potential of the firms' resources that are pooled together. Firm cooperation is viewed as the mechanism to maximize the value through effectively combining the resources of the partners exploiting complementarities (see Kogut, 1988; Hagedoorn, 1993; Das and Teng 2000; Hagedoorn, Link and Vonortas 2000).

The Industrial Organization (I.O.) literature emphasizes competitive motives for engaging in R&D cooperation among competitors (horizontal cooperation), concentrating on spillovers and appropriability issues. When anticipated, voluntary or involuntary transfers of know-how complicate R&D strategies in a non-trivial way. De Bondt (1996) provides an overview of the impact of spillovers on non-cooperative R&D investment levels. A similar focus on the effects of spillovers on R&D investment is omni-present in reviewing the I.O. literature on R&D cooperation (e.g. Katz, 1986; Spence, 1984; d'Aspremont & Jacquemin, 1988; De Bondt & Veugelers, 1991; Vonortas, 1994; Katsoulacos & Ulph, 1998; Kamien et al., 1992; Suzumura, 1992; and Leahy & Neary, 1997). A first finding in these models is that investment in R&D when firms cooperate is increasing in the level of the spillover. A second finding across the various models is that when spillovers are high enough, i.e. above a critical level, cooperation in R&D will result in higher R&D investment compared to non-cooperating firms. Cooperation allows the firms to overcome the disincentive effect from the positive externality that outgoing spillovers create on rival firms. This suggests that R&D co-operation is most beneficial for technological progress when technology is difficult to keep proprietary. Although spillovers will increase the stock of effective knowledge and hence have a market expansion or cost reduction effect, large spillovers typically have a disincentive effect on the firm's levels of non-cooperative R&D. This disincentive effect is demonstrated most clearly in strategic two-stage models where firms take into account that whenever knowledge leaks out to competing firms, this will have a negative impact on their own profitability, thus reducing the attractiveness of investing in R&D. The nature of product market competition critically shapes this disincentive effect, with the critical spillover level depending on whether firms are producing substitutes or complements.[1] When goods are substitutes the level of product differentiation and the number of rivals are important parameters that determine the critical spillover level (De Bondt et al, 1992; Röller et al, 1997). Similarly, inter-industry cooperation is more likely to boost R&D investments as compared to intra-industry co-operation (Steurs, 1995).

Given the assumption of coordination through joint profit maximization, while ignoring any explicit costs to R&D cooperation, these models find that cooperation always increases the firms' profitability. Spillovers increase the profitability of R&D cooperation and once spillovers are sufficiently high, i.e. above the critical spillover level, higher spillovers make R&D cooperation increasingly more attractive as compared to independent R&D (De Bondt & Veugelers, 1991). On the other hand, higher spillover levels also increase the potential profits from cheating by a partner and from free-riding by an outsider to the cooperative agreement. Hence R&D cooperation becomes more profitable the more firms are able to restrict outgoing spillovers and selectively share information with cooperation partners. This result emphasizes a dual role of spillovers: outgoing spillovers may jeopardize the cooperative agreement and incoming spillovers increase the attractiveness of cooperation.

Recent I.O. models take into account that firms can attempt to manage spillovers, trying to minimize outgoing spillovers while at the same time maximizing the incoming spillovers. Minimizing outgoing spillovers can be accomplished through the use of effective legal and strategic protection measures. Firms can maximize incoming spillovers by voluntarily increasing the spillovers among cooperating partners, as in the research joint venture scenario of Kamien et al (1992) and Katsoulacos and Ulph (1998). Such information sharing, which increases the incoming spillover for partners, is found to further increase the profitability of cooperation in R&D. In addition, firms can increase the effectiveness of incoming spillovers by investing in "absorptive capacity". Cohen and Levinthal (1989) argue that external knowledge is more effective for the innovation process when the firm engages in own R&D. The direct effect of higher absorptive capacity is thus to increase the effectiveness of incoming information. Finally, 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) show that firms that cooperatively choose their R&D expenditures, maximize information

[1] When firms are marketing complementary goods, cooperation always results in higher R&D investment levels than non-cooperation, independent of the level of spillovers.

flows -their incoming spillovers through the choice of very broad research directions for the research joint venture. If the firms cannot coordinate their R&D expenditures, they are more concerned about managing their outgoing spillovers by choosing a more narrow research approach.

Theory has not paid much attention to the different types of partners in R&D cooperation, i.e. vertical cooperation, horizontal cooperation, or, cooperation with research institutes. Most of the I.O. literature in particular has focused on cooperation among horizontal partners. Different types of partners may nevertheless be associated with different motives and problems of R&D cooperation. Distinguishing between different types of cooperative R&D agreements — one would expect that generic incoming spillovers strongly affect the choice for cooperation with research institutes. In contrast, appropriation is a key issue when dealing with more commercially sensitive information in horizontal cooperative agreements. However, also in vertical cooperative agreements, commercially sensitive information often leaks out to competitors through common suppliers or customers. Hence, only firms that can sufficiently protect their proprietary information are willing to engage in this type of cooperative agreements, an issue which may be less present in cooperative agreements with research institutes and universities.

Summarizing the theoretical literature on spillovers and R&D cooperation, we expect that higher incoming spillovers increase the scope for learning within cooperative R&D agreements. Because of an improved technological competence of the partners, the marginal benefit of forming a research joint venture is higher, implying a higher probability of cooperation. The theoretical literature does not provide clear-cut predictions about the sign of the outgoing spillovers variable. On the one hand, lower appropriability, increases the scope for the internalization of information flows between firms through cooperation in R&D. On the other hand, lower appropriability increases free rider problems related to R&D investments, which reduce profitability and threaten the stability of cooperative agreements in R&D. When the appropriation regime is tight, i.e. protection is more effective, firms can more easily enter into R&D cooperation, controlling knowledge flows to non-partners or non-loyal partners. Furthermore, the recent literature shows that cooperation is not only influenced by exogenous spillovers but at the same time may be used as a vehicle to improve knowledge transfers, leading to a simultaneous relationship between cooperation and spillovers. A similar simultaneous relationship holds between cooperation and own R&D. Not only will own R&D enhance the efficiency of cooperation through the absorptive capacity notion, but also external sourcing through cooperation may stimulate or discourage own R&D.

Empirical Research

There is an expanding empirical literature on the determinants of R&D cooperation. Given the difficulties to empirically assess the profitability of R&D cooperation, most studies indirectly use the frequency of occurrence of R&D cooperation to assess which characteristics are more beneficial to

R&D cooperation. Product complementarities among partners are found to positively affect the likelihood of R&D cooperation (Röller et al., 1997). Sakakibara (1997a,b) finds that access to complementary knowledge is one of the most important objectives of establishing government sponsored research corporations in Japan. Tyler & Steensma (1995) provide evidence for the importance of cost and risk sharing for the success of R&D cooperation.

Röller et al (1997) and Colombo and Gerrone (1996) provide find evidence for firm size and R&D intensity of firms to be beneficial to 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. Kleinknecht & van Reijnen (1992) find that having an own R&D department increases the probability of co-operation. Colombo and Gerrone (1996) suggest that the relationship between R&D intensity and R&D cooperation should be treated as a two-way relationship: firms with own R&D are more likely to co-operate, while co-operation may also stimulate or substitute for own in house R&D. They test for Granger causality between a firm's R&D intensity and its technology cooperative agreements and conclude that a simultaneous treatment of in house R&D intensity and technological co-operation indeed is the appropriate framework. Veugelers (1997) taking into account this simultaneous relationship, finds that firms who spend more on internal R&D have a significantly higher probability of co-operation in R&D. Kaiser (2002), using a simultaneous equations framework, finds a positive but only weakly significant effect of cooperation on own R&D expenditures. Cassiman and Veugelers (2002) provide evidence of a strongly positive effect of own R&D activities on cooperation in R&D, but after controlling for endogeneity through a two-step procedure, this effect became less significant. Becker and Dietz (2002) are concerned with the relationship between R&D cooperation and R&D input and output. In a simultaneous equation model estimated on German firm data, they find that an aggregate count of R&D cooperation partnerships has a positive impact on R&D intensity and vice versa.

The relationship between R&D cooperation and R&D spillovers, while relatively well developed in theoretical models, remains largely unexplored in empirical work. Cassiman & Veugelers (2002), study the relationship between R&D cooperation and the importance of public information sources for firm's innovation process (public spillovers). They find that incoming public spillovers as well as outgoing spillovers (appropriability) have important and separately identifiable effects. Firms with higher incoming public spillovers have a higher probability of cooperating in R&D, while high outgoing spillovers, i.e. low appropriability of the results of R&D, affect the decision to cooperate negatively.

Empirical work on R&D cooperation distinguishing between type of partner has been limited and has often focused on singling out university-firm links (e.g. Mohnen, 2002; Cassiman and Veugelers, 2002b). Cassiman and Veugelers (2002), when analyzing the impact of spillovers on cooperation could only distinguish between research institutes and vertically related partners (their sample of firms did not include a sufficient number of firms cooperating horizontally). They find that higher incoming public spillovers positively affect the probability of cooperating with research institutes such as universities and public or private research labs, but have no effect on cooperation with customers or suppliers. Increased appropriability of results of the innovation process (lower outgoing spillovers), however, increases the probability of cooperating with customers or suppliers, but is unrelated to cooperative agreements with research institutes. Furthermore, taking into account the simultaneous relationship between spillovers and R&D cooperation, they find evidence for a feedback effect of cooperation in R&D on incoming spillovers and appropriability. This effect, again, only becomes apparent when distinguishing between different types of cooperative R&D agreements. Cooperative agreements with universities increase the usefulness of the publicly available pool of public knowledge and the effectiveness of appropriation mechanisms for the firm's innovation process. Cooperative agreements with suppliers or customers, however, reduce the effectiveness of strategic protection measures.

Tether (2000) claims to identify key experiential features that characterize cooperating innovators based on the UK CIS survey. These features include R&D continuity and focus on higher-level innovations, which is taken to suggesting growing complexity of technologies is a major driving force of increased levels of cooperation. However, his empirical results derived from series of logistic regressions appear sensitive to the type of the firms and the definition of high-level innovative activity. Kaiser (2002) applies a nested-logit framework to analyze firms' R&D cooperation in the German service sector. As a first step the model considers the decision whether or not to cooperate as a function of horizontal and vertical spillover pools, a size measure, and R&D intensity while also controlling for diversification of research, ownership and location of the firm. The second step choice concerns the type of cooperation data, but here only a distinction could be made between vertical cooperation and a mixed category of university and competitor cooperation. The cooperation type model had weak explanatory power and spillover measures emphasized by the theoretical literature nor research base variables were found to have a significant impact. In another study of collaborative R&D based on a German CIS survey, Fritsch and Lukas (2001) identify factors that increase the propensity to cooperate among German manufacturing firms. These factors are firm size, R&D expenditures and the particular assignment within the firm of 'gatekeepers' monitoring and transmitting external information to relevant internal departments. The latter parallels the argument in Veugelers (1997, 2002) for including a permanent R&D variable as facilitator of appropriation of external knowledge.

3. Empirical model, data, and estimation method

We estimate an empirical model that jointly determines the decision to engage in R&D cooperation of three types: horizontal, vertical and (research) institutional R&D partnerships. This specification takes into account that there may be systematic correlations between choices for the different cooperation types. This may be due to complementarities (positive correlation) or substitutability (negative correlation) between different cooperation types, e.g. the benefit of horizontal cooperation may be viewed to 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, e.g. the stock of tacit knowledge, that are not easily captured by measurable proxies. If such correlation exists, the estimates of separate (probit) equations of the cooperation decisions are inefficient. Instead we use a trivariate probit model to take the correlations into account, although we are not able to distinguish between the two sources of correlation.

Our panel dataset was constructed from two consecutive CIS surveys in the Netherlands in 1996 and 1998, which allows us to take past values of independent variables (from 1996) to explain the existence of R&D cooperation in 1998. This setup reduces simultaneity bias inherent to cross section analysis in a single year. The two main explanatory variables that are likely to be simultaneously determined are incoming spillovers and R&D intensity: R&D investments may increase if cooperation makes R&D activities more effective, and incoming spillovers should increase through cooperation, in particular when spillovers are measured by type (vertical, horizontal or institutional). In our model setup using two year lagged variables as instruments such bias will be reduced, but it may not be completely neutralized. Since R&D partnerships on average have a 2-3 year duration, the R&D intensity and the importance of incoming spillovers in 1996 may still be partly impacted by R&D partnerships of 1996 that are still in existence in 1998. In order to further eliminate bias, we will also look at a sub-sample of firms lacking any cooperation links in 1996 to test for the robustness of the impact of 1996 R&D intensity and incoming spillovers in impacting the establishment of new R&D cooperation in the 1996-1998 period. Although this eliminates any potential feedback effect of cooperation on R&D and spillovers, it has one important drawback. The analysis is restricted to firms without any type of R&D cooperation in 1996 among the set of innovating firms in 1996. Excluding cooperating firms reduces the number of observations by a large margin and may create a sample selection bias in itself. But in case impacts found using the complete sample are replicated in the new cooperation sample this gives further weight to the robustness of the results.

Data

The dataset used in this paper concerns establishment level (in this paper referred to as 'firms') data of firms from the CIS surveys in the Netherlands of 1996 and 1998. The CIS survey in 1998 includes 6327 innovating Dutch establishments. A sizeable proportion (26.95%) of these establishments are owned by foreign multinationals. A total of 1575 (24.9%) establishments have at least one external cooperation link. The partnerships are relatively well distributed among the different cooperation types: 908 (14.4%) of the establishments cooperate with customers/clients, 943 (14.9%) with suppliers, 686 (10.8%) with competitors, 574 (9.1%) with research institutes, and 510 (8.1%) with universities.[2] About 4.1% of the firms in the sample have 5 or 6 different types of cooperation partners, while 13.7% of the firms have 1 or 2 types of partners.

To create a panel data set, the 6327 innovating firms in 1998 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 (information on explanatory variables is only available in the survey if firms are classified as innovating firms). Due to missing values for some of the 1996 explanatory variables the number of observations used in the complete sample is 2156. The distribution of cases for the three equations by the dependent variable is presented in Table 1. There were 609 firms with R&D cooperation of any type among the 2156 innovating firms in 1998. Vertical cooperation is most prominent, independent (204) or in combination with institutional cooperation (136). A total of 109 firms have cooperative agreements of all three types. The model for newly formed cooperative agreements includes those firms that did not have a cooperation link in 1996 but reported one in 1998, and firms that did not have a partner in either 1996 or 1998. In this smaller sample (1488 firms), the number of firms with cooperation in 1998 is reduced to 269.

Dependent and Independent Variables

The dependent variables of the model are three dummy variables: whether the firm was engaged in 1998 in active R&D partnership with competitors (horizontal cooperation), suppliers and/or clients (vertical cooperation), or research institutes and/or universities (institutional cooperation). We include a range of explanatory variables based on theoretical work and earlier empirical results. Since our interest is to explore the varying determinants of R&D cooperation between the types, we include each explanatory variable in all three equations to test whether some variable impact cooperation of one type but not another. The descriptive statistics for the samples are presented in Table 1.

We include firm-specific and type-specific measures of the importance of *incoming spillovers*.[3] 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 average of scores of importance of information from suppliers and customers (*vertical incoming spillovers*), the score for information from competitors (*horizontal incoming spillovers*) and the average of scores of information from universities and innovation centers/research institutions (*institutional incoming spillovers*). We expect

[2] In addition, 577 (9.1%) cooperate with consultants. We ignore this type of cooperation in the empirical analysis because of its heterogeneous character and doubts whether linkages with consultants are genuine R&D efforts.

[3] Several alternative indirect measures of spillovers, e.g., based on uncentered correlation (Jaffe 1988, Adams 1990); Euclidean distance (Inkmann and Pohlmeier 1995); geographical distance have also be used in empirical work. 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.

that R&D cooperation of a type is more likely if the information coming from the potential partners is more important.

An important 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 at the industry level, limiting it to spillovers to competitors. The latter is not a major limitation, since the consequences of leakage of proprietary knowledge is most important if competitors benefit, but the lack of a firm-specific variable may leave unexplained heterogeneity between firms. The variable *Industry outgoing spillovers* is constructed at the 2-digit industry level and measures the mean of average scores of information obtained from competitors and patents reported by all competing firms in the industry. The reasoning is that if competitors in the industry obtain important information from competitors and through published patents (filed among others by competitors), appropriability conditions in the industry are weak. *Industry outgoing spillovers* is only expected to impact horizontal cooperation negatively since it only measures spillovers to same-industry competitors.

We were not able to include a proxy for absorptive capacity as used in previous studies, such as permanent R&D activities (Cassiman and Veugelers, 2003). Instead 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). Increasing levels of R&D intensity up to a point will be closely correlated to absorptive capacity. Further increases no longer capture absorptive capacity but are more associated with the conduct of more basic research or perhaps 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 products are substitutes and 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 for cooperation with public sector institutes and suppliers and customers. Hence, we expect a weaker impact of R&D intensity on horizontal cooperation.

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 or firm group. *Internal knowledge flows* measures the sum of scores on information from within own firm or from other firms within the group as opposed to 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 indeed shows that the means for the three types of spillover measures are higher for cooperating firms, while the mean of the internal knowledge flow variable is lower for cooperating firms.

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 the various motivations for partnerships. *Cost constraint* captures bottlenecks caused by the lack or absence 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 risks, costs, and constraints.

The literature on R&D alliances also stresses the importance of alliances in R&D when there are rapid technological developments, short product life cycles, and uncertainty concerning the technology that will be prevailing in the future. If technological developments are rapid and different technology strategies are followed it is likely that firms want to be active in different technological trajectories buying them an option to expand in that direction if any of them prevails. R&D alliances are often the result in industries such as biotechnology and electronics. To proxy for *technological uncertainty* we use take the ratio of the number of firms in the 2-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. Technological uncertainty is likely to be higher in industries characterized by rapid introduction of completely new products, providing incentives for firms to engage in cooperation. In particular institutional cooperation in research and cooperation with competitors are expected to be affected. One problem with this measure is that the question on new products is ill-reported for firms in the services sector. To get an unbiased impact of technological uncertainty we therefore include a *service dummy*: if service firms are innovative but do not answer the question on new products, we expect a positive sign of the dummy correcting for this bias in the question. The service dummy in addition may pick up any systematic differences in cooperation between manufacturing and service sectors not due to this bias.[4]

We include *firm size* (the logarithm of the number of the firm's employees). 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 may also be more attractive R&D partners.

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[4] We ran separate models for manufacturing and services firms only but found remarkably little differences in explanatory factors.

The incentive 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. We can control for this influence in case of horizontal cooperation by including the variable *industry average firm size* (mean of turnover of all innovating firms in the 2-digit industry). We expect a positive impact, but only on horizontal cooperation.

We include a dummy variable for *multinational firm*. Foreign multinational takes the value of one if the headquarters of the firm are located outside the Netherlands. To the extent that domestically owned firms are more embedded in local research networks whereas affiliates of multinational firms may rely on technology transfers from the parent, multinational firms' affiliates may be less likely to engage in R&D cooperation.[5]

Finally, we include a dummy taking the value one if the firm stated that it received an *R&D subsidy*. Since some of the R&D subsidies, national and European, are conditional on, or attempt to promote, R&D cooperation, R&D subsidiaries may have a positive impact on cooperation. However, we note R&D subsidies are expected to have a contemporaneous effect, while in our model setup and more specifically in the model of new cooperative partnerships we examine the effect of *existing* R&D subsidies on *new* R&D cooperation. Another effect of R&D subsidies may be that they reduce financial bottlenecks of the firm's R&D activities and reduce the need to cooperate.[6]

Model and estimation method

As pointed out by Golob and Regan (2002) one possibility to capture the interdependence of yes-or-no decisions is via a multinomial discrete choice model, in which the decision set is comprised by 2^n alternatives, where *n* is the number of cooperation links. The other possibility is to employ a multivariate limited dependent variable model, such as multivariate probit. The computation of the maximum likelihood function based on T-variate normal distribution requires multidimensional integration. Simulation methods have been proposed (see Train, 2002, chapter 5) to approximate such a function. The GHK (Geweke et al. 1997; Hajivassiliou et al. 1996) simulator has been a particularly popular choice. Another possibility is to apply a 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 (2002) using the same data as Berschek and Lechner (1998), shows that maximum likelihood estimates using the GHK simulator are very close to GMM estimates. We will follow the GHK simulator approach and choose a simulated

[5] We also ran the models limiting R&D cooperation to domestic cooperation. As expected, we found a stronger negative impact of the multinational firm dummy, but no major changes in the overall results.
[6] A number of other control variables were included in the model but appeared to be irrelevant to the cooperation decision and were excluded in the reported results: a self-reported measure of the firm's market position, whether the firm applied for patents in 1996, and the age of the firm.

maximum likelihood estimator that also offers possibilities of cross-equation tests and restrictions in parameters.

Our model consists of three binary choice equations. These choices are for vertical, horizontal and (research) institutional cooperation, respectively. Assume three binary dependent variables y_1, y_2 and y_3 where

$$y_1 = \begin{cases} 1 \text{ if } x_1\beta_1 + \omega_1 > 0 \\ 0 \quad \text{otherwise} \end{cases}$$

$$y_2 = \begin{cases} 1 \text{ if } x_2\beta_2 + \omega_2 > 0 \\ 0 \quad \text{otherwise} \end{cases}$$

$$y_3 = \begin{cases} 1 \text{ if } x_3\beta_3 + \omega_3 > 0 \\ 0 \quad \text{otherwise} \end{cases}$$

and $(\omega_1\ \omega_2\ \omega_3) \sim N(0, \Sigma)$ where Σ is the covariance matrix of the error terms. There are likely to be omitted variables in these choice processes that affect each of these choices hence the error terms may be correlated. In case one does not take this into account, for example with three separate probit equations, inefficient estimators result. Therefore, we apply the GHK-procedure, a maximum likelihood (MSL) estimator, which is briefly presented below.

For a trivariate probit the evaluation of the likelihood function requires the computation of a trivariate integral

(1) $\mu(\theta; \mathbf{z}_n) = \int\int\int g(\omega_1\ \omega_2\ \omega_3\,;\ \theta; y_n)\ d\omega_1 d\omega_2 d\omega_3$

where $\mu(\theta; \mathbf{z}_n)$ are probabilities such that for a random sample $\mathbf{y}$ $\{y_1\ y_2\ y_3\}$ we want to maximize the likelihood of the sample (see Hajivassiliou and Ruud 1994; Train 2002) being:

(2) $Q_N^{ML}(\theta) = \sum_{n=1}^{N} \log(\mu(\theta; \mathbf{z}_n))$

The (infeasible) maximum likelihood estimator $\hat{\theta}$ is as follows

(3) $\hat{\theta} \equiv \arg\max_{\theta} \sum_{n=1}^{N} \log(\mu(\theta; \mathbf{z}_n) \xrightarrow{P} \theta$

The maximum simulated likelihood estimator is now calculated as:

(4) $\hat{\theta}_{MSL} \equiv \arg\max_{\theta} Q_N^{ML}(\theta)$ where

(5) $Q_N^{ML}(\theta) = \sum_{n=1}^{N} \log \left[\frac{1}{R} \cdot \sum_{i=1}^{R} \mu_i(\theta; \mathbf{z}_n; \phi_{ni})\right]$

for a sequence $\{\phi_n\}$ n=1 .. N

Hajivassiliou and Ruud (1994) prove that under regularity conditions the MSL estimator θ_{MSL} is consistent if $R \rightarrow \infty$ as $N \rightarrow \infty$ with further result from Gourieroux and Monfort (1996) that if $\sqrt{N}/R \rightarrow 0$ and $R \rightarrow \infty$ as $N \rightarrow \infty$ then $\sqrt{N}(\mathbf{b}_{sml} - \beta)$ has the same limiting normal distribution with zero mean as $\sqrt{N}(\mathbf{b}_{ml} - \beta)$.

In practice the probability $Pr(\mathbf{e}<\mathbf{b}) = Pr(e_1< b_1, e_2<b_2, e_3<b_3)$ is estimated as

(6) $Pr(\mathbf{e}<\mathbf{b}) = \Phi(b_1) \cdot ((1/R \cdot \sum_{i=1}^{R} \Phi(b_1 - s_{21} \cdot \mu_1/s_{22}) \cdot (1/R \cdot \sum_{i=1}^{R} \Phi(b_3 - s_{31}\mu_1 - s_{32}\mu_2)/s_{33})$

where s_{ij} are the elements of Choleski-decomposed matrix of the error terms and μ**,** m x 1 vector of i.i.d. normal density draws such that $\mathbf{e} = \lambda \cdot (\Sigma) \cdot \mu$ (detailed exposition can be found in Hajivassilou et al. 1996; Train 2002).

4. Empirical Results

The results for the trivariate probits using the GHK-procedure for the complete sample are presented in Table 4.[7] For comparison we also report the results when using three independent univariate probits in Table 3. For the sub-sample of firms not having a cooperating link in 1996 three sets of results are reported. The *first* set of results is from three binary probit equations estimated on unequal samples. The reason for the differences in number of observations is that some firms may have established new cooperative agreements of a certain type (horizontal, vertical or institutional) but retained agreements of one of the other two types. The results are reported in the first three columns of Table 5. The second set of results is from three binary probits but estimated on a common sample. These results can be found in the last three columns of Table 5. Finally, the third set of results is from

[7] The results are obtained with a Stata 7.0 routine due to A. Terracol. They are based on 1000 random draws. These results are then compared to the set obtained from Limdep 8.0, setting the same seed and using 100 Halton draws. These results are very close to the Stata 7.0 results.

the multivariate probit model estimated on a common sample. They can be found in Table 6. In the discussion of the results we limit ourselves to the results presented in Tables 4 and 6 using the multivariate probit approach.

Table 4 reports the results for the multivariate probits using the complete sample of 2156 observations. First of all, we note that the three correlation coefficients of the error terms in the multivariate probit are positive and highly significant. They range from 0.622 to 0.779. This supports the notion of interdependence of various cooperative decisions. The positive signs could suggest that various modes of cooperation are viewed by the business units as complimentary. However, they could also result from an omitted variable bias.

The hypothesis that type-specific (incoming) spillovers positively affect the probability of cooperation is partly confirmed. *Horizontal incoming spillovers* have the expected sign in the *horizontal* cooperation equation, but the coefficient is not significant. This may be due to an insufficient correction for outgoing spillovers at the firm level, with the outgoing spillovers variable measured at the industry level not fully representative for he specific appropriability conditions for individual firms in the industry. Another reason may be that firms that rate horizontal incoming spillovers as very important may in effect technology followers rather than leaders and, as such, may not be attractive R&D partners. *Vertical incoming spillovers* have, as expected, a positive and significant effect in the *vertical* cooperation equation. *Institutional incoming spillovers* have a positive and strongly significant effect in all three cooperation equations, and, as expected, the largest impact on institutional cooperation. The impact on vertical and horizontal cooperation suggest 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. 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, while it just fails to reach conventional significance levels. Firms that operate in industries in which competitors benefit from information received from other market participants may foresee difficulties to restrict outgoing spillovers.

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 vertical cooperation with the maximum reached at a rather high level of 0.18 (percentage of R&D employees over total employees). For institutional cooperation the quadratic term is not significant, while for horizontal cooperation none of the terms are significant.[8] This is consistent with the notion that R&D-intensive

[8] Although the F-test on removing both terms from the model is rejected.

firms in horizontal partnerships also face greater risks of leakage of their proprietary knowledge which may outweigh the potential benefits of knowledge in-flows due to cooperation. For vertical relationships this only applies for highly R&D intensive firms, while the leakage issue is less crucial for private-public institutional cooperation.

The *firm size* variable is positive and significant in each of the equations, with he 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, while R&D cooperation with universities and institutes requires the largest critical size.

The *organizational capability constraint* is significantly positive in the vertical and institutional cooperation equations. The *risk constraint* variable is significant and positive for both the horizontal and vertical cooperation decisions, while the *cost constraint* variable does not have any significant impact. Risk sharing and access to complimentary knowledge faced with internal resource constraints appear important motivations for firms to seek R&D partners.

The *technological uncertainty* variable is positive and significant for the horizontal and institutional cooperation decisions. Firms in industries with shorter product life cycles and rapid technological developments are more inclined to cooperate with rivals or to cooperate in generic technologies with research institutes and universities. The technological uncertainty variable was not measured for the service industries and, therefore, we incorporated a *service dummy*. The service dummy has the expected positive effect in the horizontal and vertical cooperation equations.[9]

The effect of the *internal knowledge flow* variable is negative as expected in each of the three equations but insignificant. The *industry average firm size* variable is positive and significant in the horizontal cooperation equation as hypothesized. The availability of large innovating potential partners firms stimulates horizontal cooperative R&D. The *R&D subsidy* variable has a positive and significant impact on vertical and research institutional cooperation. Suggesting that subsidies do promote R&D partnerships. The dummy for a *multinational firm* is negative and significant in the horizontal cooperation equation: affiliates of multinationals are less likely to cooperate with local rivals, but are not less inclined to engage in vertical or institutional linkages.

New R&D Cooperation

The results obtained on the sub-sample of firms not (yet) cooperating in 1996 are presented in Table 6. The results are broadly in line with results using the complete sample results. The standard errors are generally larger, which could partly be explained with a smaller sample (1488 observations) and a smaller percentage of cooperating firms. However, a number of differences are worth noting. While vertical and institutional incoming spillovers are no longer significant in the vertical

[9] A broader specification of the multivariate system that included industry dummies was tested against a constraint specification. The LR-test Chi-square statistic of 43.43 (with 42 degrees of freedom) indicated that the constrained specification of only incorporating the service dummy could not be rejected.

cooperation equation, horizontal incoming spillovers have a significantly negative impact. This may point to a substitution effects in the role of incoming information: firms gravitate to the cooperation type that has higher informational value. Firms that rate *internal knowledge flows* as relatively important now appear less likely to form new vertical and research institutional links, with the coefficient negative and significant in the two equations. There are also a number of changes in the estimated impacts of the innovation constraint variables. The *organizational capability* variable no longer is significant, while the *risk constraint* variable remains only significant for horizontal cooperation. Cost constraints now appear with a counter-intuitive significantly negative impact on vertical cooperation. The most accentuated change in the results compared with the results for the full sample model occurs for the *R&D subsidy* dummy: the estimated effect is significantly positive in vertical and institutional cooperation in the full model and is significantly negative in the horizontal new cooperation equation. Firms that have received subsidies already in are more likely to find it optimal "to go it alone" instead of sharing funds and research results with rivals, perhaps because of the reduced cost constraints for R&D. The turn in sign may indicate that the positive impact in the full sample is due to subsidies in 1996 effectively allocated to joint R&D projects set up around that time and still in existence in 1998.

5. Conclusion.

This paper has explored the determinants of firms' decision to engage in vertical (suppliers, customers), horizontal (competitors) and research institutional (universities, research labs) types of R&D cooperation. Unlike previous studies we differentiated between these three different types of cooperation and use a broad set of determinants among which direction-specific incoming spillovers. In the modelling of cooperative decisions we limited potential problems of simultaneity bias between cooperation and its determinants, in particular R&D intensity and incoming spillovers by utilizing a two period dataset, which allowed us to employ lagged variables. In addition, we considered a sample of firms that did not (yet) cooperate in the first period, eliminating simultaneity problems. We used a multivariate probit model to reflect that firms consider simultaneously the decisions to cooperate with various partners. Positive correlations between the equations suggested that various cooperation decisions tend to be viewed by the firms as complimentary. Our results confirm that incoming spillovers are an important determinant of R&D cooperation, with vertical spillovers leading to vertical cooperation and institutional spillovers having a large impact on institutional cooperation. We found no significant impact of horizontal spillovers on horizontal cooperation, which might be attributed to insufficient controls in the empirical model for firm-specific outgoing spillovers. Institutional incoming spillovers also stimulate cooperation of the other two types, suggesting that this knowledge is more generic in nature and improves the general effectiveness of the firm's R&D

activities and R&D cooperation. R&D intensity has a positive impact on vertical and institutional cooperation, but with a decreasing marginal effect primarily on the former. This variable has no significant impact in horizontal cooperation equation. Firms with high R&D-intensities are likely to face higher risks of leakage of proprietary knowledge to the cooperating partner in case R&D cooperation is with rival firms. Larger firms are more likely to engage in any kind of R&D cooperation, with the largest firms more likely to cooperate with universities and research institutes. This suggests that larger firms are more likely to have the critical size and absorptive capacity required to engage in R&D cooperation, while R&D cooperation with universities and institutes requires the largest critical size. Cost, risk, and organizational constraints in the firm's innovation process generally have a positive impact on R&D cooperation, with the most robust result the risk factor on horizontal cooperation. For newly formed cooperation, the importance of internal knowledge flows between firms within the same grouping reduces the propensity to cooperate. R&D cooperation with institutions and competitors is more likely in case of greater technological uncertainty. The presence of large innovating rivals in an industry makes horizontal cooperation more likely, indicating that these firms are attractive cooperation partners. Foreign multinationals were found to have a lower propensity to engage in horizontal cooperation, but are not less inclined to cooperate vertically or with universities and research institutes. The estimated impact of R&D subsidies is sample sensitive: they appear to have a positive effect on R&D cooperation in the full model, but firms that have previously been granted a subsidy are less inclined to engage in horizontal cooperation. The latter effect may indicate that subsidies make cooperation less necessary to share costs or that firms do not wish to share funds with competing firms.

The results show that there is substantial 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.

Table 1. Descriptive statistics

	Sample mean (n=2156)	Mean non-cooperating firms (n=1547)	Mean cooperating firms (n=609)	Sample Mean new cooperation (n=1488)
Org. capability constraint	0.042	0.033	0.067	0.034
Cost constraint	0.061	0.054	0.080	0.047
Risk constraint	0.101	0.081	0.151	0.075
Horizontal incoming spillovers	1.107	1.070	1.202	1.024
Vertical incoming spillovers	1.268	1.234	1.355	1.191
Institutional incoming spillovers	0.445	0.363	0.656	0.343
Internal knowledge flows	0.538	0.563	0.474	0.575
Foreign multinational	0.279	0.273	0.294	0.274
R&D subsidy	0.435	0.378	0.578	0.357
Industry outgoing spillovers	0.711	0.703	0.729	0.705
R&D intensity	0.029	0.025	0.039	0.024
R&D intensity sq.	0.004	0.003	0.005	0.003
Firm size	4.455	4.303	4.841	4.270
Technological uncertainty	0.501	0.491	0.526	0.495
Industry sale effect	0.080	0.077	0.088	0.076
Service dummy	0.349	0.357	0.328	0.350

Table 2. Distribution of cases by the dependent variable

Number of cases		Number of cases for new cooperation	(New) Horizontal cooperation	(New) Vertical cooperation	(New) Institutional cooperation
	1547	1219	0	0	0
	39	19	0	0	1
	204	105	0	1	0
	136	41	0	1	1
	43	26	1	0	0
	31	13	1	0	1
	47	26	1	1	0
	109	39	1	1	1
Total	2156	1488			

Table 3. Individual probit results

	(1) Horizontal Cooperation	(2) Vertical Cooperation	(3) Institutional cooperation
Org. capability constraint	-0.172	0.551	0.398
	(0.269)	(0.215)**	(0.235)*
Cost constraint	0.029	-0.266	0.543
	(0.349)	(0.295)	(0.324)*
Risk constraint	0.391	0.305	0.030
	(0.155)**	(0.133)**	(0.153)
Horizontal incoming spillovers	0.027	-0.055	-0.012
	(0.046)	(0.039)	(0.045)
Vertical incoming spillovers	-0.070	0.142	-0.035
	(0.058)	(0.049)***	(0.057)
Institutional incoming spillovers	0.329	0.247	0.473
	(0.066)***	(0.057)***	(0.063)***
Internal knowledge flows	0.014	-0.034	-0.083
	(0.070)	(0.065)	(0.079)
Foreign multinational	-0.247	0.016	-0.101
	(0.091)***	(0.071)	(0.084)
R&D subsidy	-0.040	0.222	0.190
	(0.090)	(0.073)***	(0.084)**
Industry outgoing spillovers	-0.554	0.223	-0.221
	(0.310)*	(0.269)	(0.301)
R&D Intensity	1.848	4.040	4.065
	(1.658)	(1.480)***	(1.575)***
R&D intensity squared	-2.729	-11.976	-8.964
	(5.248)	(5.226)**	(5.153)*
Firm size	0.138	0.188	0.245
	(0.031)***	(0.027)***	(0.032)***
Technological uncertainty	0.510	0.261	0.916
	(0.242)**	(0.211)	(0.254)***
Industry average firm size	0.881	0.227	0.455
	(0.394)**	(0.373)	(0.409)
Service dummy	0.213	0.161	-0.035
	(0.093)**	(0.080)**	(0.094)
Constant	-2.026	-2.425	-2.943
	(0.276)***	(0.238)***	(0.285)***
Observations	2156	2156	2156
LL	-681.07	-1061.70	-750.67
Chi2	101.84	202.24	291.98

* significant at 10%; ** significant at 5%; *** significant at 1%
Standard errors in parentheses

Table 4. Multivariate probit, 3 equations

	(1) Horizontal Cooperation	(2) Vertical Cooperation	(3) Institutional cooperation
Org. capability constraint	-0.243	0.569	0.402
	(0.263)	(0.215)***	(0.228)*
Cost constraint	0.133	-0.305	0.504
	(0.337)	(0.295)	(0.317)
Risk constraint	0.388	0.289	0.029
	(0.151)**	(0.131)**	(0.145)
Horizontal incoming spillovers	0.003	-0.056	-0.009
	(0.045)	(0.038)	(0.043)
Vertical incoming spillovers	-0.082	0.144	-0.042
	(0.056)	(0.048)***	(0.054)
Institutional incoming spillovers	0.322	0.243	0.463
	(0.066)***	(0.057)***	(0.062)***
Internal knowledge flows	-0.018	-0.031	-0.111
	(0.071)	(0.065)	(0.081)
Foreign multinational	-0.210	0.016	-0.020
	(0.088)**	(0.071)	(0.078)
R&D subsidy	-0.017	0.231	0.219
	(0.087)	(0.073)***	(0.082)***
Industry outgoing spillovers	-0.474	0.194	-0.305
	(0.297)	(0.266)	(0.288)
R&D Intensity	1.777	3.976	3.707
	(1.660)	(1.454)***	(1.555)**
R&D intensity squared	-3.357	-11.193	-7.570
	(5.293)	(4.953)**	(5.058)
Firm size	0.139	0.188	0.224
	(0.031)***	(0.028)***	(0.030)***
Technological uncertainty	0.452	0.288	0.910
	(0.239)*	(0.210)	(0.242)***
Industry average firm size	0.923	0.254	0.440
	(0.390)**	(0.372)	(0.408)
Service dummy	0.219	0.171	-0.013
	(0.093)**	(0.080)**	(0.091)
Constant	-2.018	-2.435	-2.787
	(0.266)***	(0.236)***	(0.260)***
Rho12	0.622		
	(0.034)***		
Rho13	0.736		
	(0.030)***		
Rho23	0.779		
	(0.024)***		
Observations	2156		
LL	-2139.47		
Chi2	367.91		

* significant at 10%; ** significant at 5%; *** significant at 1%

Standard errors in parentheses
Estimation is based on 1000 draws

Table 5. Univariate probits for new cooperation

	(1) hcopnew	(2) vcopnew	(3) gcopnew	(4) hcopnew	(5) vcopnew	(6) gcopnew
Org. capability constraint	-0.356	0.660	0.447	-0.705	0.495	0.454
	(0.349)	(0.276)**	(0.282)	(0.489)	(0.298)*	(0.358)
Cost constraint	-0.385	-0.743	0.017	-0.412	-0.875	-0.572
	(0.445)	(0.438)*	(0.418)	(0.582)	(0.476)*	(0.590)
Risk constraint	0.356	0.209	0.041	0.450	0.243	-0.109
	(0.188)*	(0.185)	(0.190)	(0.246)*	(0.200)	(0.264)
Horizontal incoming spillovers	0.003	-0.084	-0.007	-0.054	-0.087	-0.033
	(0.052)	(0.048)*	(0.052)	(0.062)	(0.051)*	(0.063)
Vertical incoming spillovers	-0.033	0.017	-0.040	-0.007	0.047	-0.068
	(0.066)	(0.060)	(0.067)	(0.077)	(0.065)	(0.081)
Institutional incoming spillovers	0.328	0.194	0.322	0.214	0.136	0.309
	(0.077)***	(0.075)***	(0.079)***	(0.100)**	(0.082)*	(0.095)***
Internal knowledge flows	-0.011	-0.162	-0.219	-0.018	-0.142	-0.337
	(0.085)	(0.087)*	(0.122)*	(0.089)	(0.087)	(0.156)**
Foreign multinational	-0.160	0.037	-0.043	-0.243	-0.022	0.080
	(0.102)	(0.091)	(0.099)	(0.126)*	(0.097)	(0.118)
R&D subsidy	-0.152	0.134	0.036	-0.290	0.074	-0.119
	(0.104)	(0.092)	(0.099)	(0.128)**	(0.099)	(0.121)
Industry outgoing spillovers	-0.177	0.277	-0.082	-0.170	0.302	-0.104
	(0.358)	(0.347)	(0.366)	(0.436)	(0.386)	(0.441)
R&D Intensity	-1.261	4.154	3.993	3.040	4.573	7.401
	(1.977)	(2.069)**	(2.062)*	(2.788)	(2.173)**	(3.113)**
R&D intensity squared	5.730	-15.453	-10.285	-9.620	-13.473	-31.367
	(5.824)	(7.864)**	(7.412)	(10.684)	(8.018)*	(15.362)**
Firm size	0.088	0.215	0.213	0.112	0.215	0.238
	(0.036)**	(0.037)***	(0.040)***	(0.046)**	(0.039)***	(0.049)***
Technological uncertainty	0.296	0.276	0.932	0.089	0.269	1.219
	(0.284)	(0.266)	(0.300)***	(0.341)	(0.284)	(0.374)***
Industry average firm size	1.142	-0.176	0.315	0.828	-0.598	0.517
	(0.442)***	(0.486)	(0.520)	(0.550)	(0.604)	(0.623)
Service dummy	0.134	0.267	-0.018	0.104	0.286	-0.040
	(0.108)	(0.098)***	(0.109)	(0.126)	(0.105)***	(0.133)
Constant	-1.959	-2.456	-2.801	-1.894	-2.467	-3.021
	(0.310)***	(0.296)***	(0.331)***	(0.360)***	(0.315)***	(0.402)***
Observations	1914	1609	1863	1488	1488	1488
LL	-514.46	-647.25	-532.74	-362.41	-573.59	-356.18
Chi2	47.36	92.04	104.39	29.18	67.68	82.42

* significant at 10%; ** significant at 5%; *** significant at 1%
Standard errors in parentheses

Table 6. Multivariate probit, 3 equations on new cooperation

	(1) Horizontal Cooperation	(2) Vertical Cooperation	(3) Institutional cooperation
Org. capability constraint	-0.675	0.488	0.427
	(0.431)	(0.299)	(0.335)
Cost constraint	-0.427	-0.956	-0.728
	(0.562)	(0.479)**	(0.555)
Risk constraint	0.434	0.261	-0.015
	(0.235)*	(0.199)	(0.242)
Horizontal incoming spillovers	-0.068	-0.094	-0.052
	(0.061)	(0.051)*	(0.057)
Vertical incoming spillovers	-0.006	0.039	-0.027
	(0.075)	(0.065)	(0.072)
Institutional incoming spillovers	0.232	0.126	0.298
	(0.098)**	(0.083)	(0.090)***
Internal knowledge flows	-0.013	-0.165	-0.306
	(0.086)	(0.088)*	(0.125)**
Foreign multinational	-0.276	-0.022	0.149
	(0.122)**	(0.097)	(0.104)
R&D subsidy	-0.247	0.081	-0.071
	(0.119)**	(0.099)	(0.114)
Industry outgoing spillovers	0.057	0.302	0.038
	(0.430)	(0.384)	(0.415)
R&D Intensity	0.944	4.955	5.788
	(2.951)	(2.174)**	(2.874)**
R&D intensity squared	-7.177	-13.778	-23.796
	(12.082)	(7.872)*	(13.358)*
Firm size	0.096	0.217	0.195
	(0.044)**	(0.040)***	(0.046)***
Technological uncertainty	0.055	0.263	0.996
	(0.330)	(0.285)	(0.338)***
Industry average firm size	0.990	-0.801	0.495
	(0.545)*	(0.627)	(0.619)
Service dummy	0.163	0.291	0.050
	(0.121)	(0.105)***	(0.121)
Constant	-1.964	-2.452	-2.857
	(0.348)***	(0.313)***	(0.364)***
Rho12	0.720		
	(0.043)***		
Rho13	0.813		
	(0.036)***		
Rho23	0.759		
	(0.035)***		
Observations	1488		
LL	-1089.97		
Chi2	144.04		

* significant at 10%; ** significant at 5%; *** significant at 1%

Standard errors in parentheses
Estimation is based on 1000 draws

Table 7. Correlations

(obs=2156)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(2)	0.3272													
(3)	0.3682	0.4624												
(4)	0.0516	0.0690	0.0898											
(5)	0.0421	0.0934	0.0955	0.3638										
(6)	0.1169	0.1639	0.1458	0.2167	0.2255									
(7)	-0.0284	-0.0043	-0.0472	-0.2930	-0.4156	-0.2619								
(8)	-0.0035	0.0218	0.0092	0.0808	-0.0259	-0.0038	0.0927							
(9)	0.1043	0.1852	0.1760	0.1387	0.0759	0.3246	-0.0709	0.0195						
(10)	0.0531	0.0958	0.1002	0.1634	0.0766	0.1155	-0.0445	0.1511	0.2851					
(11)	0.0695	0.1729	0.1379	0.0970	0.0534	0.2227	-0.0237	0.0418	0.3275	0.2617				
(12)	0.0369	0.1059	0.0801	0.0338	0.0198	0.1432	-0.0095	0.0110	0.1829	0.1369	0.8870			
(13)	0.0327	0.0337	0.0899	0.1483	0.0173	0.1407	0.0501	0.1639	0.1699	0.0275	-0.0044	-0.0151		
(14)	0.0446	0.0747	0.0829	0.0727	0.0481	0.1151	-0.0883	0.0117	0.2334	0.4875	0.2109	0.1343	-0.0039	
(15)	0.0087	0.0170	0.0266	-0.0126	-0.0229	0.0505	0.0128	0.0499	0.0306	0.0888	-0.0116	-0.0184	0.1605	-0.2456

(1) Org. capability constraint
(2) Cost constraint
(3) Risk constraint
(4) Incoming Horizontal spillovers
(5) Incoming Vertical spillovers
(6) Incoming institutional spillovers
(7) Internal knowledge flows
(8) Foreign multinational
(9) R&D subsidy
(10) Industry outgoing spillovers
(11) R&D Intensity
(12 R&D intensity squared
(13) Firm Size
(14) Industry technological uncertainty
(15) Industry average firm size

Appendix A: Description of Variables

#	variable name	Definition
1	R&D intensity	R&D employees/total employees
2	R& D intensity squared	R&D employees/total employees squared
3	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
4	Risk constraint	Average of scores on the following responses: innovation project not started due to economic risks not started due to uncertain markets
5	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
6	Horizontal incoming spillover	Importance of competitors as source of knowledge for the firm's innovation process.
7	Vertical incoming spillover	Average of importance of clients and suppliers as source of knowledge for the firm's innovation process
8	Institutional incoming spillover	Average of importance of universities, innovation centers, and research institutions as source of knowledge for the firm's innovation process.
9	Internal knowledge flows	Importance of own establishment and 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
10	R&D subsidy	1 if firm received subsidy for innovation activities, else 0
11	Industry outgoing spillovers	Mean of scores of importance of information received from competitors and patents for all firms operating in the (2-digit) industry.
12	Firm size	Logarithm of number of employees
13	Technological uncertainty	Sum of sales of firms in the 2-digit industry that stated that they had introduced products new to the industry, divided by sum of sales of all firms in the industry.
14	Industry average firm size	Mean of sales by all innovating firms operating in the 2-digit industry.
15	Service dummy	1 if business unit belongs to the services sector, else 0
16	Foreign multinational	1 if headquarters of the firm is located outside the Netherlands, else 0

Note: all variables are derived from the 1996 CIS survey

Appendix B: Tabulation of 2-digit SBI codes

Tabulation of two-digit SBI codes for the sample used in estimation

SBI code	Frequency	Percent	Cummulative
11,14	9	0.42	0.42
15,16	137	6.35	6.77
17 – 19	55	2.55	9.32
21	59	2.74	12.06
22	69	3.20	15.26
23,24	98	4.55	19.81
25	77	3.57	23.38
27	26	1.21	24.58
28	154	7.14	31.73
29	177	8.21	39.94
30 - 33	127	5.89	45.83
34,35	84	3.90	49.72
20,26,36,37	163	7.56	57.28
40,41	23	1.07	58.35
45	145	6.73	65.07
50 - 55	386	17.90	82.98
60 - 64	108	5.01	87.99
70 - 74	228	10.58	98.56
90,93	31	1.44	100.00
Total	2156	100.00	

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