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Cooperative R&D and firm performance☆

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Abstract

We analyse the impact of R&D cooperation on firm performance differentiating between four types of R&D partners (competitors, suppliers, customers, and universities and research institutes), and considering two performance measures: labour productivity and productivity in innovative (new to the market) sales. Using data on a large sample of Dutch innovating firms in two waves of the Community Innovation Survey (1996, 1998), we examine the impact of R&D cooperation in 1996 on subsequent productivity growth in 1996–1998. The results confirm a major heterogeneity in the rationales and goals of R&D cooperation. Competitor and supplier cooperation focus on incremental innovations, improving the productivity performance of firms. University cooperation and again competitor cooperation are instrumental in creating innovations generating sales of products that are novel to the market, improving the growth performance of firms. Furthermore, customers and universities are important sources of knowledge for firms pursuing radical innovations, which facilitate growth in innovative sales in the absence of formal R&D cooperation.

JEL classification: D24; O31; O32

Keywords: R&D; Cooperation; Spillovers; Productivity

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1. Introduction

The observed substantial increase in R&D alliances in the late 1980s and throughout the 1990s, in particular in sectors such as biotechnology and information technology (Hagedoorn, 2002; Tyler and Steensma, 1995) has provoked a substantial academic and policy interest in the phenomenon. A large body of literature in the management domain has been produced that discusses various motives that incite firms to collaborate on R&D (Contractor and Lorange, 2002; Nooteboom, 1999). In parallel, a stream of literature in industrial organization theory has taken a game theoretical perspective to focus on the relationships between R&D cooperation, R&D investment, and inter-firm knowledge flows (termed “knowledge spillovers”). The latter literature has been most concerned with the potential impact of R&D cooperation and knowledge spillovers on R&D investment levels, and has largely been restricted to the analysis of cooperation with direct competitors. By and large, the findings suggest that the presence of (potential) effective knowledge spillovers between firms provides incentives for R&D cooperation, which in turn leads to higher R&D investment levels.

A number of empirical studies have explored the determinants of R&D cooperation (e.g. Kleinknecht and Reijnen, 1992; Fritsch and Lukas, 2001; Tether, 2002; Belderbos et al., 2004). A major finding of recent contributions is that the goals and, hence, the determinants of R&D partnerships differ depending on the type of R&D and cooperation partner. Fritsch and Lukas (2001) find for German manufacturing firms that innovative effort directed at process improvement is more likely to involve cooperation with suppliers, whereas product innovations are associated with customer cooperation. Tether (2002), using UK data on innovating firms, finds that R&D cooperation is mostly the domain of firms pursuing radical innovations rather than incremental innovations. Distinguishing more specifically between partnerships with competitors, suppliers, customers, and universities and research institutes, Belderbos et al. (2004) find substantial heterogeneity in the determinants to establish R&D collaborations with different partners. Cooperation with a type of partner generally is more likely to be chosen if that type of partner is considered an important source of knowledge for the innovation process, while knowledge sourced from universities and research institutes positively impacts all types of cooperation. R&D cooperation with universities is more likely to be chosen by R&D intensive firms in sectors that exhibit faster technological and product development.

Surprisingly, the key question whether cooperative R&D has the expected positive impact on firms’ (innovation) performance has remained largely unexplored in both the industrial organization as well as in the management literature (e.g. Tether, 2002; Das and Teng, 2000). A number of papers have included a cooperation variable in empirical models explaining differences in firms’ innovation output (Janz et al., 2003; van Leeuwen and Klomp, 2001; Klomp and van Leeuwen, 2001; Lööf and Heshmati, 2002; Monjon and Waelbroeck, 2003; Criscuolo and Haskel, 2003), but most of these studies have been primarily concerned with the impact of R&D investments on performance and did not examine systematically differences in impacts across cooperation types. Management studies have restricted analysis to particular performance indicators in specific industries, e.g. the effect of alliances on high tech start-up firm performance in the biotech industry (Baum et al., 2000), or the effect of learning in alliances on market share performance in the global automotive industry (Dussauge et al., 2002).

The contribution of this paper is to examine in detail the effects of different types of R&D cooperation on firm performance. We consider the impact of the four major types of partner-specific cooperation strategies: cooperation with competitors, suppliers, customers, and research institutes and universities. We analyse the effects of these R&D partnerships on two alternative performance measures for a large sample of Dutch firms active in manufacturing and service industries: growth of value added per employee (labour productivity), and growth of sales per employee from products new to the market (which we term ‘innovative sales productivity’). The analysis controls for the potential impact of incoming knowledge flows that are not due to R&D partnerships, as well as for the effect of the firms’ own R&D expenditures. Using data on a large sample of innovating firms in two waves of the biannual Dutch Community Innovation Survey (1996, 1998) linked to production statistics, the analysis allows for an appropriate time lag with which the impact of R&D cooperation (1996) feeds through in productivity growth (1996–1998).

The remainder of the paper is organized as follows: Section 2 provides an overview of the previous theoretical and empirical literature discussing the impact of R&D (cooperation) and knowledge spillovers on firm performance. Section 3 describes the empirical model and data. Section 4 discusses the empirical results and Section 5 gives the conclusion.

2. Previous literature

In this section, we will briefly review the theoretical and empirical literature on R&D cooperation, knowledge spillovers and productivity. A first stream of relevant literature relates to theoretical R&D cooperation models in the industrial organization tradition. This literature has focused on the role of knowledge spillovers between (potential) R&D cooperation partners. In the absence of cooperation, knowledge spillovers to competing firms are considered involuntary, as they increase the knowledge stock of competing firms and may weaken the firm's relative market position. The existence of such involuntary spillovers reduces the effectiveness of the firms' R&D efforts as they cannot appropriate all of the returns, and this results in lower R&D investment levels. R&D cooperation enables firms to internalise the knowledge spillovers and eliminate the disincentive effect of spillovers on R&D (e.g. Amir, 2003; De Bondt, 1996; Kamien et al., 1992; Suzumura, 1992; Leahy and Neary, 1997). Most of these studies make the rather implausible assumption that the level of knowledge spillovers is given and unaffected by the cooperation itself. A number of recent papers have enriched the analysis by taking into account that cooperation allows firms to increase knowledge transfers *voluntarily* among the cooperating partners (Katsoulacos and Ulph, 1998). Firms have incentives to manage the flow of spillovers to and from competitors by attempting to maximize incoming spillovers through R&D collaboration while at the same time minimizing outgoing spillovers through investments in knowledge protection (Cassiman et al., 2002; Martin, 1999; Amir et al., 2003). A limitation of this line of theoretical research is that it has been strictly focusing on R&D cooperation with competing firms, and has paid little attention to R&D collaboration with universities, or with firms that are not direct competitors. An exception is Atallah (2002), who finds that collaboration with 'vertical' partners (client firms or supplier firms) is already induced by small levels of knowledge spillovers, as pooling of R&D with vertical partners has no direct effect on competition in output markets.

The literature in the management and technology policy domain has examined broader motivations for R&D cooperation than internalising involuntary knowledge spillovers and has paid more attention to the voluntary nature of knowledge exchange in R&D alliances. Explanations for collaborative R&D that have been extensively discussed revolve around factors such as sharing risks and costs in the face of uncertain technological developments (Das and Teng, 2000; Tyler and Steensma, 1995), shortening innovation cycles (Pisano, 1990), the pursuit of efficiency gains such as economies of scope and scale or synergistic effects through efficient pooling of the firms' resources (Kogut, 1988; Das and Teng, 2000), learning through monitoring technology and market developments (Hamel, 1991; Roberts and Berry, 1985), dealing with regulations and industry standards, and responding to government subsidy policies (Benfratello and Sembenelli, 2002; Nakamura, 2003). Although it has been noted more generally that a substantial share of alliances fail (Harrigan, 1986), R&D alliances may be a source of competitive advantage and have long lasting effects on firm performance. Teece (1980) argues that organizational practices affect firms' performance and can explain sustained performance differences within industries due to slow diffusion of best practices and difficulties in imitating complex organizational capabilities. It has also been suggested that different types of collaboration may serve different purposes, where the two main goals of innovative effort are cost reduction and market expansion. Collaboration with customers is important to reduce the risk associated with the market introduction of innovations, as has been recognized since Von Hippel (1988). In particular, when products are novel and complex and hence require adaptations in use by customers, collaboration may be essential to ensure market expansion (Tether, 2002). In contrast, cooperation with suppliers is often related to the tendency to focus on core business through outsourcing, while closely collaborating with suppliers to guarantee input quality improvements aimed at further cost reductions. Cooperation with universities and research institutes is generally more aimed at innovations that may open up entire new markets or market segments (Tether, 2002; Monjon and Waelbroeck, 2003).

A number of empirical studies have found a positive impact of engaging in R&D cooperation on innovation performance, i.e. sales of innovative products (e.g. Klomp and van Leeuwen, 2001; Janz et al., 2003; van Leeuwen, 2002; Lööf and Heshmati, 2002; Criscuolo and Haskel, 2003; Faems et al., 2004), patenting (Vanhaverbeke et al., 2002), and sales growth (Cincera et al., in press). Some of these papers have also examined the effect of different cooperation types, but have produced ambiguous results. Faems et al. (2004) used cross-section data from Belgian CIS survey in 1992 and found a positive association between university cooperation and the share in firm sales of innovative products new to the market, while an aggregate measure of other cooperation types was positively associated with the share in firm sales of innovative products new to the firm (but not new to the market). Monjon and Waelbroeck (2003) regressed innovative sales levels of firms in a French CIS survey on a range of collaboration and incoming knowledge spillover variables and found a mixture of negative and positive impacts of R&D cooperation and spillovers. Cincera et al. (in press) distinguished between overseas and domestic R&D collaboration by Belgian firms and found a positive impact on productivity of the latter but a counter-intuitive negative impact of the former. Lööf and Heshmati (2002) included a selected group of cooperation types in an innovation output equation for Swedish firms and found that cooperation with competitors and universities impacted innovation output levels positively, but cooperation with customers negatively. As the above studies use cross-sectional data drawn from a single survey, the ambiguous results may be partly attributed to the difficulties in allowing for an appropriate lag with which cooperative R&D impacts innovative output and performance. At the same time, if there are unobserved firm characteristics that impact at the same time firms' incentives to cooperate and their innovative output, a positive correlation between cooperation and innovation may be spurious rather than causal (Van Leeuwen and Klomp, 2001).

There is a large body of empirical literature examining the sources of productivity growth and in particular, the role of inter-firm knowledge spillovers (e.g. Adams and Jaffe, 1996; Branstetter, 2001; Coe and Helpman, 1995; Basant and Flikkert, 1996). These studies have generally confirmed that knowledge spillovers that may arise from interaction with other firms through international trade, foreign direct investments, and input–output linkages, have a positive impact on productivity growth. Similarly, empirical studies have documented the positive impact of own R&D on productivity at the firm level (e.g. Grilliches and Mairesse, 1984; Lichtenberg and Siegel, 1991; Hall and Mairesse, 1995). A related literature has been concerned with the role of foreign multinational enterprises (MNEs) in productivity performance (Griffith, 1999; Harris and Robinson, 2003). In these studies MNEs are generally found to be more productive than their local industry competitors, which is attributed to MNEs efficient exploitation of firm-specific assets allowing for multi-plant economies of scale (e.g. Pfaffermayr, 1999) and the transfer of accumulated tacit and specialized knowledge on production (Aitken and Harrison, 1999).

In summary, the literature suggests that an analysis of different types of cooperation strategies should take into account the different possible aims of (collaborative) R&D efforts. Labour productivity increases may be more reflective of incremental innovations and affected by collaborative R&D aimed at cost reductions, while sales expansion through innovative products is more likely to be related to basic R&D efforts and client collaboration. We explore this by examining empirically the effect of cooperation on two different types of productivity performance: labour productivity growth and the growth in sales of innovative products that are new to the market per employee ('innovative sales productivity'). Furthermore, we follow the suggestion in the literature that analysis of the performance effects of R&D cooperation should control for the positive impact of incoming knowledge spillovers, as well as R&D expenditures, while the existence of multinational group linkages should also be taken into account. Since the analysis couples two waves of the Community Innovation Survey, the analysis can allow for an appropriate time lag between R&D and innovative performance, while the potential bias of unobserved firm characteristics is reduced by including lagged productivity levels as an explanatory variable.

3. Empirical model, data and descriptive statistics

The goal of the empirical analysis is to determine whether different types of R&D collaboration affect a firm's growth in labour productivity and innovative sales productivity. To examine this effect the analysis should control for the effect of own R&D efforts as well as the impact of incoming knowledge flows that are not due to cooperation. Our specification in Eq. (1) has as dependent variable, the growth in productivity from 1996 (t) to 1998 ($t + 1$). We include explanatory variables measured in the preceding period as well as the lagged level of productivity (in 1996). In the absence of the possibility of including fixed firm effects, this specification has the major advantage that it partly adjusts for unobserved firm attributes that are relatively constant over time.[1] We estimate the following growth in productivity equation:

$$\begin{aligned}\Delta \log(\text{prodv})_i = {} & \alpha + \beta X_i + \delta \text{rdint}_i + \zeta_1 \text{Comp\_coop}_i \\ & + \zeta_2 \text{Cust\_coop}_i + \zeta_3 \text{Supp\_coop}_i \\ & + \zeta_4 \text{Univ\_coop}_i + \gamma_1 \text{Comp\_spil}_i \\ & + \gamma_2 \text{Cust\_spil}_i + \gamma_3 \text{Supp\_spil}_i \\ & + \gamma_4 \text{Univ\_spil}_i + \theta \log(\text{prodv})_i + \varepsilon_i \end{aligned} \tag{1}$$

where all right-hand side variables are measured at time t and where $\Delta \log(\text{prodv})_i = \log(\text{prodv}_{i,t+1}) - \log(\text{prodv}_{i,t})$ is the growth in productivity measured as either value added per employee or sales generated by new to the market products per employee, respectively. Labour productivity growth will be most affected by cost reducing innovation, while innovative sales productivity growth is more affected by demand expansion oriented innovation. Differences in the impact of cooperative R&D on the two performance measures can demonstrate the variety in purposes of different collaborative strategies. The model includes four dummies for cooperation types with the different possible partners: competitors, customers, suppliers, and universities and research institutes (henceforward for convenience labelled 'universities').[2] The same potential partners are identified by the firms as potential sources of incoming knowledge spillovers, which are expected to have an additional impact on productivity growth. The model also includes the firm's innovation expenditure as percentage of sales (innovation intensity). The log(Prodv) variable is the firm's productivity level in 1996. Since highly productive firms that are at the frontier of productivity are less likely to be able to achieve strong growth rates in productivity than firms that are followers, we expect θ to fall within the interval $[-1, 0]$.[3] If θ is zero, the productivity frontier effect is absent and there is no gradual convergence between leading firms and productivity laggards. If θ is -1, than a productivity lead in one period is fully neutralized in the next and past productivity has no impact on future productivity levels.[4] The X-vector consists of other firm-level control variables, such as size, dummy variables controlling for foreign and domestic group membership, dummies for the stated objectives of innovation (cost reducing versus product improving), and dummies for the industry of the firm at the two-digit level.

One worry is that our specification does not allow separating the effect of the incoming spillovers from the effect of cooperation: cooperation can have a direct effect on productivity but will at the same time increase the reported incoming spillovers from the collaboration partner firm/institution. Since we are interested in estimating the full impact of formal cooperation, we have to separate spillovers due to purposeful informational exchanges that arise in formal cooperative arrangements from spillovers that are not due to such cooperation (e.g. arising from market contacts with suppliers and customers). We want to adjust the spillover variables from the

[1] A second advantage is that it allows for the effects of the exogenous variables to be interpreted in line with Granger-causation. The Granger approach to the question of whether x causes y is to see to what extent the current y is explained by past values of y and then to consider whether adding lagged values of x can improve the statistical explanation. The variable is said to be Granger-caused by x if the coefficients on the lagged values of are statistically significant. Note that the current model is restricted to a single lag in both x and y.

[2] We do not include cooperation with consultants in the empirical analysis because of its heterogeneous character and doubts whether linkages with consultants are genuine R&D efforts.

[3] Since the model includes a full set of industry dummies, this variable can also be interpreted as the effect of the productivity level of the firm relative to the industry mean in 1996.

[4] To see this one can simply rewrite the relevant part of (1) as $\log(\text{prodv}_{t+1}) = (1 + \theta)(\text{prodv}_t)$.

influence of formal cooperation such that the estimated coefficients for R&D cooperation measure the full impact of R&D collaboration on productivity growth. This adjusted measure can be obtained by taking the residuals obtained from regressing the full spillover variable by partner on the corresponding cooperation variable (we added a set of industry dummies).

$$\text{Comp\_spil}_i = \lambda_{\text{hor}}\,\text{Comp\_coop}_i + Z_i + \eta_i^{\text{comp}} \qquad (2)$$

$$\text{Cust\_spil}_i = \lambda_{\text{cust}}\,\text{Cust\_coop}_i + Z_i + \eta_i^{\text{cust}} \qquad (3)$$

$$\text{Supp\_spil}_i = \lambda_{\text{supp}}\,\text{Supp\_coop}_i + Z_i + \eta_i^{\text{supp}} \qquad (4)$$

$$\text{Univ\_spil}_i = \lambda_{\text{inst}}\,\text{Univ\_coop}_i + Z_i + \eta_i^{\text{univ}} \qquad (5)$$

The estimated residuals from these equations $\hat{\eta}_t^{\text{comp}}$ through $\hat{\eta}_i^{\text{univ}}$ are then included in place of the spillover variables Comp_spil_i through Univ_spil_i in our specification. The residuals are no longer systematically related to firms' R&D collaborations and are not due to purposeful exchanges in R&D partnerships.[5]

3.1. Data and variables

The empirical analysis uses the data from two consecutive Community Innovation Surveys (CIS) conducted in 1996 and 1998 in the Netherlands, as well as information from the production statistics database in the same years. It has been only recently that researchers have been able to utilize consecutive CIS surveys merged with production statistics.[6] An additional advantage of the Dutch CIS surveys is that they have been held every other year rather than in 4-year intervals as has been customary in other EU countries. This allows us to more accurately examine performance changes over a suitable period (2 years). The CIS surveys, conducted by Statistics Netherlands (CBS) contains information concerning R&D and innovation activities of the firm, including innovation expenditures, innovation in partnership data and sources of knowledge used in the innovation process. The production statistics database includes information on output, employment, and value added. The CIS and production statistics surveys are sent to all large firms and to a random sample of smaller firms in the Netherlands. To create a 2-year data set, 6327 innovating firms in 1998 are matched with information on these firms in 1996 survey: 2353 firms could be linked to the 1996 survey and were classified as innovating firms in that survey. We then linked these firms via a unique id number to the production statistics data. The data are at the establishment level and include manufacturing as well as service firms. Due to the missing values for some of the explanatory variables the complete sample includes 2056 firms.

The labour productivity growth variable is the growth in net value added per employee (drawn from the production statistics) between 1996 and 1998. The alternative performance measure 'innovation sales productivity growth' is the growth in the value of sales per employee of product and services that are new to the market, between 1996 and 1998. This variable is drawn from the CIS surveys, in which firms are asked to indicate what percentage of sales has been due products or services introduced in the passed 2 years that were new to the industry, not just novel to the firm. Firms that increase the performance on this variable are likely to be more productive in the pursuit of more substantial rather than incremental innovations. These in turn are a prerequisite for further firm growth (Klomp and Van Leeuwen, 2001).

The cooperation variables are taken from the 1996 CIS survey and are dummy variables taking the value one if the firm indicated that it was or had been engaged during 1994–1996 in active R&D cooperation with competitors, suppliers, customers, and universities or research institutes, respectively. Hence we posit that cooperative R&D projects in 1994–1996 have their main impact on productivity growth in the 2-year period 1996–1998. This is a relatively plausible assumption, given that R&D efforts require some time to translate into innovative output and productivity ad-

[5] Whereas the four knowledge spillover variables included in the model identify the *source* of the spillover, there are a number of other types of incoming spillovers in the CIS survey that identify the *channel* of the spillover (databases, trade fairs, patents). There is a clear and arguably substantial overlap in these measures (e.g. if information from competitors is important, it may reach the firms through patents or trade shows) making it problematic to include all types of spillovers available in the survey. We did include a composite measure of all the other spillover ratings by the firms in the empirical model, but this variable proved insignificant with no impact on the estimates of the four source-specific spillover measures. The source-specific spillovers are apparently able to capture the lion's share of the impact of incoming knowledge on productivity growth.

[6] Other examples are Belderbos et al. (2004) and Klomp and Van Leeuwen (2001).

vances. But it is not ruled out that some cooperative projects may have a faster impact on productivity. If this is the case, then early R&D projects (e.g. those started in or before 1994) may already have had their impact on 1996 productivity levels and show no further impact in 1996–1998, in which case the empirical results will underestimate the impact of cooperation. In order to address this empirically, we also test for the impact of an alternative cooperation measure: whether a firm is a ‘consistent’ R&D collaborator, i.e. whether the firm is cooperating with the respective type of partner both in 1996 and 1998. If cooperative projects have a relatively quick impact on productivity, the persistent cooperation variables may show more robust results.

Incoming knowledge spillovers are direct measures of the importance of different sources of incoming knowledge for the firms’ innovation process. The CIS survey asks each firm to rate on a Likert scale (1–5) the importance of various external sources of information in terms of the “effectiveness in the firms’ innovation process” in the past 2 years. Given this wording of the question (firms are asked to identify incoming knowledge that have already been effectively used in the innovation process), the answers are more likely to indicate the contribution of such spillovers to current innovation output than future innovation output. Hence, effective spillovers in 1994–1996 (the 1996 CIS survey) are likely to have their main impact on the 1996 productivity level rather than on subsequent productivity growth in 1996–1998. Therefore, we do not include the 1996 spillover measure but instead the spillover measure from the 1998 survey (effective spillovers during 1996–1998) in our model explaining 1996–1998 productivity growth. As discussed above, we do not use the scores as explanatory variables but adjust the spillover measures for the impact of cooperation. We regress the 1998 spillover rating by source on 1996 cooperation and a set of industry dummies, and take the residuals of these equations as a measure of spillovers that are not due to purposeful exchanges in formal R&D partnerships.

We also include an R&D input measure in line with the previous literature that documented a positive relationship between research intensity and productivity. Our R&D measure is total innovation expenditures as percentage of sales. Such expenditures include, in addition to internal R&D, expenditures on extramural R&D contracts paid to other firms and research centres, and expenditures on technology licenses, among others. Hence, the variable also controls for the impact of external technology acquisition. Innovation intensity is taken from the 1996 survey to allow for a 2-year lag with which innovation investments impact productivity.

Further control variables include a set of 2-digit industry dummies (we distinguish 19 industries) and firm size (the logarithm of the number of employees). We also allow for differences in productivity growth performance between independent firms and firms that are part of a domestic group or a foreign MNE. Group firms may show higher growth rates if they can draw on technology and organizational expertise from headquarters and other groups firms. The Dutch industrial structure is characterized by the presence of several large multinational corporations, such as Akzo-Nobel, DSM, Philips, Shell and Unilever, which are dominating the Dutch technological infrastructure and responsible for a large share of business R&D. These large companies function as the core of firm networks with comparable research intensities (i.e. Verspagen, 1999).

Finally, we include demand-pull and cost-push variables in the model as controls. The demand-pull variable is a sum of scores on the importance of objectives of innovation relating to demand factors. Cost-push is the sum of scores on importance of objectives relating to cost reduction. If cost-reduction is a major motivation for innovations efforts, it may be more likely that R&D translates directly into improved labour productivity. Demand expansion orientation is most likely to impact innovative sales productivity.

3.2. Descriptive statistics

The distribution of cases by industry and descriptive statistics is presented in Table 1. There are 630 firms with R&D cooperation of any type among the innovating firms in the combined sample. Supplier cooperation is the most frequent, with 375 firms indicating to be engaged in this type of collaboration, followed by customer cooperation (353 firms), university cooperation (280) and competitor cooperation (226). Some 1426 firms reported to have none of these four links. The comparison across industries indicates that

Table 1
Distribution of firms across industries and R&D cooperation strategies

NACE	Sector	No. of observation in sample	Share %	Share non-cooperating firms	No. of observation	Share if Competitor cooperation = 1	No. of observation	Share if supplier cooperation = 1	No. of observation	Share if customer cooperation = 1	No. of observation	Share if University Cooperation = 1	No. of observation
11, 14	Mining	6	0.3	0.4	5	0.0	0	0.0	0	0.0	0	0.4	1
15, 16	Food	134	6.5	6.4	91	7.5	17	8.3	31	7.1	25	10.7	30
17–19	Textile	51	2.5	2.7	38	2.7	6	2.4	9	2.0	7	2.9	8
21	Paper	59	2.9	2.7	38	3.5	8	4.3	16	3.4	12	4.6	13
22	Printing, publishing	69	3.4	3.9	56	1.3	3	2.1	8	1.1	4	0.7	2
23, 24	Petroleum and chemicals	93	4.5	3.5	50	4.9	11	5.1	19	8.8	31	7.5	21
25	Rubber and plastic	77	3.8	3.4	48	4.4	10	4.3	16	5.7	20	3.2	9
27	Metallurgy	26	1.3	0.8	11	3.1	7	2.9	11	3.1	11	3.6	10
28	Metal products	153	7.4	7.4	105	6.6	15	8.3	31	8.2	29	7.1	20
29	Machines, equipment	172	8.4	9.5	135	4.0	9	5.1	19	6.2	22	5.0	14
30–33	Electronics	125	6.1	5.8	83	4.9	11	5.6	21	7.4	26	8.2	23
34, 35	Cars and transport	84	4.1	3.9	55	6.6	15	4.5	17	4.3	15	5.4	15
20, 26, 36, 37	Other industry	149	7.3	7.7	110	7.1	16	5.6	21	5.4	19	5.4	15
40, 41	Utilities	23	1.1	0.8	11	3.1	7	1.6	6	1.1	4	2.9	8
45	Construction	143	7.0	7.5	107	8.0	18	6.1	23	3.7	13	8.2	23
50–55	Hotel, catering	364	17.7	18.1	258	15.0	34	18.7	70	15.9	56	9.3	26
60–64	Transportation, storage	86	4.2	4.6	66	3.1	7	3.5	13	4.0	14	1.1	3
70–74	Business services	214	10.4	9.8	140	13.3	30	10.1	38	11.1	39	12.9	36
90, 93	Environmental, other services	28	1.4	1.3	19	0.9	2	1.6	6	1.7	6	1.1	3
Total		2056	100.0	100.0	1426	100.0	226	100.0	375	100.0	353	100.0	280

the propensity to cooperate is not dissimilar between services and manufacturing industries. Cooperation is comparatively more frequent in (petro)chemicals, metallurgy, and business services. Science-based industries such as electronics and chemicals, but also the food and metallurgy industries, report a higher share of university cooperation compared to the other types of cooperation.

Table 2 provides a contingency table displaying the means of the variables used in the model by type of cooperation. This information provides some preliminary evidence that there exist significant differences along several key parameters between firms having an R&D cooperation link and the non-collaborating firms. Collaborating firms report substantially greater incoming spillovers of all four kinds compared to non-cooperating firms (the *F*-tests in columns 6–7 show that these differences are significant). With the exception of competitor spillovers, source-specific spillovers are greatest for firms that cooperate with the source, as expected (*F*-tests again show that these differences overall are significant). The most dramatic difference is in university spillovers: firms that engage in R&D collaborations with universities or research institutes report to receive spillovers more than twice the magnitude as spillovers benefiting non-collaborating firms. These figures indicate that the importance for the firms' innovation process of knowledge coming from a specific source is a reason to engage in cooperation (Belderbos et al., 2004), but they are also indicative of subsequent purposeful increases in knowledge transfers within the collaborative agreement. Table 2 also shows cooperating firms to be larger and more R&D intensive, to be more often part of a domestic or foreign group, and to report a greater emphasis on both cost reducing and demand expanding innovation.

Finally, collaborating firms in Table 2 show higher labour productivity levels and higher innovative sales per employee, with the latter highest for firms cooperating with customers and universities. However, these simple mean comparisons cannot be taken as evidence of the impact of cooperation strategies on productivity, as this requires controlling for initial productivity levels, industry differences, and the joint impact of the other variables in a multivariate analysis. The results of

Table 2
Descriptive statistics for different R&D cooperation profiles

	No cooperation (1)	Competitor cooperation =1 (2)	Supplier cooperation =1 (3)	Customer cooperation =1 (4)	University cooperation = 1 (5)	Mean[a] test 1 *F*-value (6)	Mean[b] test 2 *F*-value (7)
Competitor spillovers	0.978	1.128	1.157	1.108	1.179	3.54	5.46**
Supplier spillovers	1.081	1.031	1.245	1.133	1.089	13.63***	9.84***
Customer spillovers	1.203	1.372	1.456	1.595	1.514	45.10***	44.50***
University spillovers	0.340	0.546	0.550	0.562	0.779	156.45***	156.49***
Firm size	161	374	465	325	568		
Innovation intensity	0.027	0.038	0.034	0.041	0.051		
Foreign multinational	0.189	0.186	0.240	0.258	0.221		
Domestic group	0.250	0.332	0.315	0.306	0.307		
Cost push	1.906	2.438	2.333	2.354	2.564		
Demand pull	3.694	4.372	4.315	4.462	4.450		
Log(value added per employee), 1998	4.459	4.667	4.627	4.641	4.670		
Log(innovative sales per employee), 1998	1.389	1.714	1.919	2.059	2.013		
No. of observations (new sales sample)	1426 (939)	226 (154)	375 (248)	353 (238)	280 (212)		

[a] The test is the comparison of the received incoming spillovers between the groups of firms that reported engagement in competitor (supplier, customer, university) cooperation vis-a-vis the firms that reported no such engagement.

[b] The test is the comparison of the received incoming spillovers between the groups of firms that reported engagement in competitor (supplier, customer, university) cooperation vis-a-vis the firms that reported no cooperation links at all.

** Significant at 5%.

*** Significant at 1%.

this analysis, estimates of Eqs. (1)–(5), are discussed below.

4. Empirical results

Table 3 reports the results of all variants of Eq. (1) with the spillover measures instrumented by the error term of Eqs. (2)–(5).[7] The auxiliary regressions (2)–(5) of the full spillover measures on the corresponding cooperation dummies in the previous period (not reported here) showed that cooperation is indeed a highly significant explanatory factor of the corresponding spillovers. For both dependent variables, labour productivity growth and innovative sales productivity growth, we first estimate an equation with aggregated measures of cooperation and spillovers, to make comparisons possible with earlier results. Results from the aggregated specification for labour productivity growth (model 1) strongly confirm the contribution of R&D cooperation to productivity growth. The cooperation variable is highly significant and positive. Taking the exponent of the coefficient minus one gives the proportional increase in productivity compared with non-cooperating firms, which amounts to a substantial 13% difference in productivity. In addition to the aggregate cooperation measure, the aggregate spillover measure and innovation intensity are positive and significant. Productivity growth is also higher for affiliates of foreign multinational firms and (marginally) higher for domestic group firms, while firm size and the direction of innovative efforts (demand enhancing or cost saving) have no appreciable impact. The lagged productivity variable is highly significant and negative, indicating that productivity leaders are less able to show further productivity growth. The estimated coefficient indicates that a firm with a higher productivity level in 1996 are only able to maintain 48 (1–52) percent of this lead in current productivity.[8]

[7] We also estimated the models with a robust regression technique to correct for possible heteroscedasticity, but found only trivial differences in standard errors compared with the least squares estimation.

[8] The estimate of 48% appears quite small and maybe should be interpreted with care. However, other research (e.g. Blundel and Bond, 2000) using GMM techniques find similar values for the legged productivity term in production function equations.

If spillovers and cooperation are differentiated by type of partner and source in model 2, only competitor cooperation is found to have an independent positive impact on labour productivity growth. If the cooperation dummy takes the value 1, only for persistent collaborators (firms that are cooperating with the respective partners both in 1996 and 1998) both competitor and supplier cooperation are found to have positive and significant impacts (model 3). In model 2, the individual source-specific spillovers are not significant, but in model 3, university spillovers do have a marginally significant and positive impact on labour productivity growth.

Models 4–6 present the results with the growth in firms' productivity in generating sales of innovative products new to the market per employee as the dependent variable. In the aggregate specification (model 4), again cooperation and spillovers are significant contributors to this type of productivity growth, but in the differentiated equations (models 5 and 6) we see different impacts of the different cooperation types. Now it is university cooperation that has a significant impact on productivity growth and competitor cooperation gets a marginally significant impact for persistent collaborators (model 6). In addition, clear contributions are confirmed by spillovers (not due to cooperation) from universities and from customers. Surprisingly, innovation intensity has no significant impact here, but larger firms are more successful in obtaining this type of productivity growth. Affiliates of foreign multinationals again are able to record systematically higher productivity growth (albeit only marginally significant), but domestic group membership has no effect. The cost and demand orientation of innovative efforts matter strongly for productivity growth in the expected direction. A demand orientation is more likely to translate into growth in new product sales, but a cost orientation has a negative impact. Firms that devote more R&D efforts to cost reduction are not able to devote a much attention to market expansion and perform less in this type of productivity growth. Lagged productivity has a significantly negative impact with a coefficient of 0.72, indicating that firms with a higher productivity level in 1996 are only able to maintain 28% of this lead in current productivity. This indicates that a past leading performance in innovative sales productivity is more difficult to sustain than a lead in labour productivity.

Table 3
Regression results for productivity growth, 1996–1998

	Growth value added per employee (growth labour productivity)			Growth new to the market sales per employee (growth innovative sales productivity)		
	(1)	(2)	(3)[a]	(4)	(5)	(6)[a]
R&D cooperation	0.0593*** (0.0225)			0.1823* (0.1055)		
Competitor cooperation		0.0747** (0.0364)	0.1122* (0.0604)		−0.1611 (0.1698)	0.4922* (0.2757)
Supplier cooperation		0.0208 (0.0308)	0.1079** (0.0444)		−0.0119 (0.1469)	−0.0978 (0.1941)
Customer cooperation		−0.0110 (0.0320)	−0.0268 (0.0456)		0.0780 (0.1479)	0.2477 (0.1940)
University cooperation		0.0214 (0.0351)	0.0676 (0.0472)		0.3239** (0.1614)	0.5066** (0.2003)
Incoming spillovers	0.0080*** (0.0022)			0.0521*** (0.0101)		
Competitor spillovers		0.0138 (0.0125)	0.0064 (0.0078)		−0.0507 (0.0571)	−0.0482 (0.0567)
Supplier spillovers		0.0135 (0.0120)	−0.0024 (0.0076)		−0.0254 (0.0562)	−0.0301 (0.0563)
Customer spillovers		0.0034 (0.0115)	−0.0012 (0.0072)		0.1706*** (0.0523)	0.1726*** (0.0521)
University spillovers		0.0310 (0.0195)	0.0069* (0.0040)		0.2553*** (0.0849)	0.2176*** (0.0846)
Firm size	0.0127 (0.0092)	0.0148 (0.0093)	0.0133 (0.0092)	0.0889* (0.0480)	0.1127** (0.0483)	0.0814* (0.0477)
Innovation intensity	0.0054*** (0.0009)	0.0055*** (0.0009)	0.0055*** (0.0009)	0.0612 (0.6149)	0.1025 (0.6207)	0.0007 (0.6185)
Foreign multinational	0.1332*** (0.0278)	0.1420*** (0.0280)	0.1363*** (0.0280)	0.1712 (0.1296)	0.2164* (0.1313)	0.2346* (0.1302)
Domestic group	0.0431* (0.0237)	0.0472** (0.0238)	0.0426 (0.0238)	−0.1499 (0.1099)	−0.1283 (0.1102)	−0.1576 (0.1096)
Cost push innovation	0.0072 (0.0061)	0.0067 (0.0061)	0.0073 (0.0062)	−0.0672** 0.0277	−0.0602** (0.0278)	−0.0586** (0.0277)
Demand pull innovation	0.0038 (0.0069)	0.0052 (0.0070)	0.0053 (0.0072)	0.0590* (0.0340)	0.0587* (0.0343)	0.0607* (0.0340)
Log(productivity), 1996	−0.5252*** (0.0155)	−0.5218*** (0.0155)	−0.5245*** (0.0155)	−0.7231*** (0.0270)	−0.7163*** (0.0272)	−0.7200*** (0.0270)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.39	0.39	0.39	0.37	0.37	0.37
No. of observations	2056	2056	2056	1360	1360	1360

Standard errors in parentheses.

[a] Cooperation variables in columns (2) and (5) take the value one if an establishment indicated that it was engaged in a particular strategy in the 1996 survey (within the period 1994–1996). Cooperation variables in columns (3) and (6) take the value one if firms engaged in 'persistent cooperation': they reported the specific type of cooperation in the two consecutive surveys, 1994–1996 and 1996–1998.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

Overall, the results show that R&D cooperation, innovation intensity, and incoming spillovers all have independent impacts on productivity growth (with the exception of innovation intensity in the innovative sales equations). The results diverge once spillovers and cooperation are differentiated by source and partner. The direction of this divergence corresponds to our priors concerning the purposes of different types of collaboration. R&D cooperation with suppliers appears more of an incremental nature focused on reducing input costs and labour productivity. Cooperation with universities is more focused on innovations aimed at creating novel products, improving innovative sales productivity. Competitor collaboration is the only type of collaboration that has multiple purposes and impacts, effective in generating both labour productivity increases (e.g. through cost sharing in R&D) and innovative sales productivity increases (e.g. enabling the start of innovation projects through risk sharing and improving sales through the establishment of technological standards). Customer cooperation, in contrast, is not found to have any discernable impact on productivity growth: perhaps because the information on customer demands and technological requirements is already effectively captured by incoming spillovers from customers through market transactions, and does not require formal collaborative R&D agreements. The role of universities in firms' productivity performance also stands out, as it is the only source of knowledge that both provides effective public spillovers (not due to collaboration) and improves firms' innovative sales productivity through formal R&D cooperation.

5. Conclusions

Despite a growing literature on R&D cooperation in both the fields of management and industrial economics, surprisingly little evidence has emerged on the performance effect of R&D collaboration. This paper analyses the impact of R&D cooperation on firm performance jointly with the impact of R&D expenditures and the effect of incoming knowledge spillovers that are not due to formal collaborative agreements. We differentiate between the type of R&D partner (competitors, suppliers, customers, and universities and research institutes) and consider two performance measures: labour productivity and productivity in innovative sales new to the market. Using data on a large sample of Dutch innovating firms in two waves of the Community Innovation Survey (1996, 1998), we examine the impact of R&D collaboration on productivity growth in 1996–1998. We find that supplier and competitor cooperation have a significant impact on labour productivity growth, while cooperation with universities and research institutes and again competitor cooperation positively affects growth in sales per employee of products and services new to the market. New product sales are furthermore stimulated by incoming knowledge spillovers (not due to collaboration) from customers and universities and research institutes. The results are sensitive to the lag with which innovation strategies are allowed to impact productivity growth. Generally, allowing for a more variable lag structure by examining the impact of cooperation strategies that are sustained over a 2–4-year period demonstrated a more robust impact of cooperation on productivity.

The results confirm a major heterogeneity in the rationales and goals of R&D cooperation, with competitor and supplier cooperation focused on incremental innovations improving the productivity performance of firms, while university cooperation and again competitor cooperation are instrumental in creating and bringing to market radical innovations, generating sales of products that are novel to the market, and hence improving the growth performance of firms (Klomp and Van Leeuwen, 2001). The findings provide qualified support for the notion that cooperating firms are generally engaged in higher level innovative activities (Tether, 2002). This holds unequivocally for firms collaborating with universities (e.g. to get access to basic research) and competitors (to allow R&D for risky projects), but not for firms engaged in 'vertical cooperation' with suppliers and customers. If the latter types of cooperation are also partly focused on more 'radical' innovations, than there is no evidence in our analysis that these efforts have an overall impact improving firms' performance in bringing novel products to the market.[9]

[9] This does not rule out that a minority of such collaborations, e.g. 'co-makerships' between firms and major suppliers, does involve more fundamental and radically innovative research efforts. We thank an anonymous referee for pointing this out.

The findings go some way in explaining the more ambiguous results obtained in previous empirical work on the effects of cooperation on innovative sales and productivity, where single performance measures were used and no (variation in) lag structures could be examined because of the cross-section nature of the data (e.g. Lööf and Heshmati, 2002; Monjon and Waelbroeck, 2003). Since different R&D strategies can impact performance with different lag structures, future research should further explore the intertemporal structure of the impact of R&D strategies on innovation output and firm performance. The increasing availability of consecutive CIS surveys will allow for the construction of panel data sets to examine the effectiveness of various innovation strategies in more detail.

Appendix A. Description of variables

No.	Variable name	Definition
1	Competitor cooperation	1 if the business unit reported engagement in innovation in cooperation strategy with competitors, else 0
2	Supplier cooperation	1 if the business unit reported engagement in innovation in cooperation strategy with suppliers, else 0
3	Customer cooperation	1 if the business unit reported engagement in innovation in cooperation strategy with customers, else 0
4	University cooperation	1 if the business unit has reported engagement in innovation in cooperation strategy with universities, innovation centers, or research institutions, else 0
5	Competitor incoming spillover	Importance of competitors as source of knowledge for the firm's innovation process. Constructed as residual from the auxiliary regression of competitor spillover taken from 1998 survey on a competitor cooperation dummy taken from 1996 survey
6	Supplier incoming spillover	Importance of suppliers as source of knowledge for the firm's innovation process. Constructed as residual from the auxiliary regression of supplier spillover taken from 1998 survey on a supplier cooperation dummy taken from 1996 survey
7	Customer incoming spillover	Importance of customers as source of knowledge for the firm's innovation process. Constructed as residual from the auxiliary regression of customer spillover taken from 1998 survey on a supplier cooperation dummy taken from 1996 survey
8	University incoming spillover	Average of importance of universities, innovation centers, and research institutions as source of knowledge for the firm's innovation process. Constructed as residual from the auxiliary regression of university spillover taken from 1998 survey on a university cooperation dummy taken from 1996 survey
9	Innovation intensity	Total innovation expenditures/sales
10	Firm size	Logarithm of number of employees
11	Domestic group	1 if the business unit is part of a domestic firm grouping, else 0
12	Foreign multinational	1 if the firm is an affiliate of a foreign multinational, else 0
13	Cost push	Importance of cost-saving objectives for the firm's innovations. Constructed as a sum of scores on four categories of objectives, relating to processes, labour, materials, and energy
14	Demand pull	Importance of demand-enhancing objectives for the firm's innovations. Constructed as sum of scores on two categories of objectives, relating to products quality and new products and markets
15	Productivity growth (value added)	Growth in the net value added per employee = log(labour productivity 1998)−log(labour productivity 1996)
16	Productivity growth (new sales)	Growth in the value of sales new to the market per employee 1996–1998 = log(1 + new sales/employees 1998)−log(1 + new sales/employees 1996)

Note: all independent variables are for 1996 except for the spillover variables.

Appendix B. Correlations

	COcoop (1)	Scoop (2)	CUcoop (3)	Ucoop (4)	COspill (5)	Sspill (6)	CUspill (7)	Uspill (8)	Fsize (9)	INNint (10)	Multinat (11)	Domgr (12)	Cpush (13)	Dpull (14)	Prodv (15)
N = 2056															
1	1.000														
2	.3293	1.000													
3	.3678	.4964	1.000												
4	.4408	.4037	.4096	1.000											
5	−.0154	.0524	.0162	.0395	1.000										
6	−.0422	.0192	.0022	−.0117	.3292	1.000									
7	−.0092	.0253	.0062	.0373	.3931	.2900	1.000								
8	−.0246	.0281	.0240	.0087	.2332	.1689	.1740	1.000							
9	.1614	.2266	.1562	.2544	.1164	.0377	.0581	.1056	1.000						
10	−.0074	−.0099	−.0098	−.0084	.0263	.0008	−.0056	−.0127	−.0840	1.000					
11	−.0144	.0443	.0628	.0189	.0210	−.0244	−.0098	−.0294	.2204	−.0113	1.000				
12	.0486	.0470	.0364	.0328	−.0028	.0254	.0286	.0185	.0903	−.0137	−.3066	1.000			
13	.0855	.0876	.0896	.1244	.1201	.0790	.0818	.0909	.1205	−.0244	.1104	−.0074	1.000		
14	.1196	.1430	.1820	.1556	.1025	.0534	.1453	.0564	.0771	−.0265	.0791	−.0055	.2689	1.000	
15/16	.0683	.0842	.1078	.1153	.0478	−.0228	.0373	.0217	.0983	−.0940	.1513	.0350	.0694	.0628	1.000
N = 1360															
1	1.000														
2	.3541	1.000													
3	.3667	.5142	1.000												
4	.4925	.4795	.4316	1.000											
5	−.0262	.0960	.0203	.0721	1.000										
6	−.0281	.0430	.0118	.0179	.3176	1.000									
7	−.0025	.0470	−.0020	.0452	.3771	.2630	1.000								
8	−.0358	.0342	.0320	−.0041	.2597	.1881	.1802	1.000							
9	.2073	.2809	.2112	.3349	.1878	.0482	.1006	.1107	1.000						
10	.0169	.0099	.0240	.0227	−.0061	−.0486	−.0217	.0852	−.1349	1.000					
11	−.0385	.0657	.0909	.0268	.0565	−.0097	−.0168	−.0221	.2863	−.0032	1.000				
12	.0932	.0715	.0450	.0424	.0290	.0159	.0779	.0228	.0903	.0004	−.3078	1.000			
13	.0911	.1089	.1211	.1488	.1231	.0935	.0792	.1022	.2093	−.0107	.1385	.0059	1.000		
14	.1279	.1580	.1923	.1709	.1171	.0705	.1511	.0795	.1434	.0906	.0894	−.0066	.3096	1.000	
16	.0754	.1587	.2116	.1097	.0556	.0336	.0989	.0660	−.0043	.0817	.0576	−.0119	.0640	.2337	1.000

Note: see Appendix A for the description of the variables.

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