Cooperative R&D and firm performance

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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 & 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 (collaboration) in 1996 on subsequent productivity growth in 1996-1998. We find that supplier and competitor cooperation have a significant impact on labour productivity growth, while competitor cooperation and collaboration with universities & research institutes positively affects growth in innovative sales per employee. Innovative sales are furthermore stimulated by incoming spillovers (not due to collaboration) from customers and universities. 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 or products that are novel to the market, improving the growth performance of firms.

1. Introduction

The observed substantial increase in R&D alliances in the late 1980s and throughout 1990s, in particular 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 body of theoretical literature has been developed in industrial organization focusing on the relationship between knowledge spillovers and R&D cooperation and, alternatively, knowledge spillovers and R&D investments, using a game theoretical perspective. 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 cooperation is induced by knowledge spillovers and 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 Reinen, 1992; Fritsch and Lucas, 2001; Tether, 2002; Belderbos et al. 2003). A major finding of recent contributions is that the goals and, hence, the determinants of R&D partnerships differ depending on the type of cooperation and partner. Fritsch and Lucas (2001) find for German manufacturing firms that innovative effort directed at process improvement is more likely to involve collaborate with suppliers, whereas product innovations is associated with customer collaboration. Tether (2002), using UK data on innovating firms, finds that cooperation is mostly associated with firms pursuing radical rather than incremental innovations. Distinguishing more specifically between partnerships with competitors, suppliers, customers, and universities & research institutes, Belderbos et al. (2003) finds substantial heterogeneity in the determinants to establish R&D collaborations with the different partners. Cooperation with a type of partner generally is more likely to be chosen if such type of partner is considered an important source of knowledge for the innovation process, while more basic knowledge sourced from universities and research institutes positively impacts all types of cooperation. Collaboration with universities is more likely to be chosen by more R&D intensive firms in sectors that exhibit faster technological and product developments.

Surprisingly, the key question whether collaborative R&D has the expected positive impact on firms' (innovation) performance has remained largely unexplored in both the industrial organization as well 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 Haskell, 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.[2] Management studies have restricted analysis on particular performance indicators in specific industries, e.g. the effect of alliances on high tech start-up firm

[2] Most of these studies use a simultaneous equations approach pioneered by Crépon et al (1998) in which innovative sales levels in turn are allowed to impact productivity or sales. In the current paper we allow R&D (cooperation) to have a direct impact on productivity.

performance in the biotech industry (Baum et al. 2002), 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 on 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 impact on productivity of incoming knowledge spillovers that not due to R&D partnerships, as well as 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 Surveys (1996, 1998) linked to production statistics, we mitigate problems of simultaneity and unobserved firm-specific effects by examining the impact of R&D (collaboration) in 1996 on subsequent productivity growth in 1996-1998.

The remainder of the paper is organized as follows: section two provides an overview of the previous theoretical and empirical literature discussing the impact of R&D (cooperation) and spillovers on firm performance. Section three describes the empirical model and data. Section four discusses the empirical results and section five concludes.

2. Previous Literature

In this section we will briefly review the theoretical and empirical literature on R&D cooperation, spillovers and productivity. Theoretical models in the industrial organization tradition have shown how knowledge spillovers increase the stock of effective knowledge of the firms and contribute to profitability by either by expanding demand or by reducing costs. Involuntary spillovers between competing firms at the same time provide an incentive for R&D cooperation as this enables firms to overcome the disincentive effect on R&D from the externality that involuntary spillovers to rival firms constitute (e.g. Amir, 2000; De Bondt, 1996; Kamien et al., 1992; Suzumura, 1992; Leahy & Neary, 1997). Recent papers have also taken into account that spillovers are not given but that cooperation allows firms to increase knowledge transfers *voluntarily* among the cooperating partners (Katsoulacos & 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). The industrial organization literature has paid little attention to collaboration between firms that are not directly competing on output markets. An exception is Atallah (2002), who finds that even with small vertical spillovers (knowledge spillovers between upstream and downstream industries) firms can profitably to engage in vertical R&D cooperation, as there are fewer or no competitive considerations involved with potential leakage's of the fruits of larger R&D investments.

The literature in the management and technology policy domain has examined broader motivations for R&D cooperation than internalising involuntary knowledge spillovers and has focused more on voluntary spillovers. Explanations for collaborative R&D that have been extensively discussed revolve around such factors as sharing risks and costs in the face of uncertain technological developments (Das and Teng, 2002; 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 firm' 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, 2003; 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 market introductions of the 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 to reduce costs, with outsourcing activities coupled with cooperation on input quality improvements aimed at further cost reductions. Cooperation with universities and research institutes is generally more aimed at radical breakthrough 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 Haskell, 2003), patenting (Vanhaverbeke et al., 2004), and sales growth (Cincera et al. forthcoming). Some of these papers have also examined the effect of different cooperation types but with ambiguous results. Monjon and Waelbroeck (2003) regressed innovative sales levels of firms in a French CIS survey on a range of collaboration and spillovers and found a mixture of negative and positive impacts of R&D cooperation and spillovers. Cincera et al. (forthcoming) distinguish between overseas and domestic collaboration by Belgian firms and find a positive impact on productivity of the latter but a counter-intuitive negative impact of the former. Lööf and Heshmati (2002) include a selected group of cooperation types in an innovation output equation for Swedish firms and found that cooperation with competitors and universities impact output levels positively while cooperation with customers had a negative effect. These ambiguous results can be partly attributed to the difficulties in allowing for different appropriate lags with which cooperative R&D impacts innovative output and performance (cf. Cincera et al., forthcoming), as well as unobserved firm traits that impact both firms' incentives to cooperate and their innovative output (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 an important role of inferred spillovers 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 (Aitkin 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. 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 may be more related to more basic R&D efforts and client collaborations. We explore this by examining in the empirical analysis 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 suggestions 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.

3. Empirical model, data and descriptive statistics

The goal of the empirical analysis is to determine whether different types of R&D collaboration affect firm productivity growth. To examine this effect the analysis should control for the impact of own R&D efforts as well as incoming knowledge flows that are not due to cooperation. Our specification in equation (1) has as dependent variable the growth in productivity from 1996 (t-1) to 1998 (t). In addition to including explanatory variables measured from the preceding period, limiting simultaneity bias, we include 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.[3] We estimate the following growth in productivity equation:

$$\Delta \log(prodv)_i = \alpha + \beta X_i + \delta rd\,\mathrm{int}_i + \zeta_1 Comp\_coop_i + \zeta_2 Cust\_coop_i + \zeta_3 Supp\_coop_i + \zeta_4 Univ\_coop_i + \gamma_1 Comp\_spil_i + \gamma_2 Cust\_spil_i + \gamma_3 Supp\_spil_i + \gamma_4 Univ\_spil_i + \theta \log(prodv)_i + \varepsilon_i \qquad (1)$$

where all left hand side variables are measured at time t and where $\Delta \log(prodv)_i = \log(prodv_{i,t+1}) - \log(prodv_{i,t})$, 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 mostly 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,

[3] A second and related advantage is that it allows for the effects of the exogenous variables to be interpreted as 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 *y* is said to be Granger-caused by *x* if the coefficients on the lagged values of *x* are statistically significant.

suppliers, and universities & research institutes (henceforward for convenience labelled 'universities').[4] The same potential partners are identified as potential sources of incoming knowledge spillovers. The model also includes the firm's Innovation intensity. The lagged *log(Prodv)* term is the level term of the dependent variable taken in the base year (1996). Firms that are highly productive and at the frontier of productivity may be less likely to be able record strong growth rates in productivity than firms that are followers.[5] In that case we expect θ to fall within the interval [-1,0]. If θ is zero, this 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 passed productivity has no impact on future productivity levels.[6] The *X*-vector consists of other firm-level control variables, such as size, dummies controlling for foreign and domestic groups, dummies for cost reducing and product improving objectives of innovation, 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. In order to estimate 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 extract the former spillovers due to collaboration by taking as the spillover measure the residuals obtained from regressing the spillover variables on the corresponding cooperation variable and the set of industry dummies.

(2) $$Comp\_spil_i = \lambda_{hor} Comp\_coop_i + Z_i + \eta_i^{comp}$$

(3) $$Cust\_spil_i = \lambda_{cust} Cust\_coop_i + Z_i + \eta_i^{cust}$$

(4) $$Supp\_spil_i = \lambda_{\sup p} Supp\_coop_i + Z_i + \eta_i^{\sup p}$$

(5) $$Univ\_spil_i = \lambda_{inst} Univ\_coop_i + Z_i + \eta_i^{univ}$$

The estimated residuals from these equations $\hat{\eta}_t^{comp}$ through $\hat{\eta}_i^{univ}$ 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.[7]

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[4] 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.

[5] 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.

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

[7] Whereas the four spillover sources included in the model identify the *source*, 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 (if information from competitors is important, it may reach the firm 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 other spillover ratings by the firm in the model, but this variable proved insignificant with no impact on the estimates of the four source-specific spillover measures and was omitted in the final specification. The source-specific spillovers are apparently able to capture the lion's share of the impact of incoming knowledge to productivity growth.

Data and Variables

The empirical analysis uses the data from two consecutive Community Innovation Surveys (CIS) from 1996 and 1998 and Production Statistics data from 1996 and 1998. It has been only recently that researchers have been able to utilize consecutive CIS surveys merged with production statistics.[8] An additional advantage of the Dutch CIS surveys is that they have been held every other year rather than in four-year intervals as has been customary in other EU countries. This allows us to more accurately examine performance changes over a suitable time frame (two years). The Netherlands Bureau of Statistics (CBS) production statistics database includes information on output, employment, and value added. The CIS database 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 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 two-year (panel) data set 6327 innovating firms in 1998 are matched with information on these firms in 1996 survey: 2353 firms could be linked to 1996 survey and were classified as innovating firms in that survey. We then link 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 of product and services that are new to the market per employee, 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 two 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 radical 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 two-year period 1996-1998. This is a relatively plausible assumption, given that R&D effects require some time to translate into innovative output and productivity advances. But it is not ruled out that some cooperative projects may lead to faster impacts 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.

[8] Other examples are Belderbos et al. (2003) and Klomp and Van Leeuwen (2001).

The firm-specific and type-specific of incoming spillovers are direct measures of the importance of source of incoming knowledge for the firms' innovation process. The CIS survey asks firms 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 two years. Given the exact wording of the question on sources of incoming knowledge, i.e. their effective use in the innovation activities, the answers are more an indicator of their contribution to innovation output than in indicators of innovation inputs. Hence, such effective spillovers in 1994-1996 (the 1996 CIS survey) are more likely to affect 1996 productivity levels than 1996-1998 productivity growth. We therefore do not include the spillover measure for 1996 but the spillover measures from the 1998 survey (effective spillovers during 1996-1998) as having an impact on 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 rates by source on 1996 cooperation and a set of industry dummies, and take the residuals of these equations as a the 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, expenditures on licenses and hence also controls for the impact of external technology sourcing.[9] Innovation intensity is taken from the 1996 survey to allow for a 2-year period in which 1996 innovation investments can 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 different productivity growth performance between independent firms and firms that are part of a domestic group or a foreign MNE. Group firms may have higher growth 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 very large multinational corporations. The large Dutch companies Akzo/Nobel, DSM, Philips, Shell and Unilever are dominating in terms of R&D expenditures, and are important elements in the Dutch technological infrastructure. These large companies are characterized as the core of firm networks with comparable research intensities (i.e. Cowan and Jonard 1999; Verspagen, 2000) and greater density of knowledge spillovers.

Finally, we include demand-pull and cost-push variables in the model as controls. The demand-pull variable is a sum of scores on importance of objectives of innovation relating to demand. 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 on new product sales productivity.

Descriptive Statistics

The distribution of cases by industry and descriptive statistics are presented in Table 1. There are 630 firms with R&D cooperation of any type among the innovating firms in the

[9] Data limitations did not allow us to further decompose innovation expenditures.

combined sample. Supplier cooperation is the most frequent, with 375 firms indicating to be engaged in this type of strategy, followed by customer cooperation (353 firms), university cooperation (280) and competitor cooperation (226). Some 1426 firms reported to have none of the three links. The comparison across industries indicates that 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 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 shows 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 shows 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 are both indicative that the importance for the firm's innovation process of knowledge coming from a specific source is reason to engage in cooperation (Belderbos et al, 2003), but also of subsequent purposeful increases in knowledge transfers within the collaborative agreement. The table also shows that cooperating firms tend to be larger and more R&D intensive, are more often part of a domestic or foreign group, and report greater emphasis on cost reduction and demand expansion. Finally, collaborating firms 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 strategy 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 this analysis, estimates of equations (1)-(5), are discussed below.

4. Empirical Results

Table 3 reports the results of all variants of equation (1) with the spillover measures instrumented by the error term of equations (2)-(5).[10] The auxiliary regressions of 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 percent difference in

[10] We also estimated the models with a robust regression technique to correct for possible heteroscedasticity, but found no non-trivial differences in standard errors compared with the least squares estimation.

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 foreign MNE-owned affiliates 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 1 percent increase in past productivity is only associated with a 0.48 (1 – 0.52) percent increase in current productivity.

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 one only for persistent collaborators (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.

Models 4-6 present the results with the dependent variable the growth in firms' productivity in generating sales of innovative products new to the market per employee. 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 a 1 percent increase in past productivity is only associated with a 0.28 (1 – 0.72) percent increase in current productivity. This shows that a past leading performance in innovative sales productivity is more difficult to sustain than labour productivity.

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 assembly processes, and therewith labour productivity. Cooperation with universities is more focused on radical innovation and creating new 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: apparently, the information on customer demands and technological requirements is already effectively captured by incoming spillovers from customers through market transactions, and do 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 expenditure and the effect of incoming spillovers that are not due to formal collaborative agreements. We differentiate between the type of R&D partner (competitors, suppliers, customers, and universities & 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 Community Innovation Survey (1996, 1998), we mitigate problems of simultaneity and unobserved firm-specific effects by examining 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 customers and universities & research institutes positively affects growth in sales per employee of products and services new to the market. New product sales are furthermore stimulated by incoming spillovers (not due to collaboration) from customers and universities & 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 longer period demonstrated a substantially 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 that cooperating firms are generally engaged in higher level innovative activities (Thether, 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 at least there is no evidence in our analysis that these efforts are effective in improving firms' performance in bringing novel products to the market.

The findings go some way in explaining the variety of results obtained in previous empirical work on the effect 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. Heshmati and Lööf, 2002; Monjon and Waelbroeck, 2003). Since different R&D strategies can impact performance with different lag structures, future research should explore the different possible 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.

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

NACE	Sector	No. of obs. in sample	Share %	Share non-coop	No of obs	Share if COcoop=1	No of obs	Share if Scoop=1	No of obs	Share if CUcoop=1	No of obs	Share if Ucoop=1	No of obs
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

Table 2. Descriptive statistics for different R&D cooperation profiles

	No coop	Competitor Coop=1	Supplier Coop=1	Customer. Coop=1	University Coop=1	Mean[1] Test 1 F-value	Mean[2] Test 2 F-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Competitor spillover	0.978	1.128	1.157	1.108	1.179	3.54	5.46**
Supplier spillover	1.081	1.031	1.245	1.133	1.089	13.63***	9.84***
Customer spillover	1.203	1.372	1.456	1.595	1.514	45.10***	44.50***
University spillover	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 MNE	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)98	4.459	4.667	4.627	4.641	4.670		
Log(innovative sales per employee) 98	1.389	1.714	1.919	2.059	2.013		
# observations (new sales sample)	1426 (939)	226 (154)	375 (248)	353 (238)	280 (212)		

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

1. 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-à-vis the establishments that have not reported such engagement.
2. The test is the comparison of the received incoming spillovers between the groups of firms that reported engagement in competitor (supplier, customer, university) vis-à-vis the establishments that have reported no cooperation links at all.

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)+	(4)	(5)	(6)+
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 MNE	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)	-.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
Number of obs.	2056	2056	2056	1360	1360	1360

* significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors in parentheses
+ Cooperation variables in columns (2) and (5) take a value of 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 a value of one if firms engaged in persistent cooperation: cooperation in the two consecutive surveys, 1994-1996 and 1996-1998.

Appendix A: Description of Variables

#	variable name	Definition
1	Competitor cooperation	1 if the business unit reported engagement in innovation in cooperation strategy with competitors, else zero
2	Supplier cooperation	1 if the business unit reported engagement in innovation in cooperation strategy with suppliers, else zero
3	Customer cooperation	1 if the business unit reported engagement in innovation in cooperation strategy with customers, else zero
4	University cooperation	1 if the business unit has reported engagement in innovation in cooperation strategy with universities, innovation centers, or research institutions, else zero
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 MNE	1 if the firm is affiliate of a foreign MNE, else 0
13	Cost push	Importance of cost-saving objectives for the firm's innovations Constructed as a sum of scores on 4 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 2 categories of objectives, relating to products quality and new products and markets.
	Productivity growth (value added)	Growth in the net value added per employee = log (labour productivity 1998) – log (labour productivity 1996)
	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

(N=2056)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	COcoop	Scoop	CUcoop	Ucoop	COspill	Sspill	CUspill	Uspill	Fsize	INNint	MNE	Domgr	Cpush	Dpull	prodv
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	.0683	.0842	.1078	.1153	.0478	-.0228	.0373	.0217	.0983	-.0940	.1513	.0350	.0694	.0628	1.000

N=1360

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Ccoop	Scoop	CUcoop	Ucoop	COspill	Sspill	CUspill	Uspill	Fsizel	INNint	MNE	Domgr	Cpush	Dpull	prodv
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	
15	.0754	.1587	.2116	.1097	.0556	.0336	.0989	.0660	-.0043	.0817	.0576	-.0119	.0640	.2337	1.00