Cooperative research and firm performance

Réka Horváth [*,†]

May 13, 2001

Abstract

The aim of this paper is to provide a microeconometric analysis of the impact of research joint venture participation on productivity, using a large panel of around 6200 firms. The findings of the theoretical literature on this topic are ambiguous and there are very few empirical papers analyzing this problem. I find evidence that participation in research consortia increases productivity.

Keywords: research joint ventures, firm performance, productivity

JEL classification: O320, L110, D240

---

[*]I.D.E.A - International Doctorate in Economic Analysis, Universitat Autònoma de Barcelona, Departament d'Economia i d'Història Econòmica, Edifici B, 08193 Bellaterra-Barcelona, Spain. E-mail: horeka@idea.uab.es. Telefax: 34-935812012.

[†]I would like to thank John Van Reenen for support and advise. I am also grateful to David Pérez-Castrillo, Bruno Cassiman, Inés Macho-Stadler, Reinhilde Veugelers and participants of the 2^{nd} CEPR Workshop of Applied Industrial Organization and workshop paricipants at the Universitat Autònoma de Barcelona for their comments. Important part of the work presented in this paper was carried out while visiting at the University College London within the European Network for Training in Economic Research program. This research was undertaken with support from the European Union's Phare ACE Programme.

1 Introduction

With the opening of the world economy and increasing competition firms develop new strategies. The new strategy involves more intense networking. Firms engage in cooperative agreements not only with their suppliers and customers but also with their direct competitors. This cooperation takes place in different fields including the distribution, production and research and development phases. The motives of cooperation are cost and risk sharing, access to partners know-how, markets or products. Furthermore, cooperation can bring about efficiency enhancements, such as economies of scale in the production, distribution or R&D phases or synergy effects from exchanging and/or sharing complementary know-how (Veugelers, 1998).

This paper focuses on cooperation in research and development. Many aspects of cooperative R&D were studied in the economic literature[1]. The theoretical literature has analysed extensively how spillovers affect R&D investment in a cooperative situation compared to competition, and how spillovers influence the profitability and welfare of R&D cooperation. Furthermore, the theoretical literature deals with are stability of research joint ventures, organizational design and asymmetries between research partners.

The importance of research alliances is acknowledged by government policy in various countries. Research joint ventures (RJVs) are granted exemption from anti-trust laws and their formation is encouraged by subsidies.

In the USA the National Cooperative Research Act (1984) and the National Cooperative Research and Production Act (1993) guarantee that every research alliance filed at the Federal Register is evaluated separately if they fail to fulfill antitrust laws. The Clinton administration increased the budget of the Advanced Technology Program that funds collaborative research projects from the private sector to encourage joint research (Branstetter and Sakakibara, 1998).

In Europe Article 81(3) (former 85(3)) of the EC treaty allows the EC Commission to exempt research alliances from Article 81(1) (which prohibits restrictive practices between firms which may affect the trade between the member states or the competition within the EC). In 1985 the Commission granted a block exemption to certain categories of R&D agreements. Moreover, it allows the joint exploitation of the results of that R&D. This exemption is for five years (if the participants are not direct competitors or if they are competitors but the sum of their market shares is less twenty percent). Regulation 151/93 also allows the joint marketing of the product wherever the common market share is less than 10%. Furthermore, there are also several programs established and funded by the European Commission to

[1] See Veugelers (1998) for a detailed survey.

promote cooperation in research. The European Strategic Program for Research in Information Technologies (ESPRIT) is by far the largest of these programs. Between 1983 and 1996 around 9000 organizations participated in over 1200 ESPRIT-financed projects (Lichtenberg, 1996).

In Japan industrial policy actively supported the formation of research consortia since 1959 (Sakakibara, 1997).

Productivity growth, as the engine of economic growth, is one of the main concern of industrial policy. Research joint ventures are exempt form antitrust laws because they are considered to promote efficiency. This can be either productive efficiency or other types, like R&D cost sharing. Also, as we saw before one of the reasons why firms form RJVs is to gain efficiency. This is why analyzing the effects of research joint venture participation on productivity is an interesting issue.

Evaluating the overall benefits of cooperative research is very difficult because the cooperation may have an impact both on R&D spending and the competitive structure of the industry. Firms that are cooperating in research and development might be inclined to do so even in the product market competition, a behaviour that should concern antitrust authorities.

Geroski (1992) summarizes the theoretical findings on this topic. He concludes that R&D ventures are desirable whenever technological spillovers and positive pecuniary externalities (risk sharing) exist. Also, a non-exclusive consortia which operates between firms with complementary skills and products that undertakes pro-competitive research is preferable to a cooperative research agreement between firms on the same output market.

Following Geroski's argument, when evaluating the impact of cooperative R&D we have to separate its direct effect on productivity and its indirect effect through research intensity and competition. How does cooperation in R&D affect productivity? R&D output is considered to have a positive effect on productivity (many times this output is a new process which allows lower unit costs in production). In case of joint research, the research productivity is affected. So, the same amount of R&D investment results in more (or less) innovation. Then, if the competitive structure and firms' R&D investments are unaffected, cooperation in innovative activities increases (decreases) productivity compared to the competitive R&D case.

This direct effect of joint research and development is studied by Kamien et al. (1992), Beath et al. (1998) and Baumol (1999). The common feature of their analysis is that they model process innovation (cost reduction).

Kamien et al. (1992) present an oligopoly model with spillovers where firms compete either a la Cournot or a la Bertrand in the product market. They examine R&D performance and welfare in four different research scenarios. They find that a research joint venture that cooperates in its R&D decisions yields the lowest unit cost with lower research intensities under Cournot competition, and, in most cases, under Bertrand competition. Diminishing returns in the R&D production function are crucial in their model.

Beath et al. (1998) present a non-tournament model of process innovation with spillovers in the R&D process and with a Cournot duopolium in the output market. They explicitly model the innovation as a two stage process where in the first stage the knowledge is produced and in the second stage this knowledge is employed to reduce unit cost. They distinguish between simple and complementary research paths. The research process, like in Kamien et al. (1992) exhibits diminishing returns (either in the first or in the second stage). They show that in the case of a simple research path the RJV only operates one research lab and gets the same cost reduction cheaper than in the competitive case. In case of complementary research paths the RJV either operates one or two research labs, depending where diminishing returns occur in the innovation process, and the level of cost reduction is at least as high as in the competitive case with spending less in the RJV than the sum of the two firms spending separately.

Baumol (1999), on the other hand finds in a Cournot oligopolistic setting where research outputs are complementary that when the number of cooperating firms increases, each firms' unit cost decreases but with an increase in R&D investment. Thus, the implications of cooperation for productivity are ambiguous.

The very few empirical papers are centered around the motives for participation in research consortia. Only a handful of the studies evaluate the performance of participating firms. The performance measures used in these papers are research intensity (Roller et al, 1999), profitability (Siebert 1997) and stock market valuation (Sleuwagen et al., 1995 and Scott, 1996). Surprisingly, only very little attention was paid to the impact of joint R&D on productivity[2]. The only exceptions I know of are the studies by Irwin and Klenow (1996) about the labor productivity of Semantech firms, and Branstetter and Sakakibara (1998) about the research productivity of Japanese research consortia. The authors of both studies estimate the effect of participation in *government sponsored* R&D consortia.

Irwin and Klenow (1996) evaluated the SEMATECH program in the US. SEMATECH was set up to conduct research and development for manufacturing semiconductor products. The consortium was set up in 1987 and enjoyed government subsidies between 1987-1996. Irwin and Klenow used a panel of firm level variables for the period 1970-1993. They found that the SEMATECH firms spent less on

[2]The general lack of time-series dimension in the data makes it difficult for researchers to carry out productivity studies, because they cannot really control for fixed effects and possible endogeneity.

research and had higher sales growth than non-participating firms. On the other hand, they did not find significant difference between non-member and member firms in terms of labor productivity growth, physical investment and returns on assets. A weak point of their analysis was the control group they used. The fixed effects model they used controlled for permanent differences in firm performance but it did not correct for the possible endogeneity in the response for SEMATECH participation: that the distribution of the parameter of the participation dummy may differ systematically for participating and non-participating firms.

Branstetter and Sakakibara (1998) conducted a microeconometric analysis of Japanese research consortia. They found that government sponsored R&D consortia participation increased R&D spending. Moreover, they found that participating firms had higher research productivity than other firms. They measured research output by the number of patents. They controlled for the possible endogeneity in the response for participation in a RJV. Following the logic outlined in the previous section, increased research productivity means a positive direct effect of joint research on productivity.

In this paper I study the productivity implications of research joint venture participation using a large panel of European, Japanese and US companies. Furthermore, using a sample of around 1500 US firm with available information on R&D spending I separate the effect of total R&D investment and RJV participation on productivity. Using the generalised method of moments estimation technique developed by Arellano and Bond I control for the possible endogeneity of the independent variables. I find evidence that joint R&D increases productivity. The result is similar even when the effect through R&D investment is separated. The results suggest that when R&D spending is controlled for it is the horizotal form of R&D cooperation that brings about the most significant productivity improvement. This is consistent with the findings of the theoretical literature that cost-sharing is an important incentive in forming horizontal research consortia.

In the next sections I describe the empirical investigation. In section 3 I discuss the results of the analysis. Section 4 concludes.

2 Empirical investigation

The model

Consider the following log-linear Cobb-Douglas production function:

$$y_{it} = \lambda y_{i,t-1} + (1-\lambda)\beta_n n_{it} + (1-\lambda)\beta_k k_{it} + \alpha r_{it} + \gamma_t + \eta_i + \epsilon 1_{it} + m_{it} \quad (1)$$
$$\epsilon 1_{it} \sim MA(0)$$

Where y_{it} is the log output of firm i in year t, n_{it} is log employment and k_{it} is log capital stock. The term r_{it} stands for the log R&D output (result of R&D) of the firm i. The term γ_t is a year specific intercept, η_i is an unobservable firm specific effect, $\epsilon 1_{it}$ is a productivity shock and m_{it} is measurement error. In case of constant returns to scale $\beta_n + \beta_k = 1$, but this is not necessarily imposed. The inclusion of the lagged output is the simplest way of describing the fact that it takes some time for the output to reach its new long run level whenever the inputs change. The inclusion of this lag also supports the assumption on the serially uncorrelated productivity shocks (Nickell (1996) considers the same production function).

To analyse the role of research joint venture participation I assume that the R&D production function is the following:

$$R_{it} = RD^{\mu}_{i,t-1} e^{\nu RJV_{i,t-1}} e^{\epsilon 2_{it}} \quad (2)$$
$$\epsilon 2_{it} \sim MA(0),$$

where R_{it} is the output (result) of research and development, $RD_{i,t-1}$ is the R&D stock of the company, $RJV_{i,t-1}$ is the number of research joint ventures the firm participates in and $\epsilon 2_{it}$ is a research productivity shock. Thus, the output of innovative activity depends on the R&D spending and on an R&D productivity term. This research productivity term depends on the number of cooperative research agreements.[3] The lagged levels of R&D stock and RJV participation refer to the fact that their effect on research output is not immediate. I also estimate the equation with earlier lags of the RJV participation.

Taking the logarithm of equation (2) results in a simple log-linear form:

$$r_{it} = \mu rd_{i,t-1} + \nu RJV_{i,t-1} + \epsilon 2_{it}. \quad (3)$$

Introducing (3) into (1) and rearranging the resulting equation we get:

$$y_{it} = \pi_1 y_{i,t-1} + \pi_2 n_{it} + \pi_3 k_{it} + \pi_4 RJV_{i,t-1} + \pi_5 rd_{i,t-1} + \gamma_t + \eta_i + \omega_{it} \quad (4)$$

Notice that the error term ($\omega_{it} = \epsilon 1_{it} + \alpha\epsilon 2_{it} + m_{it}$) follows an MA(0) process if there is no measurement error. In the presence of measurement error this process can be different from MA(0), depending on the marginal process of m_{it}.

[3]This way of modeling the innovation process is very similar to the one used by Branstetter and Sakakibara (1998).

Estimation

To eliminate the firm specific effect I take first differences of the equation in (4).

Thus, the benchmark equation I estimate is the following:

$$\Delta y_{it} = \pi_1 \Delta y_{i,t-1} + \pi_2 \Delta n_{it} + \pi_3 \Delta k_{it} + \pi_4 \Delta RJV_{i,t-1} + \pi_5 \Delta rd_{i,t-1} + \\ + \pi_6 year + \omega_{it} \qquad (5)$$

Notice that with this specification the coefficient of the RJV term measures the total effect of cooperative research net of the effect of change in R&D investment on productivity. On the other hand, omitting the rd variable π_4 measures the total effect of RJV participation on productivity.[4]

Note that constant returns to scale would mean that the sum of π_1, π_2 and π_3 is equal to 1. I will also present result when CRS is imposed.

The values of employment, capital stock, research joint venture participation, R&D stock and lagged sales are possibly correlated with the error term and the firm specific effect. However, assuming the usual initial conditions ($E(x_{i1}\omega_{it}) = 0$ for $t = 2, 3, ..., T$ where x_{i1} represents the endogenous regressors) to hold, in the absence of measurement error all the lagged levels of these regressors beyond $t-1$ can be used as instruments after first differencing to eliminate the firm specific effect. The crucial assumption is the absence of serial correlation. This will be tested.

However, there is a possible problem: if the marginal processes for the endogenous variables are highly persistent the lagged levels can be weakly correlated with the subsequent first differences. In this case the GMM estimator has been found to have poor finite sample properties (Blundell and Bond, 1998), therefore the use of system GMM estimator can be recommended. However, in the analysis presented in this paper this does not seem to be a problem.

Data

The data come from different sources. The information about research consortia comes from the SDCA-SDC Worldwide Joint Ventures & Alliances database.[5] This

[4]Note that if RJV participation and R&D expenditure are correlated, then omitting the R&D variable may simply imply that the coefficient of the RJV participation reflects R&D influencing productivity.

[5]Thanks to Bruno Cassimann and the TSER Project SOE1-CT97-1059 for providing the data.

database has information about transactions valued at least 1 million USD between 1985-1992 and transactions of any value after 1992.[6] Since this database has only scarce information about the characteristics of the participating firms I merged it with other databases, which include firm level accounting data in a panel structure. The databases used for the matching are Global Vantage and Compustat.[7] The Global Vantage database contains accounting data for large firms worldwide. The Compustat database has information about (mainly listed) North-American companies.

The merged database contains around 20,000 firms in a panel structure between 1985-1995 worldwide. There are around 900 firms that participate in R&D alliances. However, in this paper I use a subsample of European, Japanese and US firms. Due to missing observations I also eliminated many firms. The dataset used in this paper contains an unbalanced panel of around 6200 firms for the period 1985-1995. This database is biased towards large firms. The Appendix contains descriptive statistics of the sample and subsamples used for the analysis.

The Global Vantage and Compustat databases contain worldwide information (output, employment, etc.) about firms. This is why I used the ultimate parent of firms in the SDCA-SDC database to merge with the above the databases.

The variables used in the estimations are the following:

Output, as a proxy I use net real sales. Other possibility would be to construct a measure of value added using the wage bill, pre-tax profits, interest payments and depreciation. However, the reported profits can be different from the true ones, so this measure may not be reliable (see Nickell, 1996).

Employment, the variable measures the full-time, part-time and seasonal employment.

Capital, I proxy capital stock with real total assets.

R&D stock, this variable is constructed using the real R&D expenditures of firms and a 0.15 depreciation rate. I assume that before the beginning of the sample period the growth rate of R&D investment was the same as the average growth rate in the sample period. Where this is not available, I assume a 5% growth rate. This variable is missing in many observations, mainly in Europe where firms are not legally required to disclose R&D expenditure. This is why I show results with and without this variable. For the US I have information whether the R&D expenditure contains a government subsidy. But using this extra information does not add to the

[6] For years after 1992 I only use data about alliances with transaction values greater than 1 million USD.

[7] Thanks to the IFS for the data.

analysis since firms decide about their optimal R&D investment internalising this subsidy. On the other hand, this information can be useful when assessing firms' incentives to form research consortia.

RJV participation, the variable contains the number of research joint ventures the firm has joined since 1985. Since there is no information about research consortia participation before 1985, the levels of this variable may contain serious measurement error. This is not a problem in the first differenced equation but it is not possible to use system-GMM as this requires information about levels. Also, the information contained in this variable constrains the possible functional forms of the R&D production function I can consider. I cannot use the logarithm of this variable since I do not know the levels. In some specifications I distinguish among three type of research joint ventures. I define horizontal RJVs as joint research between firms in industries with the same 2-digit SIC code. Similarly, vertical RJVs consist of firms from different 2-digit SIC industries. Vertical consortia that have a university participant are treated separately.

The Appendix contains detailed descriptive statistics of the above variables.

3 Results

Table 1 contains the main results for the mixed (USA, Japan and Europe) sample. The first two columns contain results without imposing constant returns to scale. The third column shows the results for the same sample as in the second column with imposing CRS.[8] In table 1 the total effect of RJV participation on productivity is measured, i. e. R&D intensity and change in the competitive structure are not controlled for.

Table 2 shows results for the same specifications as Table 1 for a subsample of US firms.

Table 3 shows results for a subsample of US firms with information about R&D spending. Here I investigate the effects of cooperative research on productivity net of R&D effects.

Table 4 differentiates among the three types of research joint ventures. The table refers to the US subsample with R&D data as this is the only sample that allows me to investigate the net RJV effect.

[8] When imposing CRS the DPD98 program uses one more lag when constructing the variables. Consequently firms with only three consecutive observations are dropped. In column 2 I use this subsample in the non-constrained specification to obtain fully comparable results.

Table 5 shows the results for introducing earlier lags of RJV participation into the estimated equation. For this exercise I use the US subsample that proved to be more reliable than the mixed sample.

Total RJV effect

The instruments in the first two columns of Table 1 are valid (although only marginally). In these columns negative first order serial correlation is accepted. Second order serial correlation is rejected. This is in accordance with the assumptions and taking first differences.

In the specification of the third column there is evidence for second order serial correlation. This does not validate the use of the GMM method. Consequently, the results are not reliable. This is consistent with the fact that using the results of the second column constant returns to scale are rejected (not presented in the table).

In all columns there is a positive sign associated with the coefficient of the RJV variable. In the first column the coefficient is significant on the 10% level. Thus, in the mixed sample there is evidence that RJV participation significantly improves productivity.

In Table 2 the same exercise is repeated with the same qualitative results. Thus, CRS are rejected and there is evidence for the productivity-enhancing effect of RJV participation. This sample seems to be more robust than the mixed sample, the change in sample size influences significance on a lesser scale.

The size of the RJV effect in the US sample is marginally larger than in the mixed sample (one additional cooperative research agreement increases output by around 1%).

Of course, one should keep in mind that these results show only the total effect: changes in the competitive structure and R&D investment are not controlled for.

Direct RJV effect

I have constructed a subsample where the firm's R&D spending can be controlled for to investigate the relation between the direct and indirect effects of research joint venture participation. As the descriptive statistics in the Appendix show, this subsample has data about the larger firms in the USA sample. The data in this subsample allows us to control for possible correlation between research joint venture participation and R&D spending. Thus, we can calculate the effect of joint research of productivity net of any additional R&D effect. Note that the effects of change in the competitive structure of the industry as a result of cooperative research are not controlled for. Thus, the results are to be interpreted with caution.

The results are shown in Table 3. In all three specifications first order serial correlation is accepted and second order serial correlation is rejected and the instruments are valid. All variables are significant.

The first column shows the total effect of joint research on output. In the second column the coefficient of the RJV variable shows the total effect net the indirect effect through R&D spending. In the last column only R&D expenditure is introduced to investigate the robustness of the results.

The results show that the effect of RJV participation is not diminished when controlling for R&D spending. This suggests that the magnitude of the total effect of RJV participation does not reflect an increase in research expenditure but rather an increase in research productivity. When the different types of RJV's are treated separately this results changes as can be seen in table 4.[9]

Vertical and horizontal research joint ventures

In table 4 I distinguish among the different types of research consortia. I treat separately horizontal and vertical research joint ventures. Horizontal research joint ventures ($HRJV$) are formed exclusively between firms that compete on the output market. I define vertical research joint ventures ($VRJV$) as research consortia with at least one participant that is not a competitor of the others. Furthermore, I form a third category that includes all those (vertical) RJVs that have at least one university participant ($URJV$).

The first column contains the same estimation result as the first column of the previous table. This indicates that when the R&D stock is not controlled for participation in a RJV increases productivity. The RJV variable is significant on the 10% level.

In the second column the three different types of research consortia participation are introduced rather than a single RJV variable. The result shows that research cooperation with universities decreases productivity on the short run. This is consistent with the fact that such research joint ventures engage rather in basic research that will give results on the long run at the same time taking resources (money and personel) from more commercially oriented research. The positive coefficients of the other two types of RJVs are not significant.

[9]This finding is consistent with the results of Rõller et al. (1997). They found no evidence that RJV participation influences R&D spending when not controlling for different types of research consortia.

The most interesting result is included in the third column. Once the R&D stock of the companies is controlled for the sign of the *URJV* variable and its significance level practically does not change. However, the coefficient associated with participation in horizontal RJVs increases and becomes significant on the 5% level! This clearly indicates that when competitors form a research consortium their productivity increases. This increase is partly offset by a decrease in R&D spending. Thus, the cost sharing hypothesis of the horizontal research joint ventures is accepted. s

Different lags of the RJV participation

Using the first lag of the RJV participation variable is questionable. We do not have any information about the time-span of the impact of cooperative research on productivity. Many times the cooperation is only the exchange of the already existing know-how (for example the research aims to find the correct shape of the product of one firm that can be used in the machine of the other). On the other hand, cooperative research between firms and universities often involve basic research, which has its returns only on the long run.

The length of the panel does not allow for using early lags. This is why I decided to investigate the effects of introducing only the second lag of RJV participation in addition. The results show that participation in an additional research joint venture altogether increases productivity (the sum of the coefficients of the first and second lags is positive and jointly significant). Also, the effect in one year is more important (and significant) than in two years.

This suggests that joint research increases productivity within a year. This observation supports the theory that firms in RJVs learn from each other. Thus, even if a specific project will produce results over a longer period, firms can use the know-how learnt from their partners in their individual production processes.

4 Conclusion and further work

Using a sample of around 6200 firms I estimated the effect of research joint venture participation on productivity. I found evidence that joint research improves productivity. This result supports the industrial policy of governments which encourages the formation of research consortia.

I have also found indirect evidence that an important reason for forming horizontal research joint ventures is to share costs. A posible research direction is to try to find direct evidence for this. This analysis is embedded in a more general topic: the incentives of firms that form research joint ventures.

Furthermore, it would be especially interesting to study the effect of the change in the European policy towards RJVs, namely that after 1993 research consortia may market their innovation together if their joint market power is not significant (less than 10 %). The analysis of this effect may give us further information about the effectiveness of industrial policy.

Table 1: Impact of RJV participation on productivity (1985-1995), mixed sample

Independent variables	I	II	III
$y_{i,t-1}$	.431	.465	.291
	(12.84)	(9.26)	(6.91)
n_{it}	.263	.211	.300
	(3.84)	(2.09)	(2.55)
k_{it}	.342	.377	.409
	(7.56)	(5.58)	
$RJV_{i,t-1}$	.007	.003	.006
	(1.76)	(.98)	(1.63)
1^{st} serial corr	-7.5	-5.9	-7.1
(p-value)	(.00)	(.00)	(.00)
2^{nd} serial corr	-.1	-.3	-3.6
(p-value)	(.96)	(.80)	(.00)
Sargan-test	35.2	33.0	50.3
degrees of freedom	16	14	14
(p-value)	(.01)	(.01)	(.00)
Number of obs.	32428	26213	26213
Number of firms	6215	5517	5517

Instruments used in the first two columns are y_{t-2} and n_{t-2}, while in the third column y_{t-3} and n_{t-3} are used. Capital is treated as strictly exogenous in all columns. In the first two columns results are qualitatively the same when including further lags as instruments. Equations were estimated using the DPD98 package written by Arellano and Bond. All four estimations include jointly significant time dummies. The table reports consistent one-step estimators that are robust to heteroskedasticy of general form. The two step (fully efficient) estimators are not reported, because Arellano and Bond (1991) indicate that standard errors are overstatedly low in this case (t-values are in parentheses).

Table 2: Impact of RJV participation on productivity (1985-1995), USA

Independent variables	I	II	III
$y_{i,t-1}$	.437	.449	.274
	(11.35)	(8.18)	(8.84)
n_{it}	.394	.431	.448
	(4.52)	(3.21)	(2.53)
k_{it}	.243	.219	.278
	(3.78)	(2.31)	
$RJV_{i,t-1}$	.011	.007	.010
	(1.98)	(1.74)	(1.63)
1^{st} serial corr	-5.9	-4.8	-6.1
(p-value)	(.00)	(.00)	(.00)
2^{nd} serial corr	-.1	-.1	-2.9
(p-value)	(.89)	(.94)	(.00)
Sargan-test	16.8	13.5	7.8
degrees of freedom	16	14	14
(p-value)	(.40)	(.49)	(.90)
Number of obs.	19258	16102	16102
Number of firms	3156	2894	2894

Instruments used in the first two columns are y_{t-2} and n_{t-2}, while in the third column y_{t-3} and n_{t-3} are used. Capital is treated as strictly exogenous in all columns. In all columns results are qualitatively the same when including further lags as instruments. Equations were estimated using the DPD98 package written by Arellano and Bond. All four estimations include jointly significant time dummies. The table reports consistent one-step estimators that are robust to heteroskedasticy of general form. The two step (fully efficient) estimators are not reported, because Arellano and Bond (1991) indicate that standard errors are overstatedly low in this case (t-values are in parentheses).

Table 3: Impact of RJV participation on productivity (1985-1995), USA

Independent variables	I	II	III
$y_{i,t-1}$	.390	.228	.239
	(5.31)	(2.19)	(2.26)
n_{it}	.479	.531	.488
	(4.15)	(3.53)	(3.19)
k_{it}	.195	.189	.214
	(2.59)	(2.26)	(2.55)
$RJV_{i,t-1}$	.012	.012	
	(1.83)	(2.00)	
$R\&D_{i,t-1}$		.157	.157
		(1.66)	(1.67)
1^{st} serial corr	-3.8	-3.2	-3.2
(p-value)	(.00)	(.00)	(.00)
2^{nd} serial corr	1.4	1.5	1.5
(p-value)	(.16)	(.13)	(.13)
Sargan-test	22.0	52.3	51.6
degrees of freedom	16	30	30
(p-value)	(.14)	(.01)	(.01)
Number of obs.	9290	9290	9290
Number of firms	1574	1574	1574

Instruments used in the first column are y_{t-2} and n_{t-2} while in the second and third columns y_{t-3}, y_{t-4}, n_{t-2} and $R\&D_{t-2}$ are used. Capital is treated as strictly exogenous in all columns. The results are qualitatively the same when including further lags as instruments. The equations were estimated using the DPD98 package written by Arellano and Bond. All four estimations include jointly significant time dummies. The table reports consistent one-step estimators that are robust to heteroskedasticy of general form (t-values are in parentheses).

Table 4: Impact of RJV participation on productivity (1985-1995), USA

Independent variables	I	II	III
$y_{i,t-1}$	.390	.391	.229
	(5.31)	(5.32)	(2.20)
n_{it}	.479	.478	.531
	(4.15)	(4.15)	(3.54)
k_{it}	.195	.195	.189
	(2.59)	(2.60)	(2.27)
$RJV_{i,t-1}$	.012		
	(1.83)		
$VRJV_{i,t-1}$		.011	.009
		(1.50)	(1.14)
$HRJV_{i,t-1}$		.016	.022
		(1.13)	(1.97)
$URJV_{i,t-1}$		-.104	-.096
		(-2.72)	(-2.52)
$R\&D_{i,t-1}$			.157
			(1.67)
1^{st} serial corr	-3.8	-3.85	-3.2
(p-value)	(.00)	(.00)	(.00)
2^{nd} serial corr	1.41	1.41	1.52
(p-value)	(.16)	(.16)	(.13)
Sargan-test	22.2	22.2	52.3
degrees of freedom	14	16	30
(p-value)	(.14)	(.14)	(.01)
Number of obs.	9290	9290	9290
Number of firms	1574	1574	1574

Instruments used in the first two columns are y_{t-2} and n_{t-2} while third column y_{t-3}, y_{t-4}, n_{t-2} and $R\&D_{t-2}$ are used. Capital is treated as strictly exogenous in all columns. The results are qualitatively the same when including further lags as instruments. The equations were estimated using the DPD98 package written by Arellano and Bond. All four estimations include jointly significant time dummies. The table reports consistent one-step estimators that are robust to heteroskedasticy of general form (t-values are in parentheses).

Table 5: Total impact of RJV participation on productivity (1985-1995)

Independent variables	I	II	III
$y_{i,t-1}$	.449	.447	.449
	(8.18)	(8.17)	(8.17)
n_{it}	.431	.420	.430
	(3.21)	(3.15)	(3.20)
k_{it}	.219	.227	.220
	(2.31)	(2.41)	(2.32)
$RJV_{i,t-1}$	.009		.010
	(1.74)		(1.40)
$RJV_{i,t-2}$		.002	-.004
		(.32)	(-.52)
1^{st} serial corr	-4.8	-4.8	-4.8
(p-value)	(.00)	(.00)	(.00)
2^{nd} serial corr	-.1	-.1	.1
(p-value)	(.94)	(.96)	(.94)
Sargan-test	13.5	13.5	13.6
degrees of freedom	14	14	14
(p-value)	(.49)	(.49)	(.48)
Number of obs.	16102	16102	16102
Number of firms	2894	2894	2894

Instruments used are y_{t-2} and n_{t-2} while capital is treated strictly exogenous in all columns. The results are qualitatively the same when including further lags as instruments. The equations were estimated using the DPD98 package written by Arellano and Bond. All three estimations include jointly significant time dummies. The table reports consistent one-step estimators that are robust to heteroskedasticy of general form (t-values are in parentheses).

Appendix

Mixed Sample

The sample contains information of 6215 firms in an unbalanced panel with the length peaking around 10 periods (1828 firms). There are 389 firms participating in at least one research joint venture. The maximum number of research joint ventures (formed after 1985) a firm joins in a year is 10.

The following table shows the means of the variables for the (sub)samples used in the different columns of Table 1.

Table 6: Descriptive statistics - means

Variable	col I	col II and III
net sales (million USD)	1944	1974
employment	10927	11194
total assets (million USD)	2201	2240
Δ RJV	0.020	0.021
Number of obs.	44858	42764
Number of firms	6215	5517

The following table shows the number of observations per year for the (sub)samples used in the different columns of Table 1.

Table 7: Number of observations per year

Year	col I	col II and III
1985	2862	2679
1986	3983	3749
1987	4704	4405
1988	5074	4900
1989	5193	4974
1990	5169	4958
1991	5060	4893
1992	4390	4178
1993	3882	3694
1994	3592	3418
1995	949	916
Number of obs.	44858	42764

The following table shows the balance of panel for the (sub)samples used in the different columns of Table 1.

Table 8: Balance of panel

Period	col I	col II and III
3	698	
4	692	692
5	676	676
6	465	465
7	637	637
8	420	420
9	531	531
10	1828	1828
11	268	268
Number of firms	6215	5517

The following table shows the composition of the (sub)samples used in the different columns of Table 1 by country.

Table 9: Firms by country

Country/region	col I	col II and III
USA	3156	2894
Europe	1870	1546
Japan	1189	1077
Number of firms	6215	5517

The US sample

The sample contains information about 3156 firms. There are 238 firms participating in at least one research joint venture. The maximum number of research joint ventures (formed after 1985) a firm joins in a year is 10.

The subsample where information about R&D spending is available contains data about 1574 firms. There are 181 firms participating in at least one research joint venture. The maximum number of research joint ventures (formed after 1985) a firm joins in a year is 10. There are 143 firms that join vertical research joint ventures, 76 firms that start horizontal research joint ventures and 16 firms that engage in joint reserach with universities.

The following table shows the means of the variables for the (sub)samples used in Tables 2, 3 4 and 5. The first column corresponds to the sample used in the estimation of the first column of Table 2, the second column corresponds to the sample used in the last two columns of Table 2 and in all columns of Table 5. The third column corresponds to the sample used in Tables 3 and 4.

Table 10: Descriptive statistics - means

Variable	I	II	III
net sales (million USD)	1510	1542	1948
employment	9994	10171	11666
total assets (million USD)	1684	1724	1933
Δ RJV	0.021	0.022	0.037
Δ VRJV			0.084
Δ RRJV			0.030
Δ URJV			0.001
R&D expenditure (million USD)			58
Number of obs.	25570	24784	12364
Number of firms	3156	2894	1574

The following table shows the number of observations per year for the (sub)samples used in the different columns of Table 2, 3, 4 and 5. The first column corresponds to the sample used in estimation of the first column of Table 2, the second column corresponds to the sample used in the last two columns of Table 2 and in all columns of Table 5. The third column corresponds to the sample used in Tables 3 and 4.

Table 11: Number of observations per year

Year	I	II	III
1985	2264	2161	1072
1986	2480	2358	1199
1987	2656	2522	1289
1988	2662	2625	1305
1989	2607	2584	1260
1990	2543	2524	1235
1991	2558	2538	1238
1992	2562	2464	1241
1993	2487	2378	1212
1994	2340	2238	1141
1995	411	392	246
Number of obs.	25570	24784	12438

The following table shows the balance of panel for the (sub)samples used in the different columns of Table 2, 3, 4 and 5. The first column correspond to the sample used in estimation of the first column of Table 2, the second column corresponds to the sample used in the last two columns of Table 2 and in all columns of Table 5. The third column corresponds to the sample used in Tables 3 and 4.

Table 12: Balance of panel

Period	I	II	III
3	262		141
4	273	273	155
5	202	202	117
6	176	176	93
7	155	155	98
8	186	186	80
9	224	224	114
10	1421	1421	636
11	257	257	140
Number of firms	3156	2894	1574

References

[1] Arellano,M. and S.R.Bond, 1991, "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations", *Review of Economic Studies*, Vol.58, pp 277-297.

[2] Arellano,M. and S.R.Bond, 1998, "Dynamic panel data estimation using DPD98 for Gauss",mimeo, Institute for Fiscal Studies, London.

[3] Baumol, 1999, "Dissemination of inventions and technology consortia", *mimeo.*

[4] Beath,J., J Poyago-Theotoky and D.Ulph, 1998, "Organization design and information sharing in a research joint venture with spillovers", *Bulletin of Economic Research*, Vol.50, No.1, pp 47-59.

[5] Blundell,R. and S.R. Bond, 1999, "GMM estimation with persistent panel data: an application to production functions", *The Institute for Fiscal Studies Working Paper Series*, No.W99/4.

[6] Branstetter, L. and M. Sakakibara, 1998, "Japanese research consortia: a microeconometric analysis of industrial policy", *The Journal of Industrial Economics*, Vol. XLVI, No 2, pp 207-233.

[7] Contractor,F. and P.Lorange, 1988, "Cooperative strategies in international business", Lexington Books.

[8] Geroski, P.A., 1992, "Antitrust policy towards cooperative R&D ventures", *Oxford Review of Economic Policy*, Vol.9, No.2, pp 58-71.

[9] Haagedoorn,J. and J.Schakenraad, 1991, "The role of interfirm cooperation agreements in the globalisation of economy and technology", Merit, Maastricht.

[10] Harrigan,K., 1985, "Strategies for joint ventures", Lexington Books.

[11] Irwin,D. and P.Klenow, 1996, "High tech R&D subsidies: the effects of Sematech", *Journal of International Economics*, Vol.40, pp 323-344.

[12] Lichtenberg,F.R., 1996, "The European Strategic Program for Research in Information Technologies (ESPRIT): An Ex-Post Analysis", *Columbia PaineWebber Working Paper Series in Money, Economics and Finance*, 96/09, pp 30-68.

[13] Kamien,M.I., E.Muller and I.Zang, 1992, "Research joint ventures and R&D cartels", *American Economic Review*, Vol.82, No.5, pp 1293-1306.

[14] Mariti,P. and R.Smiley, 1983, "Cooperative agreements and the organisation of industry", *Journal of Industrial economics*, Vol.32, No.2, pp 183-198.

[15] Nickell,S., 1996, "Competition and corporate performance", *Journal of Political Economy*, Vol.104, pp 724-746.

[16] Porter,M. and M.Fuller, 1986, "Coalitions and global strategy", in: M.Porter(ed.) *Competition in global industries*, HBS Press, Boston.

[17] Rõller, L., M.Tombak and R.Siebert, 1997, "Why firms form research joint ventures: theory and evidence", *mimeo.*

[18] Sakakibara M., 1997, "Heterogeneity of firm capabilities and cooperative research and development: an empirical examination of motives", *Strategic Management Journal*, No.18, pp 143-164.

[19] Scott, J.T., 1996, "Environmental research joint ventures among manufacturers", *Review of Industrial Organization*, No.11, pp 655-679.

[20] Siebert,R., 1997, "The impact of research joint ventures on firm performance: an empirical assessment", *WZB Working paper.*

[21] Sleuwaegen,L., G.Hartog and H Commandeur, 1995, "International strategic alliances of leading dutch firms: market responses following the type of alliance and nationality of the partner", *Working Paper Erasmus University Rotterdam.*

[22] Veugelers, R., 1998, "Collaboration in R&D: an assessment of theoretical and empirical findings", *De Economist*, Vol.146, pp 419-443.