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R&D Cooperation and R&D Intensity: Theory and Micro–Econometric Evidence for German Manufacturing Industries*

by

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Abstract: This paper develops a three stage oligopoly game for R&D cooperation, R&D expenditure and product market competition. In the first stage, firms decide whether or not to conduct R&D in cooperation with other firms. In the second stage the level of R&D investment is determined. Finally, firms compete in a Cournot–oligopoly product market. While earlier models on R&D cooperation only considered process innovation, the model presented here also takes product innovation into account. It is shown that the optimal R&D investment has virtually the same structure for both process and product innovation.

The main hypothesis of our theoretical model are tested in the empirical part of this paper.

Keywords: R&D cooperation, R&D intensity, spillovers, nested logit model, Minimum Distance Estimator

JEL–classification: O31, L13, C24, C25

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I Introduction

The number of R&D cooperations has increased considerably during the past 30 years. While in 1971 only ten percent of all firms were involved in R&D cooperations in Germany, 20 years later almost half of the firms in manufacturing industries conduct cooperative R&D (see König et al., [1994]). Starting point of this development certainly were the positive results of some large R&D cooperative agreements which were established in Japan and the USA in the seventies and eighties. Spencer and Grindley [1993] argue that the R&D consortium SEMATECH has significantly contributed to the leading role of the US in semiconductor industries. American supporters of R&D joint ventures (RJVs) stress the advantages of cooperative R&D in stimulating innovative activity, an aspect also becoming apparent from positive experiences with cooperative R&D in Japan. The success of German mechanical engineering in the seventies and eighties is often traced back to part industrially financed research institutions (see Jorde and Teece [1990]).

Traditional microeconomists are often blamed for failing to develop an adequate model for R&D cooperations. Since the end of the eighties and first half of the nineties a number of theoretical frameworks for the analysis of R&D activity has been developed. Starting from the seminal paper by D'Aspremont and Jacquemin [1988, 1990], some authors (e.g. Kamien et al. [1992], Suzumura [1992], Choi [1993], Ziss [1994]) developed two–step oligopoly models for cost–reducing innovations. The central message of these models is: if externalities are high enough, R&D cooperation turns out to be effective in counteracting too small R&D activity without affecting product market competition. These theoretical models contributed to adjustments of the antitrust law. The antitrust law of the US as well as of the European Community contains specific regulations allowing firms to jointly conduct R&D. Critics of these regulations often claim that it is hardly imaginable that cooperation can be restricted to the R&D stage alone. Further, empirical evidence in favor of R&D cooperation is dismissed. The last topic seems to be a deficit which should be reduced especially in light of the fact that governmental R&D subsidies are increasingly often bound to cooperative R&D.

Empirical analysis on the impact of cooperative R&D on R&D intensity and results are rare indeed. Fölster [1995] finds for Sweden that governmental subsidies of R&D cooperations do not affect R&D investment in any direction. For SEMATECH, Irwin and Klenow [1996] find a reduction of R&D investment and an increase in profitability of SEMATECH members. For Germany, König et al. [1994] present results of a simultaneous equation model for R&D intensity and cooperative activity. Without distinguishing between types of cooperative partners (customers, suppliers, universities), they find a positive effect of cooperations on R&D investment. A positive impact of horizontal cooperations and horizontal R&D spillovers on the R&D intensity of German firms is shown by Inkmann [1997]. He also demonstrates that horizontal spillovers increase the tendency to cooperate with customers. Röller et al. [1997] analyze U.S. firms which participate in RJVs. They find a tendency towards cooperation among firms of similar size and RJV formation to be dependent on a number of industry specific effects.

The present contribution is in line with these papers. We show that implications derived from a cooperation model for process innovation can easily be extended to the case of product innovations. Starting from a linear demand framework, which is extended to take account of utilities derived from incremental product innovations, we study the determinants of R&D cooperation in a three step oligopoly framework. Main hypothesis derived

from are theoretical model are tested in the empirical part of this paper.
Our empirical evidence is broadly consistent with the theoretical framework. We find vertical spillovers to be more important for the R&D cooperation decision and for R&D intensity. They have a significant and negative impact on R&D expenditures and influence firm's decision to cooperate with customers and suppliers positively. R&D productivity has a larger impact on R&D expenditures for cooperating than for non–cooperating firms.
In section II we present a three stages oligopoly game for R&D cooperation, R&D expenditure and product market competition. Main hypothesis derived from our theoretical model are empirically tested in section IV. The data set and the variables used in the empirical part of this paper are described in section III. Section V summarizes the results and sketches suggestions for further research.

II A Game Theoretic Approach

II.1 Market Demand and Product Quality

The standard models for the theoretical analysis of R&D cooperations are mostly concerned with process innovations. Process innovations improve supply conditions of a firm due to decreasing production cost.[1] These models are primarily based on a system of linear demand functions. The explicit specification of the demand side is to show how product quality can be introduced in a simple way. We assume that in the economy there are Z identical consumers, who are endowed with an exogenously given income Y. In the household behavior modeled here, product innovations only affect a part of household's demand system. M indicates the part of the income spent onthose goods not affacted by cross–price and cross–quality effects due to changes in price and quality of product i.[2] We call these goods 'non–industrial' hereafter since we are concerned with manufacturing industries in the empirical part of this paper. The budget restriction of a household demanding N goods is given by:

$$M \;=\; Y - \sum_{i=1}^{N} p_i\, q_i. \tag{1}$$

The utility function to be maximized is:

$$U(q_1, \ldots, q_N) \;=\; \sum_{i=1}^{N} a(q_i - \frac{q_i^2}{u_i^2}) - 2\; a\; \sigma \sum_{i=1}^{N} \sum_{l<i} \frac{q_i}{u_i}\frac{q_l}{u_l} + M. \tag{2}$$

This utility function is consistent with the standard utility function used e.g. by Sutton [1997] in a Cournot–framework or by Deneckere and Davidson [1985] in the context of Bertrand competition. Product quality is depicted by a quality index u_i, where, for simplicity, $u_i > 1$ is assumed. The larger u_i, the higher is the utility of a household from consumption of good q_i. The parameter σ is a measure of substitutability of the N goods and $-1 \leq \sigma \leq 1$. If $\sigma = 1$, the goods are perfect substitutes and if $\sigma = -1$ the goods are

[1] Theoretical frameworks focussing on process innovations are presented by, i.a., D'Aspremont and Jacquemin [1988, 1990], Katz and Ordover [1990], Suzumura [1992] or Kamien et al. [1992].

[2] However, consumers will adjust M in order to meet the budget constraint if innovation takes place.

perfect complements. If $\sigma = 0$, the extreme case of a monopoly is present. The utility function has the usual properties. Market demand for good q_i is represented by the sum of individual demands of the Z identical consumers. The demand function of the households is derived from first order conditions for the utility of a household. For simplification we set $2a/Z = b$ so that the demand for industrial goods is given by a system of demand equations of the form:

$$p_i \; = \; a - \frac{b}{u_i^2}\, q_i - \frac{b\sigma}{u_i} \sum_{l \neq i}^{N} \frac{q_l}{u_l}, \tag{3}$$

where q_i and q_l now denote market demands. Except for the quality index, we yield a system of the usual linear market demand functions. As apparent from equation (3), an increase in market demand (i.e., an increase in the number of consumers as well as an increase in product quality) shifts and turns the demand function out to the right. In the framework of the partial analysis introduced here, the simultaneous increase in product quality is not a null sum game. In order to meet the budget constraint, households decrease the demand for non industrial goods M if the quality of 'industrial' goods increase.

II.2 Supply and Market Equilibrium

The supply side of the model consists of N one-product firms. Following the tradition of R&D cooperation models (c.f. Kamien et al. [1992]), market structure is modeled as a Cournot–oligopoly. Firms can decrease production cost (process innovation) or increase product quality (product innovation) by conducting R&D. Standard process innovation is used as the benchmark for product innovation in order to show whether the model's implications are different for process and product innovation. R&D efforts do not only contribute to production and product quality of firms conducting R&D, but also spill over to competitors, customers and suppliers. R&D performing firms, however, have the choice of conducting R&D in cooperation with customers, suppliers and/or competitors. In this case, results of R&D are assumed to be fully exchanged. By performing cooperative R&D, firms can at least partially internalize the externalities related to the R&D process.[3]

The deterministic R&D model suggested here falls short of real innovation processes which are driven by risk and irreversabilities. It also is somewhat ahistorical as neither a modeling of the intertemporal investment decision nor past R&D investment decisions are incorporated. The model introduced here is merely related to a sequential 'trial and error' process.

The briefly described model of R&D cooperation is very similar to the model of Kamien et al. [1992] and the duopoly model of Röller et al. [1997].[4] The main difference of our model in comparison to most existing models for R&D cooperation lies in the incorporation of product innovation. In the following, only the general model structure and main hypotheses are sketched. These hypotheses are empirically tested afterwards. A firms' decision to conduct either product– or process innovation is not modeled here. Both cases are analyzed separately. Only the structure of the result is compared. The simultaneous

[3] Only when a certain number of trials is performed, R&D results are obtained.

[4] Suzumara [1992] shows that the main results of D'Aspremont and Jacquemin [1988, 1990], Kamien et al. [1992] and others can also be obtained if more general utility functions are used.

modeling of the decision to conduct product– and process innovation is left for future research.[5]
The decision to cooperatively conduct R&D is modeled as a three stage subgame perfect Cournot game solved by backward induction. In the third stage of the game, firms decide upon the individual amount of output given production cost and product quality. R&D expenditures are thus sunk endogenous cost. Their level is determined in the second stage of the game. The type of decision reached in the first stage — whether or not to cooperate —, yields varying profit maximization functions. The main assumptions on production techniques, R&D spillovers and R&D production functions for product- and process innovations are briefly introduced below. The production conditions are captured by a linear marginal cost function k_i. By conducting R&D, firms can decrease marginal costs of their products. Denoting X_i the effective level of R&D of firm i, the marginal cost function for firm is given by:

$$k_i \;=\; c_i \;- f(X_i) \tag{4}$$

with $f(0) = 0$, $f(X_i) \leq c$, $f'(X_i) > 0$, $f''(X_i) < 0$, $lim_{X_i \to \infty} f'(X_i) \to 0$ and $(a - k_i)f''(X_i) + f'(X_i)^2 < 0$. Expression $f(X_i)$ denotes the production function of process innovations. The assumptions with respect to level and form of the R&D production function make sure that it pays for all firms to conduct R&D. We also assume that R&D cost show a steeper increase than the returns to R&D. With respect to product innovations the following properties of the production function for product innovations are assumed:

$$u_i = g(X_i) \tag{5}$$

with $g(0) = 1$, $g'(X_i) > 0$, $g''(X_i) < 0$ and $g(X_i)g''(X_i) + g'(X_i)^2 < 0$.
'Effective' R&D investment is the only determinant of both the R&D production function for process innovations and the production function for product innovation.[6] The effective R&D expenditures (X_i) of firm i comprise both R&D expenditures of firm i and R&D expenditures of other firms which are received by R&D spillovers $\alpha \sum_{j \neq i} x_j$ and $\beta \sum_{j \neq i} x_j$ (c.f. Kamien et al. [1992]):

$$X_i^{PD} \;=\; x_i^{PD} \;+\; \alpha \sum_{j \neq i}^{N} x_j^{PD} \quad \text{and} \quad X_i^{PC} \;=\; x_i^{PC} \;+\; \beta \sum_{j \neq i}^{N} x_j^{PC} \tag{6}$$

for product (PD) and process (PC) innovation, respectively. The parameters α and β incorporate the intensity of spillovers which are identical for all firms by assumption. The larger this parameter, the more advantageous other firms' R&D expenditure is for the firm at hand. If $\alpha, \beta = 1$, R&D expenditures of the other firms have the same productivity as the own R&D expenditures. If $\alpha, \beta = 0$, there are no spillovers. The fact that spillovers are not always adopted costlessly is neglected here (c.f. Cohen and Levinthal [1989]).[7]

[5] As in the model of Harhoff [1997] or Levin and Reiss [1988], the relation of product to process R&D determines the reaction of product quality or the amount of production cost. We omit the explicit modeling since empirically, there is no sharp distinction between product and process R&D.

[6] Our data do not allow to separate process R&D from product R&D. Moreover, a broad majority (80.6 percent) of the firms in our sample have introduced both product and process innovations.We thus disregard the distinction of process and product R&D for the sake of brevity in our description of stage 3.

[7] The notion of an absorption capacity on own R&D efforts could be depicted by allowing α and β to be a function of x_i.

II.2.1 Stage 3: Product market competition when R&D expenditures are given

The N firms choose the optimal level output given parametrically sunk R&D cost. Collusive agreements concerning the level of output are not allowed. Firms maximize their profit function Π_i independently from one another by choosing the optimal level of output q_i.

$$max_{q_i}\ \Pi_i \ = \ (p_i - k_i)\ q_i - x_i^{PD} - x_i^{PC}, \quad i = 1, \ldots, N, \tag{7}$$

where x_i^{PD} (x_i^{PC})denotes the amount of R&D spent for product (process) innovations of firm i.
The optimal choice of the level of output is derived using the Cournot assumption and is given by:

$$q_i^* \ = \ \frac{(a-k_i)u_i^2 + \frac{\sigma}{2-\sigma}\ u_i\ \sum_{l \neq i}^{N} \Big((a-k_i)u_i - (a-k_l)u_l\Big)}{b\Big(2 + \sigma(N-1)\Big)} \tag{8}$$

Equation (8) show that smaller marginal cost c.p. lead to higher output levels.[8] Similar effects are present for differences in product quality: firms with superior product quality yield higher output levels. It can also be seen that a decrease in production cost of firm j leads to higher output levels of this firm in the case of complementary products. The same is true for an increase in product quality of the competitor's products. The condition for optimal output shown by Kamien et al. [1992] is a special case under $u_i = u_j = 1$ for substitutive products. Therefore, for both product and process innovation, an increase of R&D expenditures leads to an increase in output. Due to spillovers, an increase of R&D expenditures of firm i enhances product quality and, likewise, reduces production cost of firms $i \neq j$. At the same time, the relative position of firms $i \neq j$ to firm i deteriorates. For large spillovers it can be shown that the product quality enhancing/production cost decreasing effect can overcompensate the deterioration of the relative position of firms $i \neq j$.[9] This indicates incentives to form an RJV. If products are complements, even small spillovers have positive consequences on product demand of firm i due to an increase in demand of product j which in turn results from a quality improvement due to spillovers.[10] The effect of spillovers and the resulting incentives to cooperate are thus not solely dependent on the amount of spillovers but also on the substitutability of products. Therefore, incentives to form an RJV should differ with the type of cooperation partner. Finally, for both process and product innovation the total level of output increases if at least one firm increases R&D expenditures.

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[8] The case of different marginal cost and the resulting incentives to conduct R&D in cooperation for duopolies is analyzed by Röller et al. [1997]. The case of asymmetric marginal cost is not considered hereafter.

[9] The results of sufficiently large spillovers are thoroughly discussed in the literature (cf. Suzumura [1992], Choi [1993], Ziss [1994]). A formal exposition can therefore be omitted here.

[10] See Harhoff [1997] for a differenciated setting of the capturing of vertical relationships and, in the context of vertical relationships in R&D cooperation, see Inkmann [1997].

II.2.2 Stage 2: Determination of the R&D intensity

The decision on R&D expenditures is modeled in the second stage of the game. In the case of independent decisions on the R&D expenditure level the maximization function is given by:

$$max_{x_i}\ \Pi_i \;=\; \frac{b}{u_i^2} q_i^{*^2} - x_i^{PD} - x_i^{PC}, \quad i = 1, \ldots, N, \tag{9}$$

where q_i^* denotes the optimal level of output which was determined in the third stage of the game, given the R&D effort for product, x_i^{PD}, and process innovation, x_i^{PC}. For simplification, it is assumed that firms do neither have advantages nor different product qualities over other firms except for R&D intensity. It is further assumed that firms are also identical with respect to production functions for process and product innovation. A symmetric equilibrium for R&D effort results under these assumptions. Therefore, the firm subscript i is omitted. Under these assumptions in the case of competition in the R&D stage for product innovations, the optimal R&D expenditure follows from:

$$\frac{2g(X^*)g'(X^*)(a-k)^2}{(2-\sigma)b\Big(2+\sigma(N-1)\Big)^2}\Big(2-\sigma+\sigma(N-1)(1-\alpha)\Big) \;=\; 1. \tag{10}$$

Likewise for process innovation:

$$\frac{2(a-k)f'(X^*)}{(2-\sigma)b\Big(2+\sigma(N-1)\Big)^2}\Big(2-\sigma+\sigma(N-1)(1-\beta)\Big) \;=\; 1. \tag{11}$$

Both equations are very similar in structure. Large differences with respect to comparative–static properties do not exist. Therefore, there is no need for a separate discussion of both equations. It can be shown that results already known from Kamien et al. [1992] for process innovation also hold for product innovation. In the case of an isolated optimization of R&D expenditures, an increase of the spillovers induces a decrease in R&D expenditures if goods are complements (substitutes) and spillovers are large (small). The well known problem of underinvestment in R&D arises. The higher the degree of substitutability, the less incentives for R&D investment exist.

If, in the first stage, firms decide to cooperate in R&D the maximization function for a firm is given by

$$max_{x_i} \;=\; \sum_{l=1}^{N} \Pi_l \quad \text{with} \quad \Pi_l \;=\; \frac{b}{u_l^2} q_l^{*^2} - x_l^{PD} - x_l^{PC}, \tag{12}$$

The f.o.c.'s are:

$$\frac{\partial \Pi_i}{\partial x_i} + \sum_{l \neq i}^{N} \frac{\partial \Pi_l}{\partial x_i} \;=\; 0. \tag{13}$$

The result for the optimal effective R&D in the case of product innovation is given by:

$$\frac{2g(X^*)g'(X^*)(a-k)^2}{(2-\sigma)b\Big(2+\sigma(N-1)\Big)^2}(2-\sigma)(1+(N-1)\alpha) \;=\; 1 \tag{14}$$

and in the case of process innovation:

$$\frac{2(a-k)f'(X^*)}{(2-\sigma)b(2+\sigma(N-1))^2}(2-\sigma)(1+(N-1)\beta) \;=\; 1. \tag{15}$$

In the case of R&D cooperation, the spillover parameter is set to 1 since R&D cooperation implies by definition a full sharing of R&D results. Therefore, the R&D efforts of the own firm are as important as the R&D expenditures of other firms. The consequences for the level of R&D expenditures in the case of R&D cooperation can be drawn from comparing equations (10) and (14) as well as (11) and (15). Due to the internalization of spillovers, incentives to conduct R&D are greater in the case of cooperative R&D. It can be shown that R&D expenditures are always higher under RJV than under research competition if goods are substitutes.
The level of R&D expenditures of a single firm, x_i, and thus the sum of R&D expenditures of all firms can either be higher or lower than without cooperation. From the increase of the R&D spillover due to cooperation, cost sharing effects for own R&D arise. The elimination of externalities also stimulates R&D expenditures. In the empirical part of this paper it will be tested which effect is predominant. However, it is clear that the efficiency of R&D expenditures increases on the industrial level in case of cooperation. It then follows from the properties of the innovation production function that the equilibrium with R&D cooperation is related to a higher production efficiency or a higher product quality than without cooperation.
We can also conclude from equations (14) and (15) that R&D expenditures under Cournot decrease if goods are complements (substitutes) and spillovers are large (small), that R&D expenditures increase with increasing R&D productivity, that R&D expenditures decrease with an increase in the number of competitors provided that goods are substitutes and that R&D expenditures increase with an increase in market demand. The latter three propositions hold for both RJV and research competition.

II.2.3 Stage 1: Product Market Competition when R&D Expenditures are given

The incentive for a firm to cooperatively conduct R&D becomes apparent from the comparison of profits with and without cooperation. The condition for starting a R&D cooperation is given by:

$$\Delta \;=\; \Pi_i^{JV} - \Pi_i^{C} \;=\; \Big(\frac{b}{u_i^2}q_i^2\Big)^{JV} - \Big(\frac{b}{u_i^2}q_i^2\Big)^{C} - \Big(x_i^{JV} - x_i^{C}\Big) \;>\; 0. \tag{16}$$

In the following interpretation, it is assumed that the incentive to start a R&D cooperation increases with an increasing difference of profits, Δ. Under consideration of the optimal strategies for R&D expenditures and the output level, it can be shown that the profits of an individual firm are higher with cooperation than without cooperation. This is valid for a wide parameter range. As it became visible from the structure of the product innovation model, the incentives to start a cooperation are very similar for product and process innovation. Therefore, a discussion of differences appears unnecessary.
However, the following implication should be pointed out: The incentives to start a R&D cooperation increase if the degree of spillovers decrease. With decreasing substitutability

of goods the incentives to cooperatively conduct R&D increase. For the empirical analysis, the following hypotheses can be drawn out:

(1) R&D expenditures under Cournot decrease if goods are complements (substitutes) and spillovers are large (small),

(2) R&D expenditures increase with increasing R&D productivity,

(3) R&D expenditures decrease with an increase in the number of competitors provided that goods are substitutes,

(4) R&D expenditures increase with an increase in market demand,

(5) incentives to form a RJV increase if market demand increases,

(6) incentives to form a RJV decrease if the degree of substitutability increases,

(7) incentives to form a RJV decrease if the number of competitirs increases and

(8) incentives to form a RJV decrease if spillovers increase.

Propositions (2)–(4) hold for both RJV and research competition. In addition, under certain conditions higher productivity of R&D implies increased incentives to cooperate on R&D. The theoretical model also suggests that R&D cooperations are more widespread among suppliers and customers rather than among competitors.
These hypotheses are empirically tested in section IV. The Mannheim Innovation Panel (MIP) of the ZEW is used as data source. This data base is described in the following section.

III Data

The empirical analysis is based on the first five waves of the MIP, which is collected by the ZEW and infas–Sozialforschung on behalf of the German ministry for education, research, science and technology. A detailed description of the data material is not presented here. The reader may refer to Janz and Licht [1999]. Basic methodological remarks and implementation issues for innovation surveys are described in the OSLO-manual (OECD, [1994]). The description presented here thus concentrates on the variables used in the estimations and omits any further details on the data set.

R&D cooperation

R&D cooperation is defined as "R&D activities which are jointly conducted with other firms or research institutions". It is stressed that R&D cooperation — as opposed to commissioned research — involves "joint active research work". Firms which answer to this general question in the MIP questionnaire with 'yes' can then choose from a list of possible cooperation partners where multiple responses are allowed.[11] That is, firms which

[11] First wave: Customers, suppliers, competitors, firms of own holding, consultants, universities/technical colleges, other public research institutions, privately financed research institutions, others. Fifth wave: associated firms, competitors, customers, suppliers, consultants, universities/technical colleges, other privately or publicly financed research institutions.

conduct joint research with both suppliers and customers can indicate this in the MIP questionnaire. The MIP does not contain information on the number of cooperations a firm is involved in. This should be taken into account when interpreting estimation results. The information on the type of cooperation partner is taken from the first (1992) and fifth (1996) wave of the MIP.

R&D expenditure and construction of the spillover pools

R&D activity is often thought to represent the core of innovative activity. Therefore, several questions refer to R&D issues in the MIP questionnaire. R&D expenditures is defined in analogy to the Frascati–Manual of the OECD [1993] as expenditures for "Research and development of new products and processes, i.e., a systematic enhancement of knowledge and the application to new products and processes. This also comprises design and testing of prototypes, the development of software and the acquisition of external R&D". We use the information on whether the firm conducted R&D in 1992 or 1996, respectively, and the information on their level of R&D expenditures.

The level of R&D expenditure constitutes the basis for construction of spillover pools. These spillover pools can be regarded as the empirical implementation of $\alpha \sum_{j \neq i} x_j$ and $\beta \sum_{j \neq i} x_j$. from the theoretical model. While the sum of R&D expenditures of the various firms can be estimated relatively easy, a measure for α and β does not exist. Straightforwardly, there exists a broad variety of proxy variables in the literature (cf. Griliches [1992], Kaiser [1999] and Mohnen [1989]). The approach used here is based on each firm's evaluation of the hazard that own ideas might be copied. The question for imitation hazards belongs to a group of questions on factors impeding innovative activity and was answered by the firms on a scale ranging from 1 (= very low) to 5 (= very high). We use a weighted sector average (3-digit NACE-rev. 1 level) as an indicator for the level of imitation hazard in the related sectors. The weight ν_{ij} for the ith firm of sector s is the number of firms in the population which is represented by a firm in our sample. The sector-specific indicator for imitation hazard in sector s ($s = 1, \ldots, S$) is given by:

$$\omega_s = \sum_{i \in s} \frac{\nu_{is}}{\sum_{i \in s} \nu_{is}} \frac{H\_COPY_{is}}{5} \tag{17}$$

H_COPY_{is} is the judgement of the ith firm of sector s for the imitation hazard concerning their innovation. If all firms in sector s value the imitation hazard as 'very high', the indicator takes on the value 1. We distinguish between intra– (horizontal) and intersectoral (vertical) spillovers in order to account for the entirely different impact of vertical and horizontal spillovers on the R&D decision (c.f. Bernstein and Nadiri [1988], Levin and Reiss [1988]). In the theoretical framework introduced above, α and β are identical for all firms. This assumption is relaxed in the empirical analysis. The firm–specific intrasectoral spillovers are calculated as the weighted sum of R&D expenditures of a sector minus own R&D expenditures. Intra–industry R&D spillovers S_{is}^h of firm i from sector s are given by:

$$S_{is}^h = \sum_{i \in s} (\omega_s \, R\&D_{is} \, w_{is}) - \omega_s \, R\&D_{is}, \tag{18}$$

where $R\&D_{is}$ denotes the R&D expenditures of firm i in sector s and w_{is} denotes the share of firm i's employment in total employment of industry s. The first term of equation (18) is the weighted sum — expanded by firm weights w_{is} — of R&D expenditures of firm i from sector s. The calculation was made at the level of 31 different sectors. The spillover parameter ω_s is defined in equation (17). Since the ith firm itself is part of the sum, the second part of equation (18) subtracts own R&D expenditures weighted with the imitation parameter .

The intersectoral spillovers are the difference between total R&D expenditures of manufacturing weighted with the imitation indicator and the intrasectoral spillover pool as well as with own R&D expenditures. From this calculation, it becomes clear that the amount of intersectoral spillovers, which is to the disposal of firm i, is considerably larger than the amount of intrasectoral spillovers. Even if the impact of intersectoral spillovers is small, this effect should not be underestimated due to the mass of the interindustry spillover pool. The firm-specific intersectoral R&D spillovers are given by:

$$S_{is}^{v} \;=\; \sum_{i=1}^{N}\sum_{s=1}^{S}\,(\omega_s\; R\&D_{is}\; w_{is}) \;-\; \sum_{i\in s}\,(\omega_s\; R\&D_{is}\; w_{is}) \;-\; \omega_s\; R\&D_{is}. \tag{19}$$

The measurement of spillovers is therefore closely related to the R&D expenditures which are released by potential 'lender–sectors' or competitors, respectively. However, the only spillover of relevance for the individual firm is the one touching it directly. Thus, the spillover variables constructed here merely present an upper bound.

Indicators for R&D productivity

For adequate consideration of firm heterogeneity the model assumption of identical innovation production functions is dropped in the empirical analysis. Following an idea by Levin and Reiss [1988], we assume that sectors closely related to science stay at the beginning of their development so they find themselves in an area of the production function with high marginal returns. The proximity of industries to science was calculated by means of a factor analysis of the relative importance of alternative informational sources for the innovation process. Data from the first, fourth and fifth wave of the MIP were utilized in order to achieve a high observational density. This variable, generated by a factor analysis, shows the importance a firm attributes to scientific information sources (universities, technical colleges, patent system). The second factor depicts the importance of private sources such as fairs, customer and suppliers. Both variables are generated as firm specific factor scores, weighted by the individual valuation of information sources. Individual factor scores are expanded to industry averages which are used to represent the typical technological characteristics for each firm in a sector. The factor score representing proximity to scientific information sources is denoted by *SCIENCE*, the factor score representing proximity to private information source is denoted by *PRIVATE*.

Market structure variables

In order to capture the market structure we rely on a survey question for the *number of competitors* in the market for the product with largest share of turnover, asked in the second wave of the MIP. One of the following three alternatives are to be chosen: 1-5, 6-10 and more than 10 competitors. We use the weighted average of the number of competitors at the sectoral level. Furthermore, we assume that market structure does not change much with time. Therefore, the value for 1993 should also be valid for 1992 and 1996. To calculate the industrial average **welche Aggregationsebene???**, we assign the value 3 to the 1–5 category, the value 8 to the 6–10 category and 15 to the category with no upper limit. This variable is denoted by *COMP*.

As an additional indicator for market structure, export share is considered. It is calculated as the share of exports over total sales and denoted by *EXPSHARE*. The larger the export share, the greater the market for an individual firm. That is, a larger export share is identical to a shift of the individual demand curve to the right.

Controls for observable firm heterogeneity

The sample used here captures firms of all sectors of manufacturing industries as well as firms of different sizes. The resulting firm heterogeneity is taken into account by introducing various variables. In order to capture the heterogeneity of production- and market conditions, the *Herfindahl–equivalent number of product groups* of a firm is considered. This index is defined as

$$DIVERS_{is} = \frac{1}{\sum_{l=1}^{5} share_{l,is}^2} \quad \text{with} \quad share_{5,is} = argmin(1 - \sum_{l=1}^{4} share_{l,is},\ s_{4,ij}), \quad (20)$$

where $share_{l,is}$ denotes the sales share of product group l of firm i from the sth sector. In the questionnaire only sales shares of the four most important product groups are asked for. The product share of the fifth product group is derived from the second part of equation (20). This variable is thus equivalent to the construction of firm number equivalents known from the literature of firm concentration measurement as the Hirschman–Herfindahl–Index. The larger this index, the more the firm is diversified. If the total turnover is gained from only one product group, the index variable *DIVERS* takes on the value 1. If turnover is equally distributed over the five product groups, *DIVER* takes on the value 5. However, if the sum of turnover shares is smaller than 1, larger values of the diversification index are possible.

Firms may also differ with respect to financing conditions of R&D expenditure. In order to capture possible financing restrictions data additional data taken from Germany's largest credit rating agency *Creditreform* are merged to the MIP.[12] We use a dummy variable which takes on the value 1 if *Creditreform* is unable to recommend trade credit without objections. Hence, it can be argued that additional financing costs are imposed on the firm, reducing financing possibilities of R&D.

In order to further control for observable firm heterogeneity, we also include five size class dummy variables (*SIZE1–SIZE5*) and five sector dummies.[13] The sector dummies are denoted by *FOOD* (manufacture of food products), *WOOD* (manufacture of wood and wood products), *CHEMICALS* (manufacture of chemicals), *METAL* (manufacture of basic metals and fabricated metal products), *INSTR* (manufacture of electrical and optical equipment) and *MACHINE* (manufacture of machinery, base category).

We further include a dummy variable *EAST* for East German firms.

Descriptive statistics of the variables used in our empirical model are presented in Appendix A.

IV Empirical results

Due to the complexity of the theoretical model presented in section 2, it is not possible to structurally estimate the equations derived there. Instead, we test the main hypothesis of our theoretical model as summarized at the end of section II.

How can our theoretical model be implemented empirically? Our empirical analysis proceeds in two steps. First, we analyze firm's decisions to cooperate or not cooperate.

[12]See Harhoff et al. [1998] for a description of this data set.

[13]Note that the spillover pools are generated on a 32 sector basis.

Second, we investigate the determinants of firm's R&D investment intensity (R&D investment scaled by sales) separately for non–cooperating, mixed and vertically cooperating firms while taking into account the endogeneity of such a sample split by inclusion of a Heckman [1979] — denoted by *HECKCORR* — correction term.

IV.1 Cooperation decision

In the theoretical model described above, it pays for all firms to conduct R&D. Hence, we only consider those firms which actually conduct R&D although our sample also contains 835 firms which do not invest in R&D. Further, the MIP not only contains information on whether a firm is involved in R&D cooperations, it also contains information on whether a firm conducts joint R&D horizontally (with competitors), vertically (with customers and/or suppliers). Since firms may be involved in both horizontal and vertical cooperations, a third possibility exists which we call a 'mixed' cooperation.

Figure I summarizes the decisions a firms has to reach in its R&D cooperation decision making process. In a first stage, firms decide whether or not to conduct R&D cooperatively. If it has decided to do joint R&D, it then has to reach a decision between horizontal, vertical or mixed cooperation in a second stage. In a third stage firms decide upon their level of R&D spending, given their cooperation decision.

Figure I shows that the category 'horizontal' cooperation is thinly populated, both in absolute terms and in relation to the other choices. We therefore combine the horizontal choice and the 'mixed' cooperation mode.[14]

It is important to note that the representation by a decision tree as in Figure I is of purely analytical nature. It is not implied that time actually passes by between the individual decisions since "one must distinguish between hierarchical behavior and hierarchical structure for the mathematical forms of the choice probabilities" (Pudney [1989], p.125). In fact, choosing the appropriate econometric model for such a discrete choice problem is tedious. If time actually passed by between the decision stages, a sequential model would be appropriate. If the lower stage mattered in the decision making process of the first stage, a nested multinomial logit (NMNL) model should be used. If firms decided simultaneously upon R&D cooperation and the type of cooperation partner, a multinomial logit model (MNL) would be appropriate.[15] It thus is desirable to have a flexible econometric technique at hand which nests these types of discrete choice models. Such an estimator has been prosed by van Ophem and Schram [1997] who show that the simultaneous and the sequential logit model can be combined without loosing the properties of the logit model. The sequential, the NMNL and the MNL are nested by a single parameter, λ. The interpretation of this parameter is close to the interpretation of the coefficient corresponding to the inclusive value in NMNL models: For $\lambda = 0$, the utilities of the lower stage in a decision process do not determine the utilities in the upper stages so that the model could be sequentially estimated. If $\lambda = 1$, the decision reached in the upper stage is determined by the maximum utility to be obtained in the lower stage leading to the MNL as appropriate econometric tool. If $\lambda \in (0, 1)$, an intermediate position is obtained and the NMNL is appropriate.

The estimator suggested by van Ophem and Schram [1997] does — as opposed to the

[14] See Blundell et al. (1993) for a theoretical reasoning of combining choice categories.

[15] See Eymann [1995] for a detailed discussion of these types of models and empirical examples.

traditional NMNL where the parameter related to the inclusive value is bounded within $[0,1]$ — allow for values of λ outside the [0,1] range on statistical grounds. However, for $\lambda > 1$ and $\lambda < 0$, there is no economic interpretation. Technical details of the van Ophem and Schram [1997] estimator are presented in Appendix B.

We include the variables described in section III in our model of cooperation type choice. Table I displays the estimated coefficients, standard errors and marginal effects — evaluated at the means of the involved variables[16] — obtained from our estimation.
The estimation results shown in Table I broadly support the hypothesis derived from our theoretical model. Vertical spillovers have a significant and positive effect on the probability to conduct joint R&D. They further have a significantly positive impact on the probability to choose vertically related firms as partner for R&D cooperation. Horizontal spillovers do not have a significant impact on the decision whether or not to cooperate. This may be caused by the combination of horizontal and mixed cooperations due to the insufficient number of firms which conduct R&D with horizontally related firms as the only form of cooperation. This view is supported by the positive and significant impact of horizontal spillovers on the choice of 'mixed' category.
The productivity of R&D a significant impact on the decision to vertically or mixed cooperate only. The construction of our productivity indicators *SCIENCE* and *PRIVATE* implies that we only observe inter–industry productivity differences in R&D and assume away within industry productivity differentials.[17] *SCIENCE* and *PRIVATE*, however, always carry the expected signs and are significant in the choice of cooperation partners. We observe a significant and positive impact of proximity to science — and thus of R&D productivity — on the choice of more complex R&D cooperative arrangements (mixed cooperations). Inversely, high R&D productivity leads to a decrease in the probability to choose vertically related firms as cooperation partners. Proximity to private firms, as depicted by the variable *PRIVATE*, induces firms to engaged in pure vertical relations to R&D partners. Knowledge is gained parallel to the value added chain (e.g., by buying or transferring knowledge via embodied technology and cooperation with suppliers and customers). The effects of the R&D productivity variables are therefore also compatible with the implications of our theoretical model.
The diversification index $DIVERS$ does not significantly influence firm's R&D cooperation decisions.
The market structure variable $COMP$ (the number of competitors in each firm's sector) has a negative, though insignificant (p–value 0.125) impact on the decision whether or not to cooperate at all while it has a significantly positive impact on the decision to cooperate in a vertical mode. This indicates that strong market competition makes firm hesitant with respect to horizontal cooperation.
The number of competitors, however, has a significantly positive impact on the probability to cooperate vertically. This implies that firms tend to form vertical RJVs with increased market competition. Expresed the other way around: The smaller the number of firms in a sector is, the more likely cooperating firms are engaged in horizontal R&D agreements. This is compatible with the dynamic argument that R&D cooperation can be enforced

[16]Taking the mean of the individual marginal effects did not lead to qualitatively differing results.
[17]Note that the variables *SCIENCE* and *PRIVATE* are calculated on the basis of a disaggregated 32 sector–level. Inclusion of these variables in the equations for R&D cooperation and R&D intensity does thus not lead to a simultaneity problem.

more easily if the number of firms in an industry is smaller.
Exportshare ($EXPSHARE$) do not significantly influence firm's decision whether to cooperate in R&D or to conduct R&D on it's own.

Insert Table I about here!

The variables included to control for observable firm heterogeneity are not displayed in Table I for the sake of brevity.[18] We briefly summarize signs and significancy of these variables as follows: East German firms do not significantly differ from West German firms with respect to the R&D cooperation decision and their choice of cooperation partners. Likewise, potentially credit rationed firms do not significantly differ from non–credit rationed ones in their choice of R&D cooperation and RJV partners. The size class dummy variables are jointly significant (p–value .037) for the decision between mixed and vertical cooperation and indicate an increased propensity for larger firms to cooperate in a mixed mode. Firms size does not play a significant role in the decision to cooperate at all. The set of sector dummy variables does not have a significant impact on the initial R&D cooperation decision but on the type of cooperation partner eventually chosen.
The coefficient λ is 3.7917 and hence outside the [0,1] range. A test of a simultaneous model (e.g., $\lambda = 1$) cannot be accepted at the 4.3 percent marginal significance level. The 95 percent confidence interval corresponding to our estimated λ is (.538,7.045).
The goodness of fit measures is .108 and thus appropriate for these types of models.[19]

IV.2 R&D intensity

The increasing attention towards R&D cooperation results from the models' implication that R&D cooperation increase the aggregate efficiency of R&D investment. Moreover, R&D cooperation is thought to generate R&D incentives to the individual firm. From the theoretical framework no unequivocal effect of R&D cooperation on the dimension of R&D investment can be derived. Two opposing effects are present: (i) The sharing of R&D results leads to an increased R&D efficiency and thus induces R&D saving effects. (ii) At the same time, incentives from the internalization of spillovers for exposures in R&D occur and thus stimulate R&D investment. However, what follows is that the presence of spillovers should make a difference for firms with and without R&D cooperation. This implication is tested hereafter.
Our empirical approach is to run OLS regressions for R&D investment for firm engaged in RJV's and for firms not engaged separately. We apply White's [1980] heteroskedasticity variance–covariance matrix. We then test if there exist a parameter vector which is common to both equations by applying a Minimum Distance Estimator (MDE). The basic methodology of the MDE is presented in Appendix C.
Our R&D intensity equation contains the same variables as the R&D cooperation decision estimation. Instead of actually considering R&D investment, we analyze R&D investment

[18] The entire set of estimation results for the R&D cooperation model and the R&D investment model as well as test statistics can be downloaded from the internet at: `ftp://ftp.zew.de/pub/zew-docs/div/results.pdf`.
[19] The pseudo R^2 is the goodness of fit measure of Aldrich and Nelson [1989]. See Veall and Zimmermann [1992] for a discussion of goodness of fit measure for qualitative dependent variables.

intensity (R&D investment scaled by sales). We take the natural logarithm of R&D intensity as dependent variable.

Insert Table II about here!

Estimation results of the R&D intensity equations are displayed in Table II. Vertical spillovers have a negative and significant impact of R&D intensity in all equations. For mixed or vertically cooperating firms, horizontal spillovers influence R&D intensity in a negative and significant way while horizontal spillovers do not affect the R&D intensity of non–cooperating firms. This implies that for cooperating firms, the cost saving effect overweighs efficiency gains. The effects of vertical and horizontal spillovers are thus in line with our theoretical model.

R&D productivity, as represented by the variable *SCIENCE* has a significant and positive effect on the R&D intensity of both cooperating and non–cooperating firms. It has no significant impact of the R&D intensity of non-cooperating firms. *PRIVATE* turns out to be insignificant non–cooperating firms while it is positive and significant for cooperating firms. This implies that knowledge flows on the markets are more important for cooperating firms than for non–cooperating firms where proximity to science dominates.

For the coefficients of the other variables the following effects are present: The extent of diversification has no impact on the R&D intensity of non–cooperating firms. Increased diversification, however, leads to a decrease in R&D intensity of mixed or vertically cooperating firms. **???** The higher the number of competitors, that is, the lower market concentration, the lower is R&D intensity. This is in accordance to Schumpeter's hypothesis which states that market power has an R&D enhancing effect.

However, our results contradict Schumpeter's view on firm size and innovation. We find that R&D intensity is decreasing in firm size up to a certain point in the size distribution of firms where R&D intensity begins to rise with size. This U–shaped R&D intensity/firm size relation is often found in empirical studies of innovation and firm size (see Felder et. al. [1996]). Also the industry dummies variables indicate lower R&D intensity in low tech sectors.

Finally, we conduct Minimum Distance Estimation in order to test the hypothesis if there is a common structure in the parameter estimates of the equations for cooperating and non–cooperating firms. The test results are displayed in Table III. The coefficient related to the Heckman correction coefficient is left out in these tests. Based on a Wald–type test statistic (see Appendix C), we cannot reject a common structure of the parameter estimates for non–cooperating, mixed and vertically cooperating firms. The same results holds, if it is piecewise tested for common structures across the three parameter estimates. Interestingly, the impact of horizontal spillovers on R&D intensity is significantly smaller for vertically cooperating (p–value 0.071) and almost significantly (p–value 0.127) smaller for mixed cooperating firms implying that the cost–sharing effect dominates the internalization effect in the case of R&D cooperation.

Insert Table III about here!

V Conclusion and suggestions for further research

In this paper, we derive a three stages oligopoly game for R&D cooperation, R&D investment and product market competition. The model captures both process and product innovations. It is shown that the structure of optimal R&D is the same for process and product innovation.

The most important hypothesis of our theoretical model are tested in the empirical part of this paper. Our empirical results are in line with implications of our theoretical model. We find that the presence of spillovers stimulates the formation of R&D joint venture. The impact of vertical spillovers, however, is more important than that of horizontal spillovers though our theoretical model predicts an inverse relationship. Vertical spillovers significantly and negatively influence R&D intensity, independently of whether or not firms are a RJV members. We do not find significant difference of the impact of horizontal and vertical spillovers on the R&D intensity of cooperating versus non–cooperating firm. This indicates that the cost–sharing and internalizsation effect of RJVs balance out each other. We do not find that horizontal spillovers increase the probability of horizontal co–operations. This is only compatible with the theoretical model if spillovers are small but may also be caused by not explicitly modeling horizontal cooperations in our empirical model due to a too small population of the choice horizontal cooperation.

The results presented here should be regarded as a first attempt to give empirical evidence for the formation of RJVs and the impact of RJVs on R&D intensity. A number of improvements within the present framework should be conducted in the future. First, vertical relationships should not be modeled solely by the level of substitutability of the products. Some models analyzing vertical relationships and vertical R&D co–operations already exist (e.g. Inkmann [1997]). Second, the econometric devices used here do not allow to simultaneously estimate R&D and cooperation decisions and R&D intensity. A conditional generalized method of moments estimator as suggested by Newey [1993] — though far beyond the scope of this paper — provides a solution to the simultaneity problem. Third, additional attention should be devoted to the construction of the spillover pool variables. The present paper only considers the industry affiliation of a firm and the average leak of R&D results. The data set used here contains a number of possibilities to model the ability of a firm to assimilate 'free available' know–how more directly. Attempts in this direction have recently been untertaken by Kaiser [1999].

Figure I
Decision Tree of Choice between Cooperation Partners

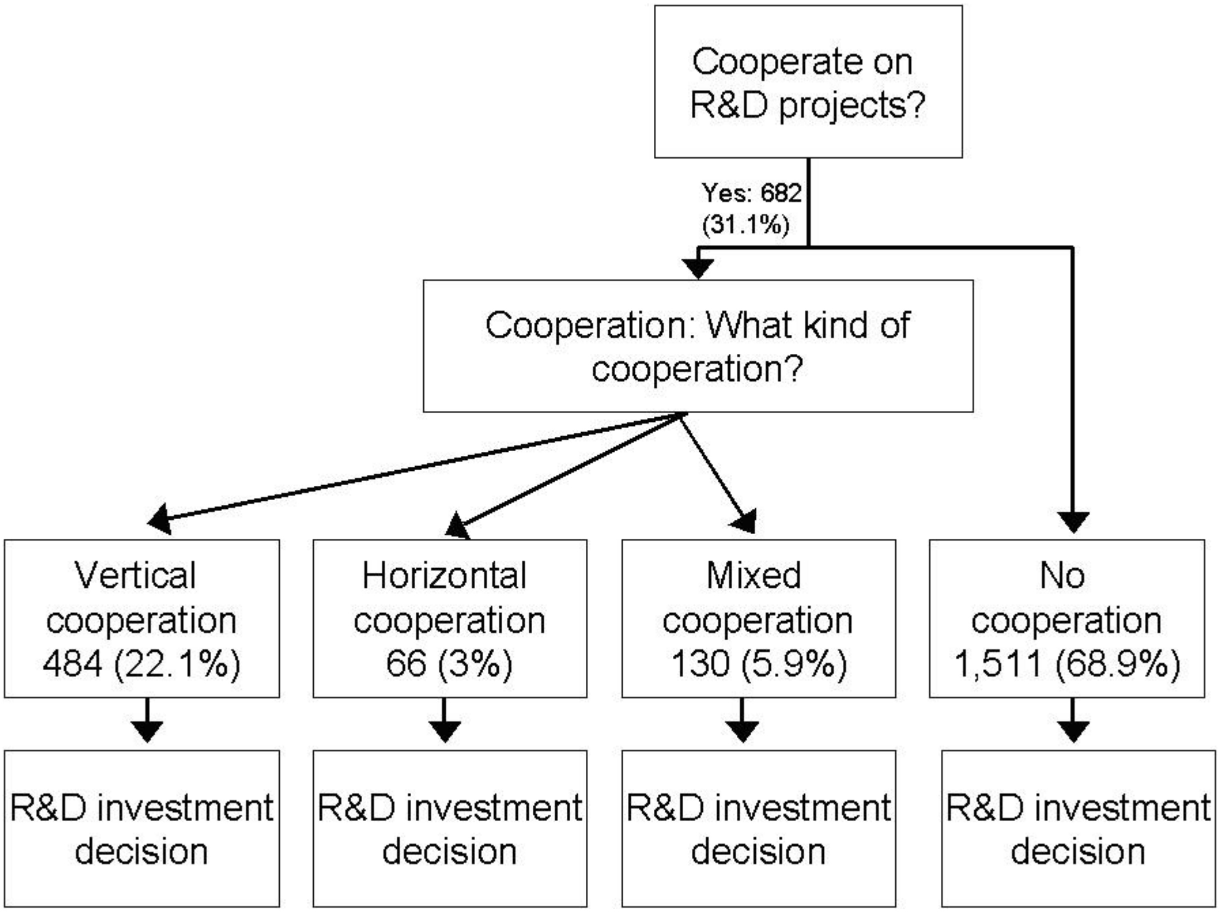

TABLE I
COOPERATION DECISION ESTIMATION RESULTS

	P(no cooperation) base: P(cooperation)			**P(mixed cooperation)** base: P(vert. cooperation)		
	coeff.	std.err.	m. eff.	coeff.	std.err.	m. eff.
$ln(S_{is}^{h})$	0.090	0.096	-0.005	0.113	0.083	0.020
$ln(S_{is}^{v})$	-1.209	0.327	-0.166	-0.340	0.224	-0.060
PRIVATE	-0.126	0.396	0.071	-0.470	0.314	-0.083
SCIENCE	0.014	0.361	-0.146	0.736	0.363	0.129
DIVERS	-0.010	0.139	0.002	-0.019	0.094	-0.003
COMP	-0.082	0.071	0.007	-0.111	0.042	-0.020
EXPSHARE	-0.212	0.405	-0.040	-0.007	0.303	-0.001
λ		3.919			1.701	
Test Statistics		χ^2 *(df)*			χ^2 *(df)*	
Firms size dummies		2.629 (4)			10.187 (4)	
Sector dummies		5.809 (5)			10.489 (5)	
Pseudo R^2				0.108		
# of obs.				2,152		

Note: Table I displays estimation results of a nested logit model proposed by van Ophem and Schram (1997). The parameter λ denotes the coefficient related to the inclusive value variable. The Pseudo R^2 is the goodness of fit measure of Aldrich and Nelson [1989], corrected by sample size. The abbreviation *m. eff.* denotes marginal effects, calculated at the means of the involved variables. The specification also includes four firms size dummy variables, five sector dummy variables, four dummy variables indicating past sales developments and a constant term.

Table II
R&D Intensity Estimation

	non–coop. firms		mixed coop. firms		vert. coop.	
	coeff.	std. err.	coeff.	std. err.	coeff.	std. err.
$ln(S_{is}^h)$	0.011	0.085	-0.120	0.057	-0.097	0.054
$ln(S_{is}^v)$	-0.216	0.142	-0.195	0.100	-0.161	0.091
PRIVATE	0.029	0.203	0.297	0.158	0.395	0.145
SCIENCE	0.429	0.174	0.454	0.170	0.400	0.161
DIVERS	0.088	0.204	-0.054	0.026	-0.052	0.024
COMP	-0.092	0.026	-0.066	0.018	-0.061	0.017
EXPSHARE	0.428	0.182	0.898	0.128	0.878	0.118
HECKCORR	-0.238	0.267	2.89	1.01	-2.572	0.956
Test Statistics	χ^2 *(df)*		χ^2 *(df)*		χ^2 *(df)*	
Firms size dummies	58.985 (4)		53.112 (4)		36.631 (4)	
Sector dummies	37.016 (5)		87.396 (5)		85.614 (5)	
Sales past dummies	3.889 (4)		6.168 (4)		4.614 (4)	
adj. R^2	0.206		0.189		0.189	
# of obs.	1,487		472		193	

Note: Table II displays OLS estimation results with White [1980] standard errors. The equations are estimated separately for non–cooperating, mixed and vertically cooperating firms. The specification also includes four firms size dummy variables, five sector dummy variables, four dummy variables indicating past sales developments, a constant and a Heckman–type correction term — denoted by *HECKCORR* — for endogeneous sample selection.

Table III
Tests for Common Parameter Structure of R&D intensity Equations

	Wald–stat.	p–val.	df
Vertical/non–cooperating firms			
entire parameter vector	50.649	0.295	46
horizontal spillover parameter only	5.295	0.071	2
vertical spillover parameter only	0.044	0.978	2
Mixed/non–cooperating firms			
entire parameter vector	37.709	0.803	46
horizontal spillover parameter only	4.127	0.127	2
vertical spillover parameter only	0.354	0.838	2
Mixed/vertical cooperating firms			
entire parameter vector	19.458	1.000	46
horizontal spillover parameter only	0.179	0.914	2
vertical spillover parameter only	0.205	0.902	2
Mixed/vertical/not cooperating firms			
entire parameter vector	67.645	0.524	69
horizontal spillover parameter only	1.726	0.631	3
vertical spillover parameter only	0.122	0.989	3

Note: Table III displays results of tests for common structure of the estimates of the R&D intensity equations for cooperating and non–cooperating firms. *P–val.* indicates the marginal significance at which the null hypothesis of common parameter structure cannot be accepted, *df* indicates the degrees of freedom. The Heckman correction type for endogeneous sample selection is left out in any of the tests listed above.

Appendix A: Descriptive statistics

	non–coop. firms			vert. coop. firms			mixed coop. firms		
$ln(R\&D/sales)$	1487	-4.1352	1.3401	472	-3.9038	1.2491	193	-3.6327	1.1881
$ln(S_{is}^h)$	1487	0.3190	1.2412	472	0.5345	1.2734	193	0.6278	1.0305
$ln(S_{is}^v)$	1487	3.2472	0.4641	472	3.4053	0.4510	193	3.2860	0.4659
PRIVATE	1487	0.0743	0.2423	472	0.0779	0.2358	193	0.0814	0.2241
SCIENCE	1487	0.1348	0.4107	472	0.1675	0.4287	193	0.4233	0.4064
DIVERS	1487	2.5378	6.3982	472	2.4560	1.8897	193	2.7166	2.1690
COMP	1487	9.7167	1.8788	472	9.4991	1.7725	193	9.0806	1.8282
EXPSHARE	1487	0.2255	0.2324	472	0.2658	0.2429	193	0.2939	0.2466
CREDIT	1487	0.8097	0.3927	472	0.7521	0.4322	193	0.6632	0.4738
EAST	1487	0.2569	0.4371	472	0.2246	0.4177	193	0.1451	0.3531
SIZE2	1487	0.1459	0.3532	472	0.1250	0.3311	193	0.0518	0.2222
SIZE3	1487	0.3961	0.4893	472	0.2860	0.4524	193	0.2124	0.4101
SIZE4	1487	0.3046	0.4604	472	0.3517	0.4780	193	0.3523	0.4789
SIZE5	1487	0.0874	0.2826	472	0.1864	0.3899	193	0.3575	0.4805
FOOD	1487	0.0989	0.2986	472	0.0508	0.2199	193	0.0415	0.1998
WOOD	1487	0.0881	0.2835	472	0.0508	0.2199	193	0.0155	0.1240
CHEMICALS	1487	0.2112	0.4083	472	0.2288	0.4205	193	0.2280	0.4206
METAL	1487	0.1325	0.3391	472	0.1314	0.3381	193	0.1140	0.3186
INSTR	1487	0.1762	0.3811	472	0.1780	0.3829	193	0.2694	0.4448
SALES++	1487	0.1009	0.3013	472	0.0953	0.2940	193	0.0622	0.2421
SALES+	1487	0.0975	0.2968	472	0.1165	0.3212	193	0.1088	0.3122
SALES-	1487	0.4351	0.4959	472	0.4280	0.4953	193	0.4611	0.4998
SALES–	1487	0.1944	0.3958	472	0.2436	0.4297	193	0.2332	0.4239

Appendix B: The van Ophem and Schram estimator

The indirect utilities $y^*_{d,i}$ of the choices 'cooperation' (*coop*), 'no cooperation' (*no coop*), 'vertical cooperation' (*vert*), and 'mixed cooperation' (*mix*) for firm i ($d = coop, no\ coop, vert, mix$) are assumed to be linear and dependent on a set of explanatory variables summarized in row vector $\boldsymbol{x_i}$:

$$\begin{array}{lclclcl} y^*_{coop,i} & = & \boldsymbol{x_i}\boldsymbol{\vartheta} & + & \lambda\ I_i & + & \omega_{no\ coop,i}, \\ y^*_{no\ coop,i} & = & \boldsymbol{x_i}\boldsymbol{\delta} & & & + & \omega_{coop,i}, \\ y^*_{vert(coop),i} & = & \boldsymbol{x_i}\boldsymbol{\alpha} & & & + & \omega_{vert(coop),i}, \\ y^*_{mix(coop),i} & = & \boldsymbol{x_i}\boldsymbol{\gamma} & & & + & \omega_{mix(coop),i}, \end{array} \tag{21}$$

where the inclusive value I_i is given by $I_i = log[exp(\boldsymbol{x_i}\boldsymbol{\alpha}) + exp(\boldsymbol{x_i}\boldsymbol{\gamma})]$. The error terms are type I extreme value distributed. Error term $\omega_{no\ coop,i}$ is independent of $\omega_{coop,i}$. Further, $\omega_{no\ coop,i}$, $\omega_{vert(coop),i}$, $\omega_{hori(coop),i}$, and $\omega_{mix(coop),i}$ are independent. Unless $\lambda = 0$, $\omega_{coop,i}$ is correlated with $\omega_{vert(coop),i}$, $\omega_{hori(coop),i}$, and $\omega_{mix(coop),i}$. The indicator variables $y_{d,i}$ take on the value 1 if the dth option is chosen, and 0 otherwise. It follows that

$$\begin{array}{lclcl} P_{coop,i} & = & P[y_{coop,i} = 1] & = & \frac{exp(\boldsymbol{x_i}\boldsymbol{\vartheta}+\lambda I_i)}{exp(\boldsymbol{x_i}\boldsymbol{\delta})+exp(\boldsymbol{x_i}\boldsymbol{\vartheta}+\lambda I_i)} \\ P_{no\ coop,i} & = & P[y_{no\ coop,i} = 1] & = & \frac{exp(\boldsymbol{x_i}\boldsymbol{\delta})}{exp(\boldsymbol{x_i}\boldsymbol{\delta})+exp(\boldsymbol{x_i}\boldsymbol{\vartheta}+\lambda I_i)} \\ P_{vert(coop),i} & = & P[y_{vert} = 1 | y_{coop} = 1] & = & \frac{exp(\boldsymbol{\alpha}\boldsymbol{x_i})}{exp(\boldsymbol{x_i}\boldsymbol{\alpha})+exp(\boldsymbol{x_i}\boldsymbol{\gamma})} \\ P_{mix(coop),i} & = & P[y_{mix} = 1 | y_{coop} = 1] & = & \frac{exp(\boldsymbol{\gamma}\boldsymbol{x_i})}{exp(\boldsymbol{x_i}\boldsymbol{\alpha})+exp(\boldsymbol{x_i}\boldsymbol{\gamma})}. \end{array} \tag{22}$$

In order to achieve identification, the following restrictions are imposed: $\boldsymbol{\alpha}$=0 and $\boldsymbol{\vartheta}$=0. The loglikelihoodfunction corresponding to firm i is:

$$log\ L_i = \sum_{d=coop,no\ coop} y_{d,i}\ P(d)_i + \sum_{d=vert,mix} y_{d,i}\ P(d)_i, \tag{23}$$

where the first part of equation (23) corresponds to the choice between cooperation and no cooperation and the second part corresponds to the choice between vertical, horizontal a mixed cooperation, given the firm decided to cooperate at all in the first stage. Equation (23) could be estimated by a two–step procedure which yielded consistent estimates for the coefficients but not for the variance–covariance matrix since the information matrix related to (23) is not block–diagonal. Thus, we estimated the model using a full information maximum likelihood procedure.[20]

The gradients corresponding to equation (23) are given by:

$$\begin{array}{lcl} \frac{\partial log\ L_i}{\partial \boldsymbol{\delta}} & = & \boldsymbol{x_i} \odot (y_{no\ coop,i} - P_{no\ coop,i}) \\ \frac{\partial log\ L_i}{\partial \lambda} & = & I_i(y_{coop,i} - P_{coop,i}) \\ \frac{\partial log\ L_i}{\partial \boldsymbol{\gamma}} & = & \boldsymbol{x_i} \odot \Big(y_{mix,i}P_{vert,i} + P_{mix,i}(\lambda(y_{coop,i} - P_{coop,i}) - y_{vert,i})\Big), \end{array} \tag{24}$$

[20] The estimation of the van Ophem and Schram [1997] procedure as well as the Minimum Distance Estimation were performed using our own GAUSS program based on the MAXLIK application module. A copy of the programs can be obtained from the authors upon request. Analytical gradients were provided in both cases. Numerical problems have not been encountered.

where $\odot$ denotes elementwise products.
The marginal effects corresponding to the probabilities shown in equations (22) are:

$$
\begin{aligned}
\frac{\partial P_{coop,i}}{\partial \boldsymbol{x_i}} &= -\Big(P_{coop,i}\ P_{no\ \ coop,i}\ P_{vert,i}\Big) \odot \Big(\boldsymbol{\delta} + exp(\boldsymbol{x_i}\boldsymbol{\gamma}) \odot (\boldsymbol{\delta} - \boldsymbol{\gamma}\lambda)\Big) \\
\frac{\partial P_{no\ \ coop,i}}{\partial \boldsymbol{x_i}} &= -\frac{\partial P_{coop,i}}{\partial \boldsymbol{x_i}}, \\
\frac{\partial P_{vert,i}}{\partial \boldsymbol{x_i}} &= -(P_{vert,i}\ P_{mix,i}) \odot \boldsymbol{\gamma} \\
\frac{\partial P_{mix,i}}{\partial \boldsymbol{x_i}} &= \ -\frac{\partial P_{vert,i}}{\partial \boldsymbol{x_i}}.
\end{aligned}
\qquad (25)
$$

Appendix C: The Minimum Distance Estimator

In order to test if there is a common structure in the parameter estimates for the choice of the alternative vertical information sources, a Minimum Distance Estimator (MDE) is used. Minimum Distance Estimation involves the estimation of the M reduced form parameter vectors in a first stage. In the present case, these reduced form parameters are the parameter estimates obtained from running separate tobit regressions for the choice alternative cooperation modes. In the second stage, the Minimum Distance Estimator is derived from minimizing the weighted difference between the auxiliary parameter vectors obtained in the first stage.
Besides the practical advantage that the MDE can be easily implemented empirically, it has the further benefit that it provides the researcher with a formal test of common structures among the auxiliary parameter vectors. The MDE is derived from minimizing the distance between the auxiliary parameter vectors under the following set of restrictions:

$$f(\boldsymbol{\beta}, \hat{\boldsymbol{\theta}}) \;=\; \boldsymbol{H}\,\boldsymbol{\beta} \;-\; \hat{\boldsymbol{\theta}} \;=\; \mathbf{0},$$

where the $M \cdot K \;\times\; K$ matrix $\boldsymbol{H}$ imposes $M \cdot K$ restrictions on $\boldsymbol{\beta}$. The $M \cdot K \times 1$ vector $\hat{\boldsymbol{\theta}}$ contains the M stacked auxiliary parameter vectors. In the present case, $\boldsymbol{H}$ is defined by M $K \times K$–dimensional stacked identity matrices. The MDE is given by the minimization of:

$$\underset{\boldsymbol{\beta}}{D} \;=\; f(\boldsymbol{\beta}, \hat{\boldsymbol{\theta}})'\; \hat{V}[\hat{\boldsymbol{\theta}}]^{-1}\; f(\boldsymbol{\beta}, \hat{\boldsymbol{\theta}}),$$

where $\hat{V}[\hat{\boldsymbol{\theta}}]$ denotes the common estimated variance–covariance matrix of the auxiliary parameter vectors. Minimization of D leads to

$$\hat{\boldsymbol{\beta}} \;=\; (H'\; \hat{V}[\hat{\boldsymbol{\theta}}]^{-1}\; H)^{-1} H'\; \hat{V}[\hat{\boldsymbol{\theta}}]^{-1}\; \hat{\boldsymbol{\theta}}$$

with variance–covariance matrix

$$\hat{V}[\hat{\boldsymbol{\beta}}] \;=\; \left(H'\; \hat{V}[\hat{\boldsymbol{\theta}}]^{-1}\; H\right)^{-1}.$$

In the present case, where the three equations were estimated using different samples, $V[\hat{\boldsymbol{\theta}}]$ is a matrix carrying the estimated variance–covariance matrices of the first stage parameter vectors on its diagonal blocks.
For testing the null hypotheses that the M auxiliary parameter vectors coincide with one another, the following Wald–type test statistics can be applied:

$$f(\boldsymbol{\beta}, \hat{\boldsymbol{\theta}})'\; \hat{V}[\hat{\boldsymbol{\theta}}]^{-1}\; f(\boldsymbol{\beta}, \hat{\boldsymbol{\theta}}) \;\sim\; \chi^2_{M \cdot K}\;.$$

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