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An empirical test of models explaining research expenditures and research cooperation: evidence for the German service sector

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Abstract

Key findings of game–theoretic models that describe the effects of spillovers, market size, research productivity and the generality of a firms' research approach on innovation efforts and on their propensity to form a research joint venture (RJV) are empirically tested using innovation survey data of the German service sector. A simultaneous econometric model for cooperation choice and innovation expenditures and a nesting logit model for the choice of different types of cooperation partners are applied in the empirical analysis. By and large, the predictions of the theoretical models are empirically validated. A central finding of this paper is that cooperating firms invest more in research than non-cooperating firms.

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1. Introduction

In 1952, John Kenneth Galbraith noted that the 'era of cheap innovation' was

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over. He claimed that firms had exhausted low-cost R&D programs and were now forced to significantly increase research efforts in order to achieve scientific progress and to gain and retain market shares. An alternative and potentially complementary solution to the cheap innovation problem is the formation of Research Joint Ventures (RJVs), where firms pool their research resources to make inventions. Such research cooperations have, however, been hampered by antitrust law until the mid-1980s.[1] More than 30 years passed by since Galbraith's statement before US and European governments considerably relaxed antitrust law to allow cooperative R&D.[2] Starting points of this relaxation were the positive results from some German and US research collaborations. Spencer and Grindley (1993) argue that the SEMATECH consortium significantly contributed to the leading position of the US in semiconductor industries. Jorde and Teece (1990) trace the success of German mechanical engineering products in the 1970s and 1980s to partly industrially-financed research institutions.

For Germany, a large increase in the number of research joint ventures (RJVs) can be observed. While only 10% of all manufacturing firms in Germany were involved in R&D cooperations in 1971, 20 years later almost half of all the firms in manufacturing industries conducted cooperative research (König et al., 1994). Based on the US Department of Justice data, Vonortas (1997) shows that a sharp increase in the number of RJVs is also present in the US. The interest of economic policy in RJVs is unchanged since R&D subsidies are increasingly often bound to joint R&D efforts.[3]

A key question in economic policy is: do cooperating firms invest more, the same or less into R&D than non-cooperating firms? The standard answer of microeconomists, as DeBondt (1996, p. 10) makes it explicit in his survey of the literature on spillovers and innovative activity: it depends on the magnitude of research spillovers present in a firm's markets. If spillovers are large, i.e. a large fraction of firm *i*'s knowledge can be costlessly absorbed by firm *j*, then

[1] The biennial report by the German monopoly commission (Monopolkommission, 1990, ch. 3.2.3) describes nine cases in which it directly or indirectly (through firms' voluntary withdrawal of the cooperation proposal after the monopoly commission had stated objections against the joint research plans) hampered research cooperation. The nine cases involved research cooperations in the development of fibreglass cables (Siemens, Philips, AEG, SEL, Kabelmetal electro), LCD displays (Siemens and VDO), utility vehicles (Daimler-Benz and Iveco), optoelectronic memory and recording systems (Bertelsmann and IBM), electronically controlled carburettors (Bosch and Deutsche Vergaser Gesellschaft), coal liquefaction (Gelsenberg and Saarbergwerke), defense technology, mechanical engineering, electromatic driving mirrors for vehicles. Firm names are not mentioned in the latter three cases.

[2] Cornerstones of this development were the passage of the National Co-operative Research Act for the US in 1984 and the announcement of the block exception from Article 85 for certain categories of R&D agreements for the EEC in 1985. See Geroski (1993) and Cassiman (2000) for a discussion of these two antitrust law amendments.

[3] E.g. the projects financed by the current 5th framework program sponsored by the European Commission (http://www.cordis.lu/fp5/results.htm).

cooperating firms spend more on R&D than non-cooperating firms. Intuitively, this result arises from two opposing effects of RJVs on research efforts. The first is the positive internalization effect that occurs due to firms' ability to internalize spillovers in an RJV. The second is the negative cost sharing effect which arises from the pooling of R&D resources.

Other issues discussed in the microeconomics literature, which will be briefly reviewed in Section 2 of this paper, are how R&D investment and firms' propensity to form an RJV are affected by spillovers, the generality of research programs, market demand and research productivity.

Since research joint ventures have received heightened attention in theoretical industrial organization in recent years and since the empirical evidence on this issue is still somewhat inversely related to the importance of RJVs in the theoretical literature, this paper aims at shedding empirical light on the driving forces of RJV formation and of research expenditures. In particular, the question whether or not cooperating firms invest more in research than non-cooperating firms is addressed empirically in this paper using innovation survey data for the German service sector.

Earlier empirical evidence is presented by Irwin and Klenow (1996), who 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 (R&D expenditures scaled by total sales) and cooperative activity and find a positive effect of cooperations on R&D investment. An insignificant impact of both vertical cooperations (cooperations between a firm and its suppliers or/and customers) and horizontal cooperations (cooperations among competitors) on the R&D intensity of German firms is found by Inkmann (2000). He also finds significant negative effects of intra-industry spillovers on R&D intensity and a significantly positive effect of inter-industry spillovers, while horizontal spillovers increase the tendency to cooperate with customers. Cassiman and Veugelers (1999) analyze Belgian firms to uncover the differential effects of incoming and outgoing spillovers and find that firms with large incoming spillovers and lower outgoing spillovers (better appropriation) have a higher probability of cooperating in R&D.

Other empirical work on RJVs has focused on the anatomy of the research partners. Kleinknecht and Reijnen (1992) study the determinants of research cooperation in Dutch manufacturing industries. They come to the quite surprising conclusion that firm size does not have a significant effect on the propensity to cooperate. By contrast, the existence of an R&D department, granted patents, licensing and sectoral affiliation significantly affect firms' propensity to cooperate. The results by Kleinknecht and Reijnen (1992) may suffer from simultaneous equation bias. Röller et al. (1998) use a simultaneous equation set-up. In their analysis of US firms that participate in RJVs they find a tendency towards cooperation among firms of similar size and that RJV formation is dependent on a number of industry-specific effects. Veugelers (1993) describes the profile of 668 international research alliances and finds that improved market access, monitoring and control as well as complementarities in assets drive cooperative research. While at least some empirical evidence exists on the relationship between R&D cooperation and R&D expenditure for manufacturing, virtually nothing is known for the service sector although this sector is almost as innovative as manufacturing industries. This paper adds to existing empirical studies in that it analyzes the service sector.[4]

Janz and Licht (1999) give a comprehensive descriptive comparison between the innovative behavior of services and manufacturing industries. They find that 58.4% of the firms from the manufacturing sector and 58.8% of the firms from the service sector introduced an innovation in 1996. While there are not many differences in these figures, innovation intensity (innovation expenditures scaled by sales) is lower in services than in manufacturing. The average innovation intensity in manufacturing is 10%, whereas it is 5% in services. In any case, these figures suggest that innovation plays a major role in the service sector as well, so that it is worthwhile to learn more about innovation patterns in this sector.

Section 2 of this paper briefly reviews existing studies and summarizes main hypotheses concerning the effect of research collaboration on research efforts as well as the effects of spillovers, the generality of the research approach, of market demand and of research productivity on research efforts and the propensity to form an RJV.[5] These hypotheses are empirically tested in Section 4 using innovation survey data which are described in Section 3. A summary and an outlook to further research conclude this paper.

2. A review of the existing literature

Microeconomists began to develop theoretical frameworks to describe R&D expenditure and R&D cooperation in the mid-1980s. Pioneering contributions to

[4] There are, however, a few studies that are concerned with the innovative activity in the service sector in general: Kleinknecht (1998) summarizes main findings of a Dutch innovation survey, which also covers the service sector. The determinants of R&D expenditures in Dutch services and manufacturing are analyzed by Brouwer and Kleinknecht (1997). Kleinknecht and Reijnen (1992) study R&D cooperations in services and manufacturing industries. Gallouj and Weinstein (1997) characterize innovative activity in the services sector. Sirilli and Evangelista (1998) provide empirical evidence on innovative behavior of Italian service firms. Finally, Amable and Palombarini (1998) conduct a comparison of R&D intensities across agriculture, manufacturing and services for eight OECD countries.

[5] Tournament games (see, e.g. Beath et al., 1997; Reinganum, 1981; Stewart, 1983; Katz and Ordover, 1990) are not considered here since it is not possible to implement them empirically using the data set analyzed in this study. Moreover, for services, patenting activities plays a very minor role in the innovative activities anyway (Janz and Licht, 1999) so that further arguments against the consideration of patent racing games in this paper are provided.

R&D investment with spillovers are Brander and Spencer (1983); Katz (1986) and Spence (1984). Probably the most influential paper is due to D'Aspremont and Jacquemin (1988).[6] They derive a two-stage Cournot duopoly game in which firms first decide upon R&D investment and then compete in the product market. The effective R&D expenditures of firm i, X_i are assumed to be the sum of their own R&D, x_i and the fraction of firm j's R&D efforts which spills over to firm i, βx_j: $X_i = x_i + \beta x_j$.[7] In the basic model by D'Aspremont and Jacquemin (1988), research expenditures are larger in an RJV than in the competition case if spillovers exceed a critical value which is equal to $1/2$ in the D'Aspremont and Jacquemin case of quadratic cost functions and linear product demand.

In a comment to D'Aspremont and Jacquemin (1988), Henriques (1990) points out that the results of the original model only hold if spillovers are not too small. Another crucial criticism is the firm symmetry assumption, an assumption which is shared by almost all of the literature on RJVs.[8] Salant and Shaffer (1998, 1999) demonstrate that the restriction to symmetric R&D efforts of RJV partners might be erroneous under certain circumstances since joint profits can be maximized by making unequal R&D investments. Another important source of critique of the D'Aspremont and Jacquemin (1988) model is that the R&D process is treated as a deterministic process and hence falls short of real innovation processes which are driven by risk and irreversabilities. Amir and Wooders (1999) weaken this property by introducing stochastic spillovers. Other contributions in that respect are Choi (1993) in a tournament game context and Beaudreau (1996) who applies a dynamic programming methodology.

The D'Aspremont and Jacquemin (1988) framework has been extended in various respects in recent years.[9] These extensions concern (i) the consideration of oligopolies (Kamien et al., 1992; Suzumura, 1992),[10] (ii) the extension to heterogenous products (Kamien et al., 1992), (iii) the incorporation of price competition on the product market (Kamien et al., 1992; Ziss, 1994; Qiu, 1997; Hinloopen, 2000),[11] (iv) product innovation (Motta, 1992; Kesteloot and DeBondt, 1993; Cohen and Klepper, 1996; Beath et al., 1997; Bonano and Haworth, 1998; Fishman and Rob, 2000; Kaiser and Licht, 1998; Levin and Reiss, 1988;

[6] D'Aspremont and Jacquemin (1990) make some clarifications concerning their earlier paper and refer to the stability conditions established by Henriques (1990).

[7] For empirical evidence on the existence and measurement of spillovers, see Bernstein and Nadiri (1988) and the surveys by Griliches (1992) and Mohnen (1989) as well as the literature review contained in Kaiser (1999).

[8] Exceptions are, i.e. Amir and Wooders 1998, 1999; Amir et al. (2000); Röller et al. (1998); Rosen (1991) as well as Veugelers and Kesteloot (1996). DeBondt and Henriques (1995) allow spillovers to be unequal.

[9] Surveys on this literature are provided by DeBondt (1996) and Veugelers (1998).

[10] DeBondt et al. (1992) study the effect of the number of rivals in an industry and the magnitude of spillovers on research efforts.

[11] Brod and Shivakumar (1997a) show that cooperative R&D is preferred over independent R&D by both consumers and firms independent of the way output is chosen.

Rosenkranz, 1995), (v) vertical cooperation (Inkmann, 2000; Banerjee and Lin, 1999),[12] (vi) the determination of the number of RJVs a firm is involved in and the size of an RJV (Poyago-Theotoky, 1995; Yi and Shin, 2000; Banerjee and Lin, 1999) and (vii) international RJVs (Brod and Shivakumar, 1997b).

The generalization of the D'Aspremont and Jacquemin (1988) paper by Kamien et al. (1992) has proved to be the most interesting one.[13] Key findings by Kamien et al. (1992) that might be empirically tested are that (i) effective R&D investment is larger under RJV than under competition if spillovers are sufficiently large,[14] (ii) an increase in spillovers leads to a reduction of research efforts if goods are complements (substitutes) and spillovers are large (small) and also tends to reduce incentive to collaborate in R&D, (iii) an increase in market demand leads to an increase in research efforts both under RJV and research competition; an increase in market demand also has a positive effect on the likelihood of RJV formation and (iv) increased research productivity leads to increased incentives to invest in R&D and also to conduct joint research.

A more relevant strand of the literature is concerned with endogenous absorptive capacity. While the more traditional models assume that firms can absorb knowledge independent of their own research efforts, empirical studies such as that by Cohen and Levinthal (1989, 1990); Levin (1988); Levin et al. (1987); Levin and Reiss, (1988) have clearly shown that the extent to which firms can eventually gain from other firms' knowledge crucially depends on their own research efforts. A general transmission of the empirical findings into a theoretic framework is due to Kamien and Zang (2000) who develop a three-stage Cournot duopoly with homogeneous products[15] in which firms first decide upon the generality of their R&D approach. Firm i's absorptive capacity is defined as $(1-\delta_i)x_i^{\delta_i}$ where the term δ_i denotes the generality of the firm's R&D agenda. The larger δ, the more specific is the R&D approach pursued by firm i and vice versa.

[12] Steurs (1995) analyzes inter-*industry* cooperations. The literature on vertical RJVs is closely related to the literature on strategic R&D investments (and hence to the 'lead user' concept by von Hippel, 1986) where upstream firms deliberately generate knowledge spillovers which are used by downstream firms leading in turn to improved product quality of upstream firms (DeBondt and Veugelers, 1991; Harhoff, 1991, 1996; Peters, 1995, 1997). Empirical evidence on this issue is provided by VanderWerf (2001).

[13] It is important to note that the Kamien et al. (1992) model has some quite different implications, e.g., with respect to R&D levels under alternative cooperation scenarios, than the D'Aspremont and Jacquemin (1988) paper as Amir (2000) has recently pointed out.

[14] Kamien et al. (1992) define two different types of research cooperations, RJV competition where the spillover pararameter β is set to 1 but firms do not coordinate their research and RJV cartelization where both are true. Much of the later literature follows this distinction and even expands upon it. Since it is, however, impossible to distinguish between these differences in the empirical part of this paper, a more thorough discussion of the differential effects of the alternative RJV schemes is omitted here.

[15] Kaiser (2000) allows for heterogeneous products within the Kamien and Zang (2000) framework but takes a backstep in that he assumes the generality parameter to be exogeneously given.

If δ_i is at its lower bound ($\delta_i = 0$), firms are both universal donors and universal recipients of the other firm's knowledge. This is the standard formulation of D'Aspremont and Jacquemin (1988) and indicates a very general R&D approach. Inversely, if δ_i is at its upper bound ($\delta_i = 1$), firm i neither absorbs from the other firms nor does its own knowledge leak.[16] In the second stage of the game, firms decide upon R&D expenditures and in the last stage, they independently decide upon output.

Empirically testable results of the Kamien and Zang (2000) model are that an increase in the generality of the R&D approach leads to an increase in research efforts provided that the R&D approach already is sufficiently general and that RJVs are more likely to occur the more general is the R&D agenda.

Earlier research has made firms' absorptive capacity endogenous by allowing the degree of information sharing an explicit decision of the firms involved in the RJV (Beath et al., 1998; Kultti and Taklo, 1998; Bhattacharya et al., 1992; Katsoulacos and Ulph, 1998a,b; Veugelers and Kesteloot, 1996). In an earlier contribution, Vonortas (1994) allowed firms to decide whether to conduct either generic or development research while Gersbach and Schmutzler (1999) endogenize spillover by making a firm's absorptive capacity dependent on its success in the competition for other firms' R&D personnel.[17]

Most of the studies cited above assume that firms cooperate at the development stage only while they remain product market competitors. Martin (1995) concludes that joint R&D increases the likelihood of product market collusion, which eventually leads to a reduction in social welfare. In their investigation of semi-collusion (cartelizaion of output, joint R&D in the development stage), Brod and Shivakumar (1999) establish the conditions under which consumers and firms are either worse or better off under semi-collusion than under competition. Cabral (2000) shows that R&D efforts are reduced below the efficient level under certain conditions in order to sustain collusion on the product market. That firms may choose to undertake cooperative R&D in order to decrease product market competition rather than to conduct process innovation is shown by Kline (2000). Hinloopen (2000) also investigates the effects of product market collusion following research cooperation and finds that RJVs are generally socially beneficial only if collusion on the product market is ruled out.[18]

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[16] E.g., effective R&D equals own R&D, $X_i = x_i$.

[17] Martin (2000) recently extended earlier racing game models to allow for endogenous absorptive capacity.

[18] her interesting aspects related to research joint ventures discussed in the literature are the stability of RJVs (see Veugelers and Kesteloot, 1994 as well as DeBondt and Wu, 1996 for a theoretical treatment, and Kogut, 1989 as well as Sinha and Cusumano, 1991 for empirical evidence), the organization of RJVs (Veugelers and Kesteloot, 1994) and the diversification of firms' research agendas within RJVs (Vonortas, 1999). For explicit treatments of optimal industrial policy design with respect to R&D, see Cassiman (2000); Cohen (1994); Jacquemin (1988); Hinloopen (1997); Leary and Neary (1997) and Spence (1984).

In order to derive empirically testable hypotheses from the large body of theoretical literature on RJVs, it is necessary to neglect important aspects and implications of the individual contributions cited above. It is, however, true to say that the main implications of the general model of Kamien et al. (1992) remain unchallenged independent of (i) the design of the product market, (ii) the nature of innovation (product vs. process R&D) and (iii) the nature of cooperation (vertical vs. horizontal R&D). Hence, ten tentative hypotheses can be condensed from the theoretical literature. These hypotheses are summarized in Table 4 along with the respective empirical findings at the end of Section 4.

3. Data

The empirical analysis is based on the first wave of the Mannheim Innovation Panel in the Service Sector (MIP-S), a data set collected by the ZEW, the Fraunhofer Institute for Systems and Innovation Research and infas-Sozialforschung on behalf of the German Ministry for Education, Research, Science and Technology. This data set is thoroughly described by Janz et al. (2000).

The MIP-S is a mail survey. Its first wave was designed and carried out in 1995. The survey's population is all firms with more than four employees. The survey design extends the traditional concept of innovation surveys in manufacturing industries as summarized in the OECD Oslo Manual (OECD, 1994) to the service sector. Information collected includes: (1) general data on the participating firms such as firm size, skill mix, sector affiliation, sales, exports; (2) innovation activity and innovation expenditures; (3) labor and training cost; (4) investment in new technologies and other physical assets; (5) factors hampering innovation; and (6) information sources for innovation.

3.1. Innovation expenditures and cooperation in innovation

According to the Oslo manual, and hence also according to the MIP-S defintion, innovation expenditures include, in addition to R&D expenditures — expenses for all activities which aim at the enlargement of existing knowledge — expenditures for the conception of new services, for the market introduction of new or markedly improved products and costs for the customization of products to new markets. The concept of innovative activity is hence broader than the concept of R&D activity and is therefore much better suited for the service sector where R&D plays a much less important role than in manufacturing (Janz and Licht, 1999). The MIP-S questionnaire defines innovation cooperation as 'cooperation in which the partners actively take part in joint innovation projects'. Firms which answer to this general question with 'yes' can then choose from a list of possible cooperation partners: (1) customers; (2) suppliers; and (3) competitors. The questionnaire allows for multiple responses concerning cooperation partners and provides neither information on the number of RJVs in which a firm is nor information on the total number of research projects pursued within the firm. It also does not ask for the amount of money spent on individual research projects.

3.2. Spillover pools

The level of innovation expenditures constitutes the basis for the construction of the spillover pools. In order to allow spillovers from vertically and from horizontally related firms to have different effects on innovation expenditures and on innovation cooperation, the empirical model distinguishes between horizontal and vertical types of cooperation. It seems worthwhile to also istinguish between horizontal and vertical spillovers. The spillovers firm i receives are defined as:

$$S_i = \sum_{j \neq i}^{N} \omega_{ij} \, x_j, \tag{1}$$

where ω_{ij} is the fraction of knowledge firm i is able to receive from firm j. It is the fraction of innovation investment of firm j which spills over to firm i. Horizontal spillovers are calculated by summing over all firms inside firm i's own sector while vertical spillovers are obtained by summing over all firms outside their own sector. In this study, spillovers from both the service and the manufacturing sector are considered.[19]

Numerous suggestions on how to calculate the spillover parameter ω_{ij} can be found in the literature. Most of the approaches to proxy ω_{ij} are based on firms' distances in 'technology space' as (Jaffe, 1988). In a recent contribution, I (Kaiser, 1999) review frequently applied methods to proxy ω_{ij} and test them against each other. I find that the uncentered correlation of firm characteristics related to the type of technology used in production proxies ω_{ij} best out of the approaches considered. This method is due to Jaffe (1986, 1988), who uses patent citation data to approximate knowledge flows between industries.[20] His assumption is that knowledge flows between industries a and b are proportional to the share of patents of industry b in the area of industry a. Jaffe (1986, 1988) applies this basic idea to firm-level data. He defines k-dimensional patent distribution vectors, $\boldsymbol{f}$, whose elements are the fractions of firm j's research efforts devoted to its k most important fields of patent activity. His measure of technological distance between firm i and firm j is the cosine between $\boldsymbol{f}_i$ and $\boldsymbol{f}_j$:

$$\omega_{ij} = \frac{\boldsymbol{f}_i' \boldsymbol{f}_j}{((\boldsymbol{f}_i' \boldsymbol{f}_i)(\boldsymbol{f}_j' \boldsymbol{f}_j))^{1/2}}. \tag{2}$$

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[19] I used the Mannheim Innovation Panel in Manufacturing (MIP-M) as a complementary data source. See Janz et al. (2000) for details on this data set.

[20] Jaffe's method is an extension of Scherer's (1982, 1984) idea to use patent data as a measure for knowledge flows between industries.

If firm i's and firm j's patent activity perfectly coincide, ω_{ij} takes on the value 1. If they do not overlap at all, it takes on the value 0. Jaffe's measure of technological distance suffers from the same drawback as the approaches of Scherer (1982, 1984) since, as Griliches (1990, p. 1669) points out: ''Not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in 'quality' (. . .)''.[21] Although Griliches' remark only matters if the ratio of patented to unpatented inventions varies across the economic units under consideration, the shortcoming that ''not all inventions are patented'' is especially binding in the services sector where innovation is often tied to tacit knowledge, which cannot be patented. Instead of filling the $\boldsymbol{f}$-vector with patent citation data, I fill it with the following variables: the shares of high (university and technical college graduates), medium (workers with completed vocational training) and unskilled labor in the total workforce, expenditures for continuing education and vocational training of the employees (per employee), labor cost per employee, investment (scaled by sales) and five variables summarizing five main factors that hamper innovative activity.[22]

For the construction of the latter five variables I applied a factor analysis on the 13 possible answers to the following question asked in the MIP questionnaires: ''Please indicate the importance of the following factors hampering your innovative activity on a scale from 1 (very important) to 5 (not important)''. The possible answers include (1) high risk with respect to the feasibility of the innovation project, (2) high risk with respect to market chances of the innovation, (3) unforeseen innovation cost, (4) high cost of the innovation project, (5) lasting amortization duration of the innovation project, (6) lack of equity, (7) lack of debt, (8) lack of qualified personnel, (9) lack of technical equipment, (10) non-matured innovative technologies, (11) internal resistance against innovations, (12) lasting administrative/authorization processes and (13) legislation. From the factor analysis of the answers five main factors can be identified which I call 'risk' (consisting of answers (1), (2) and (3)), 'cost' (answers (4)–(5)), 'capital' (answers (6)–(7)), 'internal' (answers (9)–(11)) and 'legal' (answers (12)–(13)). I use total factor scores scaled by the maximum total score for each of the three variables. For example, if firm i indicates that lack of equity is of high importance (score = 5) and indicates that lack of debt is of no importance (score = 1), the total score for factor 'capital' is $5 + 1 = 6$ and the variable eventually used takes on the value $0.6 = 6/(5 + 5)$.

Horizontal spillovers are denoted by S^h, vertical spillovers are denoted by S^v. In order to distinguish between horizontal and vertical spillovers, I aimed at obtaining

[21] Pavitt (1985, 1988) comments on the usefulness of patent statistics as indicators for economic activity. See Arundel and Kabla (1998) and Brouwer and Kleinknecht (1999) for estimates of patent propensities.

[22] These are, however, measures of firm characteristics rather than measures of technological distance in a strict sense.

quite narrowly defined sectors. In the construction of the spillover pools, I differentiate among 115 sectors: there are 66 for manufacturing and 49 for services. At least ten firms are situated in each of these sectors. Details and a thorough discussion on the way the spillover pools are constructed as well as descriptive statistics are presented in Kaiser (1999).

3.3. Indicators for the generality of the R&D approach

The construction of the empirical counterpart of the ‘generality of the R&D approach’ (Kamien and Zang, 2000) is based on the assumption that the more general a firm’s research approach is, the more heterogeneous its information sources are. That is to say that a firm that pursues a general research approach may gain from virtually all available information sources while a firm pursuing a specific research approach may only gain from specific information sources. Fortunately, the MIP-S contains a question on information sources for the innovation process. Firms were asked to indicate on a five point scale ranging from ‘not important at all’ to ‘very important’, how important the following information sources are in the innovation process: (1) customers from the service sector; (2) customers from the producing sector; (3) suppliers; (4) competitors; (5) associated firms; (6) management consultancy firms, private research institutions; (7) universities; (8) other public research institutions; (9) fairs and exhibitions; and (10) the patent system. My proxy variable for the generality of research programs is constructed as the number of information sources a firm indicates as ‘important’ or ‘very important’. Three dummy variables are constructed: *GENERAL 0–1* takes on the value 1 if the firm uses none or one information source. The dummy variable *GENERAL 2–3* is coded 1 if it uses two or three sources and *GENERAL* >3 is coded 1 if more than three information sources are used. The most densely populated category is that of 2–3 information sources (36% of the observations) and serves as the base category.

3.4. Indicators for R&D productivity

Following Levin and Reiss (1988), I assume that sectors closely related to science stay at the beginning of their development so that they find themselves in areas of R&D production with high marginal returns to R&D and hence in areas with high research productivity. Sectors closely related to science will therefore be considered as sectors with high R&D productivity. In turn, sectors closely related to product markets will be considered as sectors with low R&D productivity. I apply a canonical correlation analysis on the MIP-S questions on information sources to find common factors of the information sources already listed above. Associated firms and management consultancy firms are left out in the canonical analysis since it is not clear to what these sources are actually related. Based on findings by Kaiser and Licht (1998), it was checked whether customers, suppliers and competitors can be lumped together as 'private' information sources and whether universities, public research institutions, fairs and the patent system can be grouped together as 'scientific' information sources. The results of the canonical correlation broadly support my assumption as shown in Appendix A. The reported linear combinations for the two factors are calculated on a NACE–Rev. 1 two digit sectoral level in order to avoid potential endogeneity problems with innovation expenditures and to avoid potential multicollinearity problems with the proxy variables for the generality of the R&D approach. The R&D productivity terms are denoted by *SCIENCE* (scientific information sources) and *PRIVATE* (private information sources), respectively.

3.5. Market demand

The review of the theoretical models in Section 2 has shown that an increase in market demand has a positive effect on innovation expenditures and on innovation formation. Changes in market demand of a firm are considered in the empirical model by a set of dummy variables which represent changes in total sales on an ordinal scale. In the MIP-S, firms were asked for an assessment of their sales development over the past 3 years. The assessment ranged from 'strong decrease' to 'strong increase' on a five-point scale. The dummy variable for strong decrease takes on the value 1 if strong decrease was indicated and zero otherwise. It is denoted by $SALES--$. The other dummy variables for decrease, increase and strong increase in sales are constructed accordingly. They are denoted by $SALES-$, $SALES+$ and $SALES++$, respectively.

3.6. Controls for observable firm heterogeneity

In order to capture the heterogeneity of product market conditions, a diversification index — which differs from the traditional notion of diversification as the number of industries in which firms operate — denoted by *DIVERS*, is included in the innovation expenditure equation. It is constructed from firms' answers to an MIP-S question on the sales share of (1) customers from the producing sector, (2) customers from the services sector, (3) the state and (4) private households as the inverse of a Herfindahl index of sales concentration:

$$DIVERS_i = \frac{1}{\sum_{l=1}^{4} share_{l,i}^2}, \tag{3}$$

where $share_{l,i}$ denotes the share of the lth customer group in total sales of firm i. *DIVERS* is a measure of diversification across customer classes. The argument behind the inclusion of this variable is that firms with a diversified customer portfolio are likely to have a diversified product portfolio and hence are able to make multiple use of innovations. This seems to be even more reasonable for services where many products are customized to a large degree.

Two other variables are also included in the innovation expentiture equation only: export share, *EXPORT* and a dummy variable *FOREIGN COMP.*, which is coded one if firms report that they have to cope with foreign competition in the home market. The motivation behind the inclusion of these two variables is that firms that are export oriented and are faced by foreign competition are forced to innovate to a larger degree than firms that act in markets without pressure from foreign firms.

In order to further control for observable firm heterogeneity, the natural logarithm of the number of employees, *LSIZE*, is included in the cooperation choice equation.[23] The innovation expenditures equation also contains the squared logarithm of the number of employees, $LSIZE^2$. Additionally, three sector class dummy variables for business-related services (tax and business consultancy, architectural services, advertising, labor recruiting, industrial cleaning, (*BRS*), trade (*TRADE*) and transport (*TRANS*)) are included. Finally, I include a dummy variable *EAST* for eastern German firms.

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

4. Results

The empirical analysis proceeds in three steps. First, I analyze firms' cooperation choice. Besides analyzing the general choice to cooperate in research, as the theoretical models summarized in Section 2 do, this paper also studies the choice between horizontal cooperation and vertical cooperation. If factors determining the choice between horizontal or vertical cooperation can be identified here, this might provide some guidance to the further development of theoretical models. Therefore, the empirical approach of my first step in the empirical investigation not only analyzes the initial cooperation decision, but also the choice of vertical or horizontal partners. Second, I investigate the determinants of firms' research investment expenditures. Since firms may simultaneously choose their research efforts and research collaboration, the econometric approach takes this potential simultaneity into account. Finally, I compare the determinants of innovation intensity under RJV and research competition by applying Minimum Distance Estimation (MDE).

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[23] In earlier specifications, I also included the square of the logarithm of the number of employees in both the cooperation decision model and in the innovation expenditures equation. The restricted model did not, however, turn out to be significantly different from the restricted one (LR-test statistic: 0.417, *P*-value: 0.812).

4.1. Cooperation decision

In the theoretical model reviewed in Section 2, it pays for all firms to invest in innovation, so that they model the cooperation and research expenditure decision but not the decision *given* that firms have already decided to do research. Hence, I only consider those firms that actually invest in innovation although the sample also contains 541 firms that do not invest in innovation. Further, the MIP-S not only contains information on whether a firm is involved in innovation cooperations, it also contains information on whether a firm conducts joint research horizontally (with competitors), or vertically (with customers and/or suppliers). Since firms may be involved in both horizontal and vertical cooperations, a third possibility exists, which I call a ‘mixed’ cooperation.

Fig. 1 summarizes the decisions a firm has to reach in its research cooperation decision-making process. In a first stage, the firm decides whether or not to conduct research cooperatively. If it has decided to do joint research, it then has to reach a decision for 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.

Consistent with Hypothesis 1, Fig. 1 shows that vertical cooperation is more widespread than horizontal cooperation. The category ‘horizontal’ cooperation is thinly populated, both in absolute terms and in relation to the other choices. I therefore combine the horizontal choice and the ‘mixed’ cooperation mode.[24]

It is important to note that the representation by a decision tree, as in Fig. 1, is of purely analytical nature. It is not implied that time actually passes by between

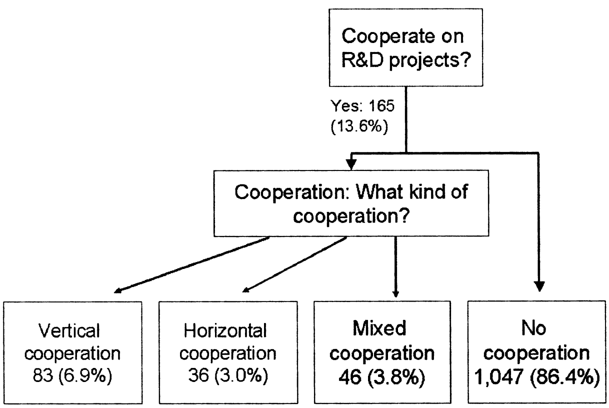

Fig. 1. Population of the alternative cooperation modes in absolute (relative) terms.

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

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 difficult. If time actually passed by between the decision stages, a sequential model would be appropriate. If the lower stage matters in the decision-making process of the first stage, a nested multinomial logit (NMNL) model should be used. If firms decide simultaneously upon R&D cooperation and the type of cooperation partner, a multinomial logit model (MNL) would be appropriate.[25] It is thus desirable to have a flexible econometric technique at hand that neststhese types of discrete choice models. Such an estimator has been proposed by van Ophem and Schram (1997), who show that the simultaneous and the sequential logit model can be combined without losing the properties of the logit model. The sequential logit model, the NMNL and the MNL are nested by a single parameter, κ. The interpretation of this parameter is close to the interpretation of the coefficient corresponding to the inclusive value in NMNL models: for $\kappa = 0$, 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 $\kappa = 1$, the decision reached in the upper stage is determined by the maximum utility obtained in the lower stage leading to the MNL as an appropriate econometric tool. If $\kappa \in (0,1)$, an intermediate position is obtained and the NMNL is appropriate.

The estimator suggested by van Ophem and Schram (1997) allows for values of κ outside the (0,1) range on statistical grounds, as opposed to the traditional NMNL where the parameter related to the inclusive value is bounded within (0,1). For $\kappa > 1$ or $\kappa < 0$, however, there is no economic interpretation. Technical details of the van Ophem and Schram (1997) estimator are presented in Appendix C.[26]

The empirical model of cooperation choice includes the following variables: horizontal and vertical spillovers in natural logarithms, $\ln(S^h)$ and $\ln(S^v)$, the R&D generality-approach variables *GENERAL* 0–1 and *GENERAL* > 3, the R&D productivity proxies *PRIVATE* and *SCIENCE*, the market demand indicators, *SALES*, a dummy variable *EAST* for eastern German firms, the natural logarithm of firm size *LSIZE*, a constant term as well as two sector affiliation dummy variables *TRANS* and *BRS* (business-related services).

Estimation results of the cooperation choice are presented in Table 1.

Horizontal spillovers have a weakly significantly positive effect on firms’ propensity to cooperate while they do not signifcantly affect the choice of vertical or mixed cooperation. The positive effect of horizontal spillovers is somewhat in contrast to Hypothesis 2, which states that an increase in spillovers tends to decrease incentives to collaborate in research. Vertical spillovers have neither a

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

[26] Appendix C as well as Appendix D and Appendix E can be downloaded as a PDF-document from International Journal of Industrial Organization’s website at http://www.fee.uva.nl/fo/ijio/eosup.htm.

Table 1
Nesting logit estimation results for cooperation choice

	P (no cooperation) Base: *P* (no cooperation)		*P* (mixed cooperation) Base: *P* (vertical cooperation)	
	Coeff.	S.E.	Coeff.	S.E.
$\ln(S^h)$	−0.3026*	0.2328	−0.0246	0.1398
$\ln(S^v)$	0.2606	3.8618	−1.6186	2.5125
PRIVATE	−1.3643	1.2475	0.4508	0.6882
SCIENCE	−1.6520**	0.9321	0.3414	0.5722
GENERAL 0 − 1	−0.0719	0.6416	0.3918	0.4237
GENERAL > 3	−1.4740**	0.9278	0.8444**	0.3914
SALES − −	−1.7122	1.6348	1.1605**	0.7036
SALES −	−0.6882	0.7127	0.2834	0.4942
SALES +	−0.9610	0.7998	0.6573*	0.4786
SALES + +	−0.8503	0.8487	0.4891	0.5589
EAST	−0.4680	0.7054	0.5318*	0.3558
TRANS	−1.9774**	1.0346	0.2261	0.6160
BRS	−0.9353	1.0071	−0.6460	0.5677
LSIZE	−0.2343*	0.1563	0.0306	0.1037
CONSTANT	10.3267	17.8197	4.5894	11.7099
κ	−2.7664	2.2485		
Wald-tests for joint significancy				
Spillover pools	1.757		0.483	
Productivity	4.435*		0.849	
Generality	3.211*		4.674*	
Sales	0.789		3.305	
Sector	3.680		2.944	
Pseudo R^2 and # of obs.				
Pseudo R^2	0.076			
# of obs.	1233			

**, * Significant at the 5 and 10% significance level, respectively.

significant impact on the probability to cooperate at all nor on the probability to cooperate in a vertical or mixed mode.

Consistent with Hypothesis 4, high research productivity — i.e., proximity to scientific information — has a significantly positive effect on RJV formation. The estimation results also suggest that an increase in the generality of the research approach leads to an increased propensity of RJV formation, a result which is consistent with Hypothesis 6.[27]

The sales dummy variables which represent market demand are both individually and jointly insignificant so that Hypothesis 8 can not be accepted. Size

[27] Note that the coefficient of *GENERAL* 0 − 1 is negative just like that of *GENERAL* > 3 but that it is not significantly different from zero, neither individually nor jointly with *GENERAL* 0 − 1 (*P*-value, 0.632).

and signs of the coefficients indicate an inverse U-shaped effect of past sales on the propensity to cooperate.

With respect to the choice of horizontal or vertical cooperation, it is shown that there is a U-shaped effect of research generality on the probability to cooperate in a mixed mode.

The control variables for observed firm heterogeneity indicate the following: (i) the larger the firms are the more likely it is that they will conduct cooperative research; and (ii) eastern German firms cooperate significantly more often in a mixed mode than western German firms.

The pseudo R^2, the McFadden (1974) Likelihood Ratio Index, is 0.076 and reasonably high for these kinds of econometric models. A likelihood ratio test cannot accept joint insignificancy of the coefficients, except for the constant terms and the parameter κ, at the 1% significance level.

The parameter κ corresponding to the inclusive value is -2.7664 and hence is outside the (0,1) range. Neither the sequential nor the multinomial logit model can be rejected at the usual significance levels.

In the next step of the empirical analysis, the determinants of innovation expenditures are investigated. A simultaneous model for cooperation decision and the decision on how much to spend on research is estimated. The econometric model is sketched in Appendix D.[28]

The estimation starts with a binary probit model for the decision of whether or not to cooperate as a first step. In a second step, an OLS model is estimated in which the fitted values of the first-step estimates are included as Heckman (1979)-type correction terms. The estimates obtained from the OLS estimation are consistent. Their estimated variance–covariance matrix is, however, inconsistent if the Heckman-type correction terms are both individually and jointly insignificantly different from zero.

The binary probit estimation contains the same variables as the nesting logit approach presented earlier. Since the results of the probit estimation for cooperation choice do not differ qualitatively from those already presented in Table 1, estimation results of the probit equation are not displayed here.

It has to be stressed that mispecification of the first-stage-model naturally has severe consequences for the second-stage-estimates. I therefore test for homoscedasticity and normality along the lines of Chesher and Irish (1987). The LM test statistics for homoscedasticity and normality are 0.0083 and 0.0022, respectively, so that both hypotheses can not be rejected at the usual significance levels (the P-values are 0.9997 and 0.2605, respectively).[29] In the second stage, I run an OLS regression of the natural logarithm of innovation expenditures on the variables

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[28] Appendix D can be downloaded from the International Journal of Industrial Organization's website at http://www.fee.uva.nl/fo/ijio/eosup.htm.

[29] The test for homoscedasticity involved all variables in the conditional mean function of the probit equation, just as the well known Breusch–Pagan test for OLS regressions.

already included in the cooperation choice equation and the firm heterogeneity control variables *DIVERS*, $LSIZE^2$, *EXPORT* and *FOREIGN COMP.*. Since the spillover pool variables and firm size are also included as natural logarithms, the coefficients related to these terms displayed in Table 2 represent elasticities. The coefficients corresponding to the other variables represent semi-elasticities.

A first striking result is that coefficients corresponding to the Heckman-type correction terms, $\rho\sigma_u D\hat{\mu}$ and $\rho\sigma_u(D-1)\hat{\lambda}$, are neither independently nor jointly

Table 2
Simultaneous model for cooperation and innovation intensity

	Coeff.	S.E.
$\ln(S^h)$	0.1203***	0.0522
$\ln(S^v)$	0.4826	0.5142
PRIVATE	−0.6348***	0.2284
SCIENCE	0.6430***	0.2712
GENERAL 0−1	−0.2688***	0.1083
GENERAL >3	−0.0754	0.0986
SALES − −	−0.3188**	0.1703
SALES −	−0.0254	0.1291
SALES +	−0.0437	0.0978
SALES + +	0.1031	0.1235
EAST	−0.2867***	0.0898
TRANS	0.7097***	0.2844
BRS	0.2171	0.2765
LSIZE	−0.3718***	0.1203
$LSIZE^2$ 0.0182*0.0128		
DIVERS	0.2571***	0.0692
EXPORT	0.2420	0.2305
FOREIGN COMP.	0.1935***	0.0822
CONSTANT	−6.2898**	3.0695
D	−1.2359	1.0677
$\rho\sigma_u\hat{\mu}D$	0.7102	0.5711
$\rho\sigma_u\hat{\lambda}(D-1)$	0.8750	1.0287
F-tests for joint significancy		
$\rho\sigma_u\hat{\lambda}(D-1)$, $\rho\sigma_u\hat{\lambda}(D-1)$	1.6610	
Spillover-pools	5.3555*	
Generality	6.3964**	
Productivity	13.6068***	
Sales	5.9162	
Sector dummies	13.9065***	
R^2 and # of obs.		
Adj. R^2	0.1325	
# of obs.	1223	

***, **, * Significant at the 1, 5 and 10% significance level, respectively. The terms $\hat{\mu}$ and $\hat{\lambda}$ denote the Heckman-type correction terms as described in Appendix D.

(*P*-value 0.4358) significantly different from zero so that the variance–covariance matrix of the two-step procedure is consistently estimated.

The estimation results show that the effect of research cooperation on innovation intensity is positive and weakly significant. On average of the involved firms, innovation intensity increases by 18.3% (median: 15.41%) if a firm is involved in an RJV. The associated standard error across firms is 14.51% (*P*-value 0.1036). With respect to the theoretical models reviewed in Section 2, some evidence is given that spillovers are 'sufficiently large' (Hypothesis 10) in the German service sector.

The estimation results also indicate a significantly positive impact of horizontal spillovers on innovation intensity, which is predicted by the theoretical models (Hypothesis 3) if goods are substitutes (complements) and spillovers are small (large). The elasticity of research expenditures with respect to horizontal spillovers is 0.1203%.

Perfectly in line with Hypothesis 5, an increase in research productivity leads to an increase in research efforts.

Research generality appears to have a positive effect on research collaboration and an inverse U-shaped impact on research efforts. Hypothesis 7 predicted an uniquely positive effect on both.

As in the cooperation choice model, market demand does not play a significant role in the research investment decision. The *SALES* dummy variables are jointly insignificantly different from zero. Hypothesis 10 predicted a positive impact of market demand on research efforts.

Market demand as proxied by the *SALES* dummy-variables does not have a significant effect on research efforts. Hypothesis 9 predicts a positive impact.

The effects of the control variables for observable firm heterogeneity on innovation expenditures can be summarized as follows: the innovation intensity of eastern German firms is 28.67% lower than that of western German firms. Firm size has an inverse U-shaped effect on innovation expenditures. The minimum, however, is outside the firms' sizes observed in the data set. The sector affiliation dummy variables turn out to be jointly significant. The coefficient related to the diversification index is positive and highly significant, indicating that firms with multiple customer groups invest more in innovation than firms with more homogeneous customers. Firms that are faced with foreign competition invest 19.35% more in innovation than firms without foreign competitors.

In a last step of the analysis, I test whether there are significant differences in the determinants of innovation expenditures between cooperating and non-cooperating firms. I split up the sample into cooperating and non-cooperating firms and run the same regression for innovation intensity separately for cooperating and non-cooperating firms. By applying a Minimum Distance Estimation (MDE), I calculate a parameter vector, which minimizes the weighted difference between the first-stage auxiliary parameter vectors. Finally, I test whether there are significant differences in these auxiliary parameter vectors. The MDE is explained in Appendix E.[30] Table 3 displays estimation results for cooperating and non-cooperating firms as well as the corresponding MDE. In order to control for endogenous sample selection, I run a Full Information Maximum Likelihood model for cooperation choice as the selection equation and innovation expenditures as the level equation. The variance of the error term of the level equation, σ_1, and the covariance term between the level and the selection equation, σ_{12}, were left out in the MDE.

The estimation results suggest that there are some large differences among the estimated parameter vectors related to cooperating and non-cooperating firms. In fact, equality of the parameter vectors cannot be accepted at the usual significance levels (Wald test statistic: 19.9307, P-value: 0.399). This is probably due to the

Table 3
Parameter estimates for the determinants of innovation intensity for cooperating and non-cooperating firms as well as the corresponding minimum distance estimates

	Cooperation		MDE		No cooperation	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
$\ln(S^h)$	0.1153	1.4327	0.1153***	0.0361	0.1116***	0.0399
$\ln(S^v)$	−0.2739	9.5111	0.3461	0.5549	0.6866	0.6002
PRIVATE	−1.0304	3.5429	−0.5935***	0.1986	−0.5008***	0.2290
SCIENCE	0.0832	5.9434	0.5822***	0.1891	0.7163***	0.2076
GENERAL 0−1	−0.4577	1.8475	−0.2577***	0.1031	−0.2532***	0.1088
GENERAL > 3	−0.0765	1.3380	−0.0957	0.0982	−0.0652	0.1058
SALES − −	−0.6362	0.6589	−0.3066**	0.1687	−0.3165**	0.1800
SALES −	−0.4748	1.5575	−0.0230	0.1382	0.0254	0.1466
SALES +	−0.0814	0.4296	−0.0584	0.1107	−0.0541	0.1191
SALES + +	0.0602	0.9409	0.1352	0.1447	0.0525	0.1543
EAST	−0.3283	1.5000	−0.2881***	0.0861	−0.2975***	0.0917
TRANS	0.1896	7.8424	0.7040***	0.1540	0.8336***	0.1629
BRS	−0.0680	8.3967	0.2156*	0.1385	0.2960**	0.1529
LSIZE	−0.0563	1.0333	−0.4385***	0.1255	−0.4568***	0.1347
$LSIZE^2$	−0.0329	0.0499	0.0261**	0.0131	0.0314***	0.0140
DIVERS	0.1475	0.2613	0.2558***	0.0762	0.2568***	0.0805
EXPORT	0.3013	0.7492	0.2798*	0.1995	0.3023*	0.2096
FOREIGN COMP.	0.2390	0.2920	0.1676**	0.0822	0.1520**	0.0875
CONSTANT	0.0384	98.0613	−5.4084**	2.6971	−7.7428***	2.9465
σ_{12}	0.1197	10.8271			−1.1760***	0.1215
σ_1	1.3073[c]	0.8129			1.4280***	0.0467
R^2 and # of obs.						
Adj. R^2	0.1703		0.0887		0.0627	
# of obs.	1223		1223		1223	

***, **, * Significant at the 1, 5 and 10% significance level, respectively.

[30] Appendix E can be downloaded from the International Journal of Industrial Organization's website at http://www.fee.uva.nl/fo/ijio/eosup.htm.

imprecision with which the parameters for the cooperating firms are measured. And this is, in turn, due to the relatively low number of cooperating firms. Since there are, at least for the significant coefficients, only slight qualitative differences between the results displayed in Table 3 and those shown in Table 2, a further discussion of the estimation results can be omitted here.

The empirical findings are summarized and compared to the theoretical predictions in Table 4.

5. Conclusion

This paper reviews main contributions of the theoretical literature on research expenditures and research cooperations and derives ten empirically testable hypotheses concerning the effects of spillovers, research productivity, the generality of the research approach and market demand on firms' propensity to conduct collaborative research as well as on the level of firms' research expenditures.

These hypotheses are empirically tested using innovation survey data for the German service sector. By and large, the derived hypothesis cannot be empirically rejected.

A central finding of this paper is that joint research tends to stimulate research expenditures. On the average, cooperating firms spend 18.3% more on innovation than firms not involved in a joint research project. The effect, however, is quite imprecisely measured with an associated standard error of 14.5%. A straightforward extension of the present paper is the explicit empirical modeling of the impact of alternative cooperation modes on innovation intensity. In this paper, the simultaneous model of research collaboration and research effort does not distinguish between horizontal and vertical cooperation and just consider the binary choice between cooperation and non-cooperation.

6. Unlinked reference

Kodde et al., 1990

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Table 4
Overview of theoretical predictions and empirical results

#	Hypothesis	Empirical finding
1.	RJVs should be more widespread among vertically (customers, suppliers) than among horizontally related firms.	True
2.	An increase in spillovers tends to reduce incentives to collaborate in R&D.	Positive effects of horizontal spillovers
3.	An increase in spillovers leads to a reduction of research efforts if goods are complements (substitutes) and spillovers are large (small).	Positive effects of horizontal spillovers
4.	An increase in research productivity has a positive effect on RJV formation.	True
5.	An increase in research productivity has a positive effect on R&D expenditures.	True
6.	An increase in the generality of a firm's R&D approach creates incentives to form an RJV.	True
7.	An increase in the generality of a firm's R&D approach leads to an increase in R&D expenditures provided that the R&D approach is already sufficiently general.	Inverse U-shaped effect
8.	An increase in market demand has a positive effect on RJV formation.	No effect
9.	An increase in market demand has a positive effect on R&D expenditures.	No effect
10.	Research efforts are larger under RJV than under research competition provided that spillovers are sufficiently large (relative to a term usually consisting of degree of product substitution, the generality of the R&D approach and the number of competitors).	Research effort under RJV larger

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Appendix A. Linear combinations for canonical correlation

	Coeff.	S.E.
Private information sources		
Customers	0.3264***	0.0668
Suppliers	0.4518***	0.0544
Competitors	0.3684***	0.0588
Scientific information sources		
Universities	0.1184*	0.0756
Public research inst.	0.3292***	0.0965
Fairs, exhibitions	0.6301***	0.0631
Patent system	0.0832	0.0680

***, * Significant at the 1 and 10% significance level, respectively. The canonical correlations are 0.3673, 0.1033 and 0.0354, respectively. The number of observations is 1284.

Appendix B. Descriptive statistics

	Mean/share	S.E.
ln(*innovation exp.*)	−5.1811	1.4482
$\ln(S^h)$	−0.2912	1.3533
$\ln(S^v)$	4.7417	0.0821
PRIVATE	3.0135	0.2528
SCIENCE	2.6606	0.2863
EAST	0.3820	0.4861

TRANS	0.1752	0.3803
BRS	0.5231	0.4997
LSIZE	4.1495	1.6319
$LSIZE^2$	20.6667	17.0074
GENERAL 0 − 1	0.3122	0.4636
GENERAL > 3	0.3285	0.4698
SALES − −	0.0714	0.2575
SALES −	0.1549	0.3620
SALES +	0.4096	0.4920
SALES + +	0.1509	0.3580
DIVERS	1.5440	0.5262
EXPORT	0.0528	0.1713
FOREIGN COMP.	0.3642	0.4814

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