The Impact of Vertical R&D Cooperation on Firm Innovation:

An Empirical Investigation

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Abstract

The recent surge of interfirm cooperative agreements can be seen to express a way for firms to respond to and organize market failure, especially in technology markets. The incentives for firms to internalize activities are to avoid the disadvantages, or capitalize on the advantages, of imperfections or disequilibria in external mechanisms of resource allocation. The purpose of this paper is to investigate empirically, on the basis of data from German firms, the impact of vertical R&D cooperation on innovation in firms. The analysis is based on a survey conducted by the “Center for European Economic Research” (Zentrum für Europäische Wirtschaftsforschung, ZEW) in Mannheim among 370 companies, mainly in the manufacturing sector. The results of the econometric analysis suggest a statistically significant impact of vertical R&D cooperation on the intensity of R&D activity in German firms. Informal modes of R&D cooperation (informal exchange of technological knowledge) seem to be more important for their innovative behavior than formal ones (joint ventures, joint development teams etc.). Since the relationship between vertical R&D cooperation and the intensity of R&D activity in innovating firms has been tested in a broader theoretical and empirical framework, the empirical results also confirm the significance of other key determinants of innovative activity, such as “technological opportunities”, “appropriability conditions” and “market demand”.

Contents

1 Introduction

A great deal of intellectual and political energy has been expended on the issue of horizontal R&D cooperation between firms.[1] Governments at both national and regional levels propagate this idea as an important part of their policies.[2] Political debate has been preceded and accompanied by extensive economic research on the question of the importance of horizontal R&D cooperation between firms with complementary activities, in order to enhance the international competitiveness of firms, industries and nations (or blocks of nations). This research has highlighted the benefits and costs of policies aimed at enhancing horizontal cooperative R&D activities between firms.

The main benefits to be expected of such policies are: (i) overcoming the R&D financial constraints in individual firms (i.e. expensive research projects can be realized as a result of cost-sharing); (ii) exploitation of economies of scale and scope in R&D; (iii) reduction of wasteful duplication in R&D; (iv) internalization of technological spillovers and other forms of externality;[3] (v) better use of synergies because each firm can contribute distinct capabilities to a common research project; and, finally, (vi) reduction of investment risks due to demand uncertainties. In short, horizontal R&D cooperation has been seen as a panacea for solving important aspects of market failure and other deficiencies in technology markets.[4]

Policies aimed at enhancing horizontal R&D cooperation between firms through government subsidies are, however, problematic in practice; they create costs for the economy at large. The major problem with these policies is that "... they can undermine incentives to conduct R&D (and other) operations efficiently, and may lead to cozy pricing arrangements for the products embodying that R&D. What is more, while monopolists may have the resources and opportunities to innovate, they lack the incentives to do so whenever the innovation threatens to displace any of their existing activities. In a sense, these horizontal strategies set one type of market failure against another, and it is not surprising that a 'cure' of this type has some side effects. Broadly speaking, the empirical evidence can be read as suggesting that such strategies do not often work very well. Innovation is almost a product of

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[2] For Europe see, for instance, COMMISSION OF EUROPEAN COMMUNITIES (1993) „White Paper" and the CECCHINI Report (1988).

[3] In addition to technological spillovers, two other externalities have been featured prominently in the literature: pecuniary externalities and environmental externalities. For a discussion, see GEROSKI (1993): 59.

[4] For a survey of the literature on this subject, see KATZ & ORDOVER (1990). For individual country studies on R&D cooperation see KÖNIG ET AL. (1993) and LICHT (1994) for Germany, KLEINKNECHT & REIJNEN (1992) for the Netherlands, ARVANITIS ET AL. (1995) for Switzerland.

active rivalry, frequently occurring simultaneously with waves of entry" (GEROSKI 1995: 140).

All these reservations regarding the efficacy of horizontal collusion – either it can lead to the exploitation of market power or it may simply be misdirected, or both – have led academics such as GEROSKI to advocate an alternative policy. This policy should be aimed at enhancing *vertical relations* between innovating firms on one hand and suppliers and users of innovations on the other.[5] Such a policy would be based on the theoretical insight and empirical evidence that innovation often requires coordination among agents operating at different stages of the innovation process, that is among innovation producers, innovation users and input suppliers.

The purpose of the paper is to investigate empirically, on the basis of data from Germany, whether these different modes of vertical relationship between innovating firms, suppliers and users do in fact have a positive impact on the innovative activities of the firms. The paper is made of three parts. In section 2 the appreciative theoretical framework is outlined. In section 3 the data, the econometric analysis and the empirical results are briefly presented. Section 4 is a brief summary of the paper.

2 Innovation and Vertical Relations Between Firms: Theoretical Background

One central question will guide our discussion of the literature: What are the factors that induce innovating firms to seek to cooperate with input suppliers and product users? In order to answer this question, I will be looking at the body of theoretical and empirical literature concerning the economics of technological innovation in industrial organizations.[6]

In the most general terms, there are three reasons why private profit-seeking agents will plausibly allocate resources to the exploration and development of new products and new techniques of production. First, they may know of, or believe in, the existence of some sort of , as yet unexploited, scientific and technological opportunities; second, they may expect that there will be a market for their new products and processes; finally, they may expect some economic benefits, net of the incurred costs, that derive from the innovations. These three major determinants of technological innovation are summarized in the literature under the headings,

[5] Vertical relations are agreements between producers of complementary, as opposed to substitute, goods and services. Each party in a vertical relationship has a fundamental interest in preventing, rather than facilitating, the exercise of market power by the other. In effect, therefore, each party is more an ally than an enemy of the public interest. In contrast, horizontal relations, which are agreements between producers of substitutes, are inherently and necessarily suspect from the point of view of public policy, because the exercise of market power by one producer always benefits the producer of substitute products.
[6] For the theory, see TIROLE (1988); for a survey of the empirical literature see DOSI (1988), COHEN AND LEVIN (1989) and COHEN (1995)

"technological opportunities", "appropriability conditions" and "market demand". In other words, technological innovations, like many other economic phenomena, are determined both by supply factors (the first two determinants above) and by demand factors. These three factors vary across industries and explain to a certain degree the empirically observable inter-industry differences in innovative activity.[7]

In contrast with the perceived tendency of the competitive market to achieve static efficiency, it is generally agreed among economic theorists that the market mechanism is likely to fall short of optimality in innovation. Many analysts conclude that there is a propensity to underinvestment in R&D (see, for example, KATZ 1986: 527–528),[8] first because spillovers mean that a substantial proportion of the benefits of an innovation are apt to go to an entity other than the one that bore its cost – and benefits may even flow to the innovator's competitors. Second, even in the absence of externalities, the innovator will not capture all the benefits if it cannot achieve perfect price discrimination, since the innovation will then enhance consumers' surplus. Third, imperfect information impedes sale of the rights to an innovation at its full value because it "... is hard to evaluate before it is transferred from the buyer to the seller, and information that has been 'loaned' to the buyer for evaluation is difficult to recover" (KATZ 1986: 528). In other words, this third problem "refers to the difficulties that buyers have in trying to value an innovation, and that sellers have in helping them without giving away crucial secrets. As knowledge is a public good, any successful sale automatically creates potential competition for the original seller, since the seller and the first buyer are both capable of selling to a second buyer, and so on." (GEROSKI 1992: 139).

All these problems – the appropriability problem, imperfect price discrimination, imperfect information and the related problems of demand valuation and resale – may cause market failure in technology markets. Since innovating firms cannot always rely on market forces to solve their problems, they seek ad hoc non-market solutions, such as cooperative agreements with other firms, especially those that, in the supply chain, are between them and suppliers and customers.[9]

Since cooperative agreements between innovating firms on one hand and suppliers and users on the other affect the supply and demand facing them, they thus influence major forces behind the innovation process. One of these major forces is the issue of how innovators solve the "appropriability problem". Consequently, a major motivation for innovating firms to seek R&D cooperation with input suppliers and users is their expectation that they will solve this problem".[10] Problems of

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[7] For a recent survey of the literature, see COHEN (1995).

[8] However, see DASGUPTA & STIGLITZ (1980) for a case in which firms have an incentive to overinvest in R&D.

[9] „The surge of interfirm agreements cannot be seen as expressing an improvement in the efficiency of markets, or a reassertion of their effectiveness, but on the contrary represents the full emergence of a new way for firms to respond to and organize market failure. The incentives of firms to internalize activities ... 'are to avoid the disadvantages, or capitalize on the advantages, of imperfections or disequilibria in external mechanisms of resource allocations'" (CHESNAIS 1988: 83).

[10] Classic discussion of the appropriability problem is given by ARROW (1962) and HIRSCHLEIFER (1971), among others. In addition to R&D cooperation between innovating

appropriability affect both the amount of R&D that firms undertake and the location of innovation. In both cases, vertical cooperation between innovating firms, suppliers and users plays an important role.

With respect to the first case – appropriability conditions affecting the amount of R&D – the following observations can be made. At base, the problem of appropriability is that innovators are not protected by sufficiently high barriers to entry, often even in the presence of patents or other intellectual property rights, to insure that they get a reasonable return for their R&D efforts (COHEN 1995; HARABI 1995b). If, however, to be commercially successful, a technological innovation must be packaged with other assets (such as specialized inputs, manufacturing or marketing capabilities, see TEECE 1986), then any artificially created shortages in the supply of critical complementary assets effectively acts as a barrier to entry into the market where the packaged technological innovation is sold. This, in turn, allows the innovator to reap monopoly profits in that market, and these can be set against the costs of its R&D program. The innovator can gain control over the supply of critical complementary assets through vertical cooperation with other firms or through vertical integration of firms providing those complementary assets.[11]

Turning to the second case, which concerns how problems of appropriability can affect the location of innovation, one can point to the following mechanism. If the returns from new knowledge are difficult to appropriate, then it is likely to be the case that such knowledge will be embodied in output if an innovator is to realize any revenue. According to von HIPPEL (1982), two hypotheses follow from this observation. First, independent innovators (for instance independent R&D labs) are less likely to innovate than agents operating in the value chain involving the innovation (as suppliers, manufacturers or users of the innovation), because they have only non-embodied knowledge to sell. Second, differences in the ability of different agents in the value chain to appropriate the rewards of innovation may give rise to incentives to innovate that translate into systematic differences in the functional source of innovation (i.e. whether it is user-, supplier- or manufacturer-led). This second hypothesis is consistent with evidence suggesting that users play a major role in the innovative process in some sectors, while manufacturers (or suppliers) play a major role in others. Von HIPPEL (1976, 1978), for example, examined 111 basic major and minor innovations in four families of scientific instruments and discovered that users dominated the innovation process in about 80 per cent of the sample innovations. The users perceived the need for a new instrument, invented it, built and applied the prototype, and spread knowledge about it. Manufacturers mainly performed product engineering work to improve the manufacturability of the product.

Other researchers have emphasized the crucial role of users and suppliers for the innovation process in other industries. CLARK ET AL. (1987) provide a particularly

firms, suppliers and customers, there are other solutions to the appropriability problem: government subsidies; horizontal R&D cooperation between innovating firms, fostering of national champions in key technology areas; strengthening the patents system (see, for example, GEROSKI 1995).

[11] For a detailed discussion of these issues, see PERRY (1989), THORELLI (1986), MONTEVERDE & TEECE (1982), KOGUT (1988), KLEIN ET AL. (1978), AYAL & IZRAELI (1990).

clear illustration of the important role played by the suppliers in giving Japanese automobile producers a comparative advantage in developing new products. They found that early supplier involvement in product design was a key component of Japanese automakers' edge in introducing new models both faster and with fewer total labor hours than their US and European counterparts.[12]

The supply of technological innovations in an industry depends, as already mentioned, on the various opportunities available to the innovators to obtain economically usable technical knowledge. Empirical researchers have identified different sources of those technological opportunities; for a recent survey, see COHEN (1995). They can be grouped into market and non-market sources. The first subgroup consists of the contributions of firms within the same line of business, of material and equipment suppliers, and of product users. The second subgroup encompasses the contributions of university research, of government research laboratories, of other government agencies, of professional or technical societies, and of independent inventors. A voluminous literature documents the contributions of these different sources. The case studies of JEWKES ET AL. (1958) contain instances of virtually every type of these sources. Specially important for this paper is von HIPPEL's (1976, 1977, 1988) treatment of the contributions of users to technological development in a variety of industries, including scientific instruments and semiconductor process equipment. Other researchers have, in contrast, documented in specific case studies the contributions of input suppliers to the innovation process.[13] KLEVORICK ET AL. (1993) offer the first broad, cross-industry empirical examination of the contributions to technical advance made by different sources of embodied and disembodied knowledge in the US manufacturing sector. They found that what they call sources "within the industrial chain", such as buyers and materials and equipment suppliers, apparently contribute much more to most industries' technical advance than non-market sources, such as universities and government laboratories. Similar results have been found for Switzerland, Germany and France.[14]

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[12] Other researchers have studied these phenomena in such industries as biotechnology (PISANO 1991), and robotics (PORTER 1990).

[13] Input suppliers were identified as major innovators in several industries: aluminum and fiberglass (COREY 1956); thermoplastics forming and modeling; application of industrial gases (WANDER & WERF 1992). The economic history literature has also shown the importance of vertical relations for innovations in certain industries. As ROSENBERG has remarked in his treatise on technology and American economic growth, the machine tool industry in the 19th century played a unique role, both in the initial solution to technical problems in user industries, such as textiles, and as the disseminator of these techniques to other industries, such as railroad locomotive manufacture. ROSENBERG's description suggests that the users played a role in the development of new equipment. He notes that before 1820 in the United States, one could not identify a distinct set of firms that were specialists in the design and manufacture of machinery. Machines were either produced by users or by firms engaged in the production of metal or wood products. Machinery-producing firms were thus first observed as adjuncts to textile factories. However, once established, these firms played an important role as the transmission center in the diffusion of new technology (ROSENBERG 1972: 98–102).

[14] For Switzerland, see HARABI (1995a) and ARVANITIS ET AL. (1995); for Germany, see ZENTRUM FÜR EUROPÄISCHE WIRTSCHAFTSFORSCHUNG (ZEW), Institut für angewandte

Finally, establishing vertical relationships with either buyers or suppliers may also solve problems arising from uncertainty in R&D or from indivisibilities in R&D (or other) production processes to the extent that doing so creates a market in circumstances where one would otherwise have been poorly defined. Furthermore, a captive market can have the advantage of creating a pocket of demand for a product with certain well-defined characteristics, and this may serve to focus R&D efforts and stimulate innovation.

3 An Empirical Investigation of German Firms

3.1 Data

Since 1993 experts working in German industry have been asked to answer questions related to the issue of the occurrence and importance of different modes of relationship between innovating firms on one hand and suppliers and users on the other. These questions are only a small part of a much larger survey called “Mannheim Innovation Panel” (MIP), which began in Germany in summer 1993. The data were collected by the Center for European Economic Research (Zentrum für Europäische Wirtschaftsforschung, ZEW) and the “Institut für angewandte Sozialforschung” (infas). The project was financed and supported by the German Ministry of Education, Science, Research and Technology (BMBF). The first wave was part of the Community Innovation Survey of the European Commission. The questionnaire follows the guidelines proposed by the OECD (1992) and is a somewhat extended version of the harmonized questionnaire for innovation surveys developed by EUROSTAT (for more details, see SMITH 1992).

The data used in this paper were gathered during the first and second waves of the MIP in 1993 and 1994. Since an adequate completion of the questionnaire required solid knowledge of the technology as well as of the market conditions in a particular line of business, the experts questioned were mainly R&D executives of selected firms. The sample frame for the 1994 survey was formed by R&D experts working in 12,576 firms. Of the 12,576 experts included in the survey, 3,122, or 25 per cent, completed the questionnaire. These 3,124 experts were active in 378 different lines of business (four- or five-digit-level industries, as defined by the German Federal Office of Statistics, 1979).[15]

Sozialwissenschaft (infas) (1994); and for France, see LHUILLERY (1996). All the surveys mentioned - HARABI (1995a), ARVANITIS ET AL. (1995), ZENTRUM FÜR EUROPÄISCHE WIRTSCHAFTSFORSCHUNG (ZEW), Institut für angewandte Sozialwissenschaft (infas) (1994) and LHUILLERY (1996) –used broad cross-section studies based upon mail surveys.

[15] If the industrial structure of their activities is taken at the two-digit level, 3.81 per cent of the respondents worked in mining and energy, 9.41 per cent in foods and textile, 8.13 per cent in lumber and paper, 8.13 per cent in chemicals and petroleum, 6.82 per cent in synthetics and rubber , 4.16 per cent in glass and ceramics, 4.26 per cent in basic metals

Since the survey in the second wave did not include certain variables (for example, innovation objectives of firms) that are crucial for this research, and which were included in the first wave, the 1994 data were matched with data from the first wave. The resulting pooled sample consisted finally of approximately 370 firms.

According to the statistical tests conducted, the samples described above are statistically representative neither of the distribution of industries in the German manufacturing sector nor of firm size.[16] Proportionally, more R&D experts from large firms in innovative industries participated in the survey than experts from small and medium-sized firms in less innovative industries.

A final point concerning the data should be kept in mind while reading and interpreting the results given below: All the survey data used in this paper were derived from subjective judgments based on imperfect information.

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processing, 7.68 per cent in fabricated metals processing, 17.38 per cent in machinery, 7.81 per cent in office machinery, computer and electrical machinery, 6.24 per cent in medical, precision and optical instruments, 4.00 per cent in motor vehicles and 5.25 per cent in construction industries. The remaining experts (6.91 per cent) were active in technical services. (See FELDER ET AL. 1994 for a detailed description of this survey.)

[16] This statement applies only to the data used in this paper, which are the original ones that have not been weighted according to the usual statistical techniques. The ZEW has, however, used these techniques, such as non-response analysis, and applied them to its different data sets.

3.2 Econometric Analysis

3.2.1 Econometric Specification

The dependent variable is the intensity of R&D activity in innovating firms – an input indicator of innovative effort at firm level. As described above, there are four groups of independent variables: appropriability conditions for R&D results, technological opportunities, market demand, and firm-level variables, such as firm-specific objectives of innovative activities and variables regarding financing constraints within firms.

Appropriability conditions are represented here by two variables: ENDOGENOUS APPROPRIATION MECHANISMS and LEGAL APPROPRIATION MECHANISMS. These are the two principal components which summarize through factor analysis items 1 to 6 of the questions #26 and #27 in the questionnaire. These questions attempted to assess the efficacy of six different means of capturing and securing competitive advantage from product and process innovations (see Table 1). The first variable represents the efficacy of secrecy, complexity of design, lead time and long-term employment of qualified personnel; the second variable represents the efficacy of patent protection and design registration (see Table 2). Theoretically, it is to be expected that effective protection of R&D results will exert a positive influence on the intensity of R&D activity in innovating firms.

Data about technological opportunities were obtained from questionnaire items related to the relevance of 12 external sources of information for the innovation activities of the firms surveyed. These sources of information are listed in Table 3 and include suppliers of materials and services, equipment suppliers, users, competitors, consultants and market analysts, industry-financed research laboratories, universities and technical colleges, government-financed research laboratories, technology-transfer institutions, patent documents, trade fairs and trade seminars and journals.

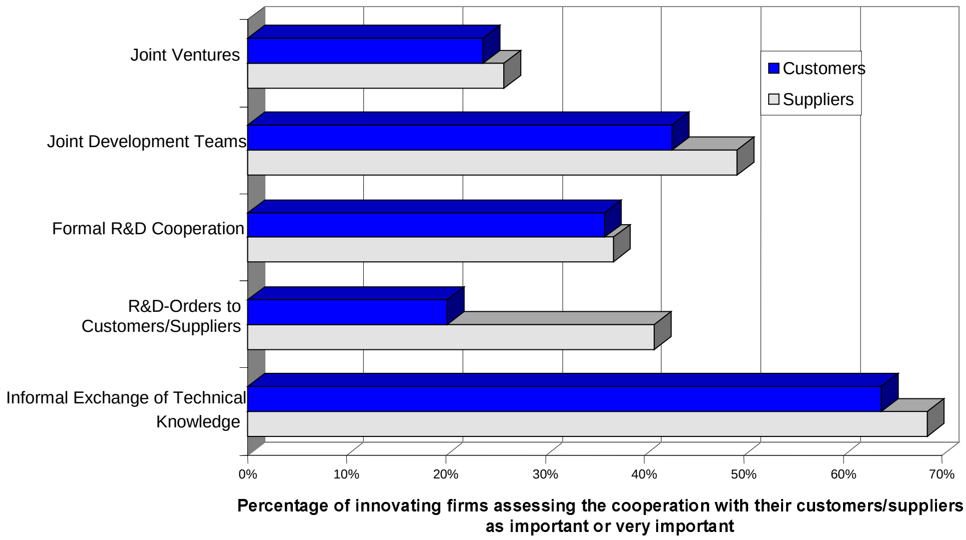
This large number of variables with relatively high inter-item correlation can be problematic in the estimation of regression equations. To reduce the number of highly collinear variables, I have employed, as many other researchers have done before, a factor-analytic procedure.[17] This technique leads to three factor scores with highly plausible groupings. The first factor – here called SCIENCE-RELATED SOURCES – receives high loadings from the questionnaire items industry-financed research laboratories, universities and technical colleges, government-financed research laboratories, and patent documents as sources of information. The second factor loads highly on users, competitors, trade fairs and trade journals. Apparently, the relevance of competitors and users is often highly correlated in these data. Information obtained from trade fairs and trade journals is related to both sources. This factor will therefore be labeled USERS & COMPETITORS. The last factor

[17] See, for instance, LEVIN ET AL. (1987), HARABI (1992), HARHOFF (1997).

retained is identified by high loadings on the two suppliers' items, and will be labeled SUPPLIERS (see Table 4).

Since additional data on the different modes of R&D cooperation between innovating firms and suppliers are available (for s short description of these data see Graph 1)[18], and these different modes can be reduced to two principal components (see Table 5), I used these two factors in the regression analysis to represent the different sources of information of suppliers. The variable SUPPLIERS I stands for the formal modes of information transfer between innovating firms and suppliers and SUPPLIERS II for the informal ones (for more details, see HARABI 1998).

Graph 1: Number of Firms that Evaluate the Different Modes of Cooperation as Important (score = 4) or Very Important (score = 5), in per cent.



The third determinant of innovation activity is market demand, or more precisely expected market demand, since firms have to make innovation decisions prior to the realization of actual demand. The Mannheim 1994 survey contains a question regarding managerial demand expectations for the three years following the survey year. The Likert-scale responses have been transformed to yield a dummy variable that assumes a unit value for all firms with high or particularly high expected demand.

In addition to industry-specific determinants, firm-level determinants of innovative activities are very important. As well as firm size, which has been controlled for by using R&D intensity at firm level as the dependent variable, the following variables are considered: three groupings of variables relating to the objectives that managers are pursuing with their enterprise's innovation activities. These variables have been derived from questionnaire items, are future-oriented and may capture demand and technology signals that are relevant for the innovation activities of these firms. The 14 different objectives listed in Table 6 could be reduced to three groupings (for the principal components, see Table 7). The first grouping consists of objectives aimed

[18] For more details see HARABI (1998).

at reducing costs and is labeled OBJECTIVES I; the second grouping consists of objectives aimed at expanding into global markets and is labeled OBJECTIVES II; and, finally, the third grouping consists of objectives aimed at creating a new domestic market and is labeled OBJECTIVES III.

Other firm-level determinants are variables related to financing constraints within firms. The first one is based, as suggested by HARHOFF (1997), on the credit-rating agency's recommendation for the maximum trade credit a supplier should grant this particular firm for the year 1993. The maximum trade credit allowance is scaled in terms of the sum of the 1993 materials and investment expenditure of the firm in order to obtain a relative measure of potential financing constraints. The logarithm of this ratio is included in the regressions under the label LNBFC. The second constraint is the firm's cost–price ratio and is computed by dividing labor and materials expenditure by total sales for 1993. The variable is labeled LNBCPR and enters the regression in logarithmic form, as HARHOFF (1997) suggests.

Finally, innovative activities vary across technologies, as empirical studies have shown. In order to control for this empirical finding, dummies for different fields in which firms have R&D activities were introduced. The 1994 survey contains questions related to this subject.

3.2.2 Econometric issues

A significant problem is related to the "noise" in the data used. This is mostly due to the fact that almost all variables – the exceptions are: R&D intensity, LNBCPR and LNBFC – were originally semantic responses to qualitative questions on the basis of a five-point semantic Lickert scale. These variables have the measurement properties of ordinal categorical data. To be useful in the econometric analysis, these semantic responses have to be converted into numerical responses. A second econometric problem is the presence of heteroscedasticity in the error terms: The assumption of equally large variance for all error terms cannot hold. In this case, OLS estimates are no longer optimal, that is, they are still unbiased but they are not efficient. Therefore, I chose the GLS procedure, which is BLUE (Best Linear Unbiased Estimator). A third problem concerns the endogeneity of the independent variable "cost-price ratio", which raises the question as to which variables can be used to achieve identification, and, if possible, overidentification in order to test the validity of the instrument set. Following HARHOFF (1997), the following variables were used as instruments: log (revenues), log (labor productivity), industry dummies, survey responses indicating past changes in revenues, employment, and demand. A Two-Stage Least Squares (2SLS) procedure was then run.

3.2.3 Empirical Results

The results of the regression analysis are summarized in Table 8 and can be interpreted as follows:

Appropriability conditions: The ability of innovating firms to capture and protect their R&D results has a positive impact on their innovative effort. The non-patent-related means of appropriability – secrecy, complexity of design, lead time and long-term employment of qualified personnel – prove to be more important for the innovative effort of firms than patent protection and design registration. In all econometric estimations listed in Table 8 the coefficient of the variable ENDOGENOUS APPROPRIATION MECHANISMS is positive and statistically significant, while the one pertaining to the variable LEGAL APPROPRIATION MECHANISMS is much lower and statistically not significant.

These results conform to theoretical expectations and are consistent with evidence from comparable studies in the USA (LEVIN ET AL. 1985, COHEN ET AL. 1987), in Switzerland (HARABI 1995b), in Germany (HARHOFF 1997) and in other European countries (KLEINKNECHT 1996).

Technological opportunities: The importance of external sources of technological opportunities for the innovative effort of firms seems to be highly differentiated. Market-related sources of technological opportunities – competitors, users and suppliers – were considered more important than non-market-related ones – universities, research institutes, agencies of technology transfer, etc.[19] Of all market-related sources, information flows stemming from competitors and users seem to be the most important ones for the innovative effort of firms. In addition, the results of the regression analysis confirm that there is a division of innovative labor among German firms. While more information and more important information transferred by competitors and users leads to higher innovative efforts within firms – in other words there is a complementarity between these economic agents in innovative activities – the opposite is true regarding the information transfer between suppliers and innovating firms. Apparently, the information produced by and transferred from suppliers to downstream firms is a substitute for the firm's own innovative efforts.

Furthermore, and this is very important with reference to the main focus of this paper, the information generated by suppliers and transferred informally to downstream firms seems to be more important for the latter than information transferred formally (for instance, in the form of a joint venture or of contractual R&D cooperation). As indicated in Table 8, the coefficient of the variable SUPPLIERS II is higher than that of SUPPLIERS I.

Market demand: The demand variable strongly supports the hypothesis that expected future demand leads to enhanced R&D activities. An indicated in Table 8, the coefficient of this variable is positive and statistically significant at either 0.01 (models 3 and 4) or 0.05 (the remaining estimates). The hypothesis that innovation is fostered by demand growth was first proposed by SCHMOOKLER (1966) and several later empirical studies have given support to this demand-pull hypothesis. (A sample of European empirical studies is presented by KLEINKNECHT 1996; for a survey of mainly American literature, see COHEN 1995.[20])

[19] Similar results were found for Switzerland (see HARABI 1995a)

[20] In this context, it is interesting to note that the demand-pull hypothesis is also supported by a recent Granger causality analysis of innovative time series by GEROSKI & WALTERS (1995). They conclude that their data „provide no reason for thinking that ... clusters of innovation cause cyclic variations in economic activity, but variations in economic activity do Granger cause changes in innovative activity" (GEROSKI & WALTERS 1995: 916).

Firm-level determinants of innovation activities: The results of Table 8 also make it possible to answer the question of how measures of corporate objectives impact on innovation activities of firms. Important for innovation activities of German firms are corporate objectives aimed at creating new markets within the European Union, in North America and in Japan. The coefficient of the variable OBJECTIVES II is positive and highly significant. Innovation activities in the German manufacturing sector seem to be driven by market demand forces.

Innovation activities vary across technologies. In order to control for this factor, dummies for different technological fields in which firms have R&D activities were introduced in the regression equations. The results suggest, as indicated in Table 8, that German firms have positive results, especially in the fields of microelectronics and medical technology, followed by laser technology, flexible integrated manufacturing and energy technology.

4 Conclusions

The purpose of this paper has been to investigate empirically, using data from German firms, the impact of vertical R&D cooperation on innovation in firms. The analysis is based on a survey conducted by the Center for European Economic Research (Zentrum für Europäische Wirtschaftsforschung, ZEW) in Mannheim among 370 companies, mainly in the manufacturing sector. The results of the econometric analysis suggest a statistically significant impact of R&D cooperation on the intensity R&D activity in German firms. Informal modes of R&D cooperation (informal exchange of technological knowledge) seem to be more significant for their innovation behavior than formal ones (joint ventures, joint development teams etc.). Since the relationship between vertical R&D cooperation and the intensity R&D activity in innovating firms has been tested in a broader theoretical and empirical framework, the empirical results also confirm the significance of other determinants of innovation activity (technological opportunities, appropriability conditions and market demand).

5 References

ARROW K. J. (1962)
"Economic Welfare and the Allocation of Resources for Invention", in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity*,. Princeton: Princeton University Press.

ARVANITIS S. ET AL. (1995)
Innovationsaktivitäten in der Schweizer Industrie. Eine Analyse der Ergebnisse der Innovationserhebung 1993. Bern: Bundesamt für Konjunkturfragen.

AYAL I., IZRAELI D. (1990)
"International Market Expansion for NEW High Tech Products through Franchising", Journal of High Technology Management Research, 1:167–80.

CECCHINI P. (1988)
1992: The European Challenge. Aldershot.

CHESNAIS F. (1988)
“Technical Cooperation Agreements Between Firms”, *STI Review*, 4: 51–119.

CLARK K. ET AL. (1987)
“Product Development in the World Automobile Industry”, *Brookings Papers on Economic Activity*, 3: 29–81.

COHEN W. M. (1995)
"Empirical Studies of Innovative Activity", in: STONEMAN P. (ed.) (1995) Handbook of The Economics of Innovation and Technological Change. Oxford: Blackwell.

COHEN W. M., LEVIN R. C., MOWERY D. C. (1987)
"Firm Size and R&D Intensity: A Re-Eximination", Journal of Industrial Economics, 35:543–563.

COHEN W. M., LEVIN R. C. (1989)
"Empirical Studies of Innovation and Market Structure“, in: SCHMALENSEE R. & WILLIG R. (1989) Handbook of Industrial Organization, Vol 2 ed., Amsterdam: North Holland.

COMMISSION OF EUROPEAN COMMUNITIES (1993)
Growth, Competitiveness, Employment: The Challenges and Ways Forward into the 21st Century, White Paper, Supplement 6/93.

COREY E. R. (1956)
“The Development of Market for New Materials”, Division of Research, Graduate School of Business Administration, Harvard University, Boston Mass.

DASGUPTA P., STIGLITZ J. E. (1980)
"Industrial Structure and the Nature of Innovative Activity", Economic Journal, 90:266–293.

DOSI G. (1988)
”Sources, Procedures, and Microeconomic Effects of Innovation", Journal of Economic Literature, 26:1120–1171.

FELDER J. ET AL. (1994)
Innovationsverhalten der Deutschen Wirtschaft. Methodenbericht zur Innovationserhebung 1993. ZEW Dokumentation Nr. 94-06.

GAHLEN B., RAMSER H. J., HESSE H. (eds.) (1993)
Ökonomische Probleme der europäischen Integration, Schriftenreihe des wirtschaftswissenschaftlichen Seminars Ottbeuren, Bd. 23. Tübingen.

GEROSKI P. A. (1992)
“Vertical Relations between Firms and Industrial Policy”, *Economic Journal*, 102: 138–51.

GEROSKI P. A. (1993)
“Antitrust Policy Towards Co-operative R&D Ventures”, *Oxford Review of Economic Policy*, 9: 58–71.

GEROSKI P. A. (1995)
“Markets for Technology: Knowledge, Innovation and Appropriability”, in: STONEMAN P. (ed.) (1995), Handbook of The Economics of Innovation and Technological Change. Oxford: Blackwell.

GEROSKI P. A. & WALTERS C. F. (1995)
“Innovative Activity Over the Business Cycle”, *Economic Journal*, 105: 916–28.

HARABI N. (1992), "Determinants of Techncial Change: Empirical Evidence from Switzerland", Empirica - Austrian Economic Papers, Vol. 19, No. 2:221–244.

HARABI N. (1995a)
“Sources of Technical Progress: Evidence from Swiss Industry”, *Economics of Innovation and New Technology*, 4: 67–76.

HARABI N. (1995b)
“Appropriability of Technological Innovations: An Empirical Analysis”. *Research Policy*, 24: 981–992.

HARABI N. (1998)
“Innovation Through Vertical Relations Between Firms, Suppliers and Customers: A Study of German Firms”, *Industry and Innovation*, 5: 157–179.

HARHOFF D. (1996)
“Strategic Spillovers and Incentives for Research and Development”, *Management Science*, 42: 907–25.

HARHOFF D. (1997)
“Innovationsanreize in einem strukturellen Oligopolmodell”, *Zeitschrift für Wirtschafts- und Sozialwissenschaften*, 117: 333–64.

HIPPEL E. VON (1976)
"The Dominant Role of Users in the Scientific Instrument Innovation Process*",
Research Policy*, 5: 212–239.

HIPPEL E. VON (1977)
"The Dominant Role of the User in Semiconductor and Electronic Subassembly Process Innovation", *IEEE Transactions on Engineering Management*, EM-24: 60–71.

HIPPEL E. VON (1978)
"Users as Innovators", *Technology Review*, 80: 31–9.

HIPPEL E. VON (1982)
"Appropriability of Innovation Benefits as a Predictor of the Source of Innovation", *Research Policy*, 11: 95–115.

HIPPEL E. VON (1988)
The Sources of Innovations. Oxford: Oxford University Press.

HIRSCHLEIFER J. (1971)
"The Private and Social Value of Information and The Reward to Inventive Activity", American Economic Review 61: 561-74.

JEWKES D., SAWERS J., STILLERMAN R. (1958)
The Sources of Invention. London: Macmillan.

KATZ M. L. (1986)
"An Analysis of Cooperative Research and Development", *Rand Journal of Economics*, 17: 527–43.

KATZ M. L., ORDOVER J. A. (1990)
"R&D Cooperation and Competition", *Brookings Papers on Microeconomics*, 137–203.

KLEIN B., CRAWFORD R., ALCHIAN A. (1978)
Vertical Integration, Competitive Rents and the Competitive Contracting Process, *Journal of Law and Economics*, 21: 297–326.

KLEINKNECHT A. (ed.) (1996)
Determinants of Innovation. The Message from New Indicators. London: Macmillan Press.

KLEINKNECHT A., REIJNEN J. O. N. (1992)
"Why Do Firms Cooperate on R&D? An Empirical Study", *Research Policy*, 21: 1–13.

KLEVORICK A. K., LEVIN R. C. NELSON R. R., WINTER S. G. (1993)
"On the Sources and Significance of Interindustry Differences in Technological Opportunities", Yale University, mimeo.

KOGUT B. (1988)
"Joint Ventures: Theoretical and Empirical Perspectives", *Strategic Management Journal*, 9: 319–32.

KÖNIG H., LICHT G., STAAT M. (1993)
"F&E-Kooperationen und Innovationsaktivität", in: GAHLEN B., RAMSER H.J., HESSE H. (eds.), *Ökonomische Probleme der europäischen Integration, Schriftenreihe des wirtschaftswissenschaftlichen Seminars Ottbeuren*, Bd. 23. Tübingen.

LEVIN R. C., COHEN W. M., MOWERY D. C. (1985)
"R&D Appropriability, Opportunity, and Market Structure: New Evidence on Some Schumpeterian Hypotheses", American Economic Review Papers and Proceedings, 75:20-24.

LEVIN R. C., KLEVORICK A. K., NELSON R. R., WINTER S. G. (1987)
"Appropriating the Returns from Industrial Research and Development", Brookings Papers on Economic Activity, 783-821.

LHUILLERY S. (1996)
L'Innovation Technologique dans l´Industrie. Ministere de L´Industrie, de la Poste et des Telecommunications. Service des statistiques industrielles. Paris.

LICHT G. (1994)
"Gemeinsam forschen - Motive und Verbreitung strategischer Allianzen in Europa", *ZEW-Wirtschaftsanalysen, Quartalshefte des Zentrums für Euroäische Wirtschaftsforschung*, *Mannheim,* Nr. 4, 371–400.

MONTEVERDE K., TEECE D. (1982)
"Appropriable Rents and Quasi-Vertical Integration", *Journal of Law and Economics*, 25: 321–328.

OECD (1992)
Proposed Guidelines For Collecting and Interpreting Technological Innovation Data. Oslo Manual, Paris: OECD.

PERRY M. (1989)
"Vertical Integration", in R. Schmalensee and R. Willig (eds), *Handbook of Industrial Organization*. Amsterdam: North Holland.

PISANO G. P. (1991)
"The Governance of Innovation: Vertical Integration and Collaborative Arrangements in the Biotechnology Industry", *Research Policy*, 20: 237–49.

PORTER M. (1990)
The Competitive Advantage of Nations. London: Macmillan.

ROSENBERG N. (1972)
Technology and American Economic Growth. Armonk: M. E. Sharpe.

SCHMALENSEE R. & WILLIG R. (1989)
Handbook of Industrial Organization, Vol 2 ed., Amsterdam: North Holland.

SCHMOOKLER J. (1966)
Invention and Economic Growth. Cambridge, Mass.: Harvard University Press.

SMITH K. (1992)
"Technological Innovation Indicators: Experience and Prospects", *Science and Public Policy*, 6: 383–392.

STONEMAN P. (ed.) (1995)
Handbook of The Economics of Innovation and Technological Change. Oxford: Blackwell.

TEECE J. D. (1986)
"Profiting from Technological Innovation: Implications for Integration, Cooperation, Licensing and Public Policy", *Research Policy*, 15: 285–305.

THORELLI H. (1986)
"Networks: Between Markets and Hierarchies", *Strategic Management Journal*, 7: 37–51.

ZENTRUM FÜR EUROPÄISCHE WIRTSCHAFTSFORSCHUNG (ZEW), Institut für angewandte Sozialwissenschaft (infas) (1994)
Zukunftsperspektiven der deutschen Wirtschaft. Unternehmensbefragung im Auftrag des Bundesministers für Forschung und Technologie (quoted: "Questionnaire").

6 Appendix

6.1 List of the Variables

Dependent variable:

Notation	Short description	Source
BFUES	R&D intensity of firm *i*: Total R&D expenditures/Total sales (FUE/UMG) Log(BFUES)	MIP 94 (B29/4b)

Independent variables:

Notation	Short description	Source
1. Technological opportunities:		
Science related sources:	Factor-analytic term	MIP 93
Competitors &Users:	Factor-analytic term Both variables derived from 12 Variables	MIP 93(A39)
Suppliers I:	Formal modes of R&D Cooperation	
Suppliers I:	Informal modes of R&D Cooperation Two factor-analytic terms derived from 5 variables	MIP 94
2. Appropriability conditions:		
Endogenous protection mechanisms Legal protection mechanisms	Two factor-analytic terms derived from 12 variables	MIP 93 (A26+A27)
3. Market demand:		
Expected demand	Firm's demand expectations (dummy variable):	MIP 94 (B9)
4. Financial constraints:		
LNBCPR	Log of cost–price ratio: Labor + materials expenditures/total sales (BKOST+MKOST)/UMG (B41+B42)/(B4b)	MIP 94
LNBFC	Maximum trade credit allowance/Sum of	CREDITREFO

	1993 materials and investment expenditures: TC/MKOST+INV	RM MIP 94 (B42+B43)
5. Goals of the firm:		
Innovation objectives I: Innovation objectives II: Innovation objectives III:	Cost-reducing Expanding to global markets Creating a new domestic market Three factor-analytic terms derived from 13 Variables	MIP 93 (A38)
6. Dummies for technological fields:		
	11 Technology dummies	MIP 94 (B31)
7. Additional variables:		
7.1 Instruments for cost–price-ratio		
	Log (revenues) Log (labor productivity) Industry dummies Survey responses indicating past changes in (dummies): revenues employment demand	
7.2 Instruments for financing constraints:		
	Legal form of the firm observed payment behavior	

6.2 Tables

Table 1: Relevance of appropriation mechanisms

Appropriation mechanism	Share of firms evaluating the mechanism as important or very important
Patent protection for products	35.62%
Design registration for products	25.00%
Secrecy for products	46.12%
Complexity of product design	54.18%
Lead time for products	77.95%
Long-term employment of qualified personnel for products	83.39%
Patent protection for processes	20.74%
Design registration for processes	13.42%
Secrecy for processes	42.83%
Complexity of process design	49.49%
Lead time for processes	73.67%
Long-term employment of qualified personnel for processes	77.25%

Table 2: Factor analysis of appropriation mechanisms

Appropriation mechanism	Rotated factor loadings		
	1	2	Uniqueness
Patent protection for products	0.10728	0.81543	0.32357
Design registration for products	0.11117	0.75429	0.41868
Secrecy for products	–0.46502	0.4757	0.55746
Complexity of product design	–0.61707	0.17802	0.58754
Lead time for products	–0.53301	0.38652	0.56650
Long-term employment of qualified personnel for products	–0.58306	0.12970	0.64322
Patent protection for processes	0.03498	0.83859	0.29555
Design registration for processes	0.02986	0.82255	0.32252
Secrecy for processes	–0.50051	0.49786	0.50163
Complexity of process design	–0.71012	0.25192	0.43227
Lead time for processes	–0.66240	0.35996	0.43166
Long-term employment of qualified personnel for processes	–0.65777	0.13115	0.55014

Table 3: Importance of Sources of Information for Innovation Activities

Source of Information	Share of Firms Evaluating the Source of Information as Important or Very Important (%)
Suppliers of material and components	65.24
Suppliers of equipment	48.72
Customers	81.69
Competitors	53.81
Consultancy firms	13.01
Industry-financed research institutes	14.01
Universities	30.26
Technical institutes	13.63
Agencies of technology transfer	11.87
Patent disclosures	27.65
Fairs/exhibitions	66.70
Journals/conferences	65.25

Table 4: Factor analysis of sources of information for innovation activities

Source of information for innovation activities	Rotated factor loadings 1	2	3	Uniqueness
Suppliers of material and components	–0.01363	0.18705	0.79630	0.33074
Suppliers of equipment	0.10356	0.00124	0.83911	0.28517
Customers	0.09941	0.68598	–0.00868	0.51948
Competitors	0.15806	0.68129	0.01120	0.51073
Consultancy firms	0.51641	0.26536	0.12452	0.64740
Industry-financed research institutes	0.76317	0.06134	0.11739	0.40003
Universities	0.79616	0.09143	–0.04409	0.35582
Technical institutes	0.85517	0.03248	0.02627	0.26695
Agencies of technology transfer	0.73470	0.09283	0.16219	0.42529
Patent disclosures	0.53400	0.35387	–0.16950	0.56089
Fairs/exhibitions	0.00623	0.72004	0.24517	0.42139
Journals/conferences	0.18395	0.52056	0.32465	0.58978

Table 5: Principal components analysis of different modes of cooperation with either customers or suppliers

	Customers		Suppliers	
	Coefficients of 1st principal component	Coefficients of 2nd principal component	Coefficients of 1st principal component	Coefficients of 2nd principal component
1. Joint ventures	0.77	–0.23	0.83	0.01
2. Joint development teams	0.67	0.31	0.80	0.19
3. Contractual R&D cooperation	0.68	0.42	0.77	0.33
4. R&D order to customers	0.75	0.13	0.65	0.46
5. Informal exchange of technical knowledge	0.07	0.93	0.14	0.95
6. Cumulative variance explained	0.46	0.65	0.56	0.72

Table 6: Importance of objectives of innovation activities

Objective of innovation activities	Share of firms evaluating the objective as important or very important (%)
Replacing old products	67.54
Increasing market share	90.78
Extending product range	
Within main product field	72.61
Outside main product field	22.61
Creating new markets	
In West Germany	60.54
In East Germany	58.63
In Eastern Europe	27.52
Within the European Union	46.94
In Japan	11.04
In North America	21.00
In other countries	20.20
Improving product quality	85.44
Environmentally sound products	54.95
Improving production feasibility	68.01
Reduction of the share of wage cost	73.66
Reduction of materials consumption	61.61
Reduction of energy consumption	48.76
Reduction of product lead times	53.33
Reduction of goods with defects	63.92
Improving working conditions	47.98
Reduction in environmental damage	46.17

Table 7: Factor analysis of objectives of innovation activities

Objective of Innovation Activities	Rotated factor loadings			
	1	2	3	Uniqueness
Replacing old products	0.08961	0.34528	0.31427	0.77398
Increasing market share	0.09384	0.04741	0.50211	0.73683
Extending product range				
Within main product field	0.08437	0.05203	0.49539	0.74476
Outside main product field	0.10575	0.10508	0.33362	0.86647
Creating new markets				
In West Germany	0.07124	0.12526	0.67938	0.51767
In East Germany	0.09486	–0.03370	0.69467	0.50730
In Eastern Europe	0.01244	0.40086	0.46922	0.61899
Within the European Union	0.06143	0.60130	0.44385	0.43767
In Japan	0.03143	0.81784	–0.04636	0.32800
In North America	0.01131	0.86593	–0.01866	0.24969
In other countries	0.03255	0.77448	0.12885	0.38252
Improving product quality	0.51205	0.01487	0.25617	0.67196
Environmentally sound products	0.43946	0.16662	0.08584	0.77174
Improving production feasibility	0.51652	–0.01765	0.36980	0.59615
Reduction of the share of wage cost	0.51000	–0.00881	0.14407	0.71907
Reduction of materials consumption	0.63513	0.08501	0.10991	0.57730
Reduction of energy consumption	0.74120	–0.03032	–0.00165	0.44970
Reduction of product lead times	0.66559	0.08174	0.16083	0.52444
Reduction of goods with defects	0.67168	0.08070	0.08703	0.53477
Improving working conditions	0.71790	–0.05118	0.02702	0.48127
Reduction in environmental damage	0.65472	0.09364	–0.12364	0.54729

Table 8: R&D intensity regressions (standard errors in parentheses)

Variable	OLS (1)	OLS (2)	GLS (3)	GLS (4)	2SLS (5)
Intercept	–4.219*	–4.089*	–4.219*	–4.089*	–3.584*
	(0.335)	(0.405)	(0.324)	(0.391)	(0.526)
LNBCPR	–	0.325***	–	0.325	1.382
	–	(0.190)	–	(0.183)	(0.673)
LNBFC	–	0.015	–	0.015	0.090
	–	(0.051)	–	(0.049)	(0.068)
SCIENCE-RELATED SOURCES	0.085	0.068	0.085	0.068	0.017
	(0.078)	(0.083)	(0.076)	(0.080)	(0.090)
COMPETITORS OR USERS	0.142***	0.162***	0.142***	0.162**	0.104
	(0.083)	(0.087)	(0.080)	(0.084)	(0.096)
SUPPLIERS I	–0.071	–0.119***	–0.071	–0.119***	–0.132***
	(0.064)	(0.067)	(0.062)	(0.065)	(0.072)
SUPPLIERS II	–0.286**	–0.281**	–0.286**	–0.281**	–0.291**
	(0.132)	(0.141)	(0.128)	(0.136)	(0.149)
ENDOGENOUS PROTECTION MECHANISMS	0.213***	0.220***	0.213**	0.220**	0.209**
	(0.083)	(0.086)	(0.080)	(0.083)	(0.092)
LEGAL PROTECTION MECHANISMS	0.085	0.068	0.085	0.068	0.116
	(0.085)	(0.090)	(0.083)	(0.087)	(0.099)
EXPECTED DEMAND	0.170**	0.153**	0.170*	0.154*	0.164**
	(0.075)	(0.079)	(0.073)	(0.076)	(0.084)
INNOVATION OBJECTIVES I	–0.105	–0.073	–0.105	–0.074	–0.042
	(0.082)	(0.084)	(0.079)	(0.081)	(0.090)
INNOVATION OBJECTIVES II	0.219*	0.269*	0.219*	0.269*	0.272*
	(0.080)	(0.082)	(0.078)	(0.079)	(0.089)
INNOVATION OBJECTIVES III	0.089	0.111	0.089	0.111	0.134
	(0.082)	(0.084)	(0.080)	(0.082)	(0.090)
TECHNOLOGICAL FIELDS:					
New materials	–0.155	–0.169	–0.156	–0.169	–0.123
	(0.152)	(0.159)	(0.147)	(0.153)	(0.170)
Microelectronics	0.550*	0.576*	0.550	0.576*	0.760*
	(0.200)	(0.210)	(0.194)	(0.203)	(0.230)
Laser technology	0.241	0.220	0.241	0.220	0.076
	(0.214)	(0.223)	(0.207)	(0.215)	(0.243)
Software	–0.110	–0.090	–0.109	–0.089	–0.033
	(0.157)	(0.164)	(0.152)	(0.158)	(0.175)
Telecommunications	–0.114	–0.067	–0.110	–0.067	–0.011
	(0.187)	(0.190)	(0.181)	(0.183)	(0.205)
Biotechnology	–0.040	–0.090	–0.040	–0.09	–0.088
	(0.337)	(0.355)	(0.327)	(0.343)	(0.377)
Medical technology	0.426***	0.530**	0.426**	0.530*	0.832*
	(0.257)	(0.264)	(0.249)	(0.254)	(0.294)
Flexible integrated manufacturing	0.004	0.007	0.004	0.007	0.049
	(0.150)	(0.1157)	(0.146)	(0.151)	(0.171)
Transport technology	–0.338	–0.248	–0.338	–0.248	–0.285
	(0.174)	(0.179)	(0.167)	(0.173)	(0.192)
Energy technology	0.089	0.104	0.089	0.104	0.021
	(0.212)	(0.216)	(0.206)	(0.208)	(0.233)
Environment technology	–0.0124	–0.066	–0.124	–0.066	–0.037
	(0.153)	0.158	(0.148)	(0.152)	(0.169)

* significant at 0.01
** significant at 0.05

*** significant at 0.10