Sectoral patterns of interactive learning : an empirical exploration using an extended resource based model

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"Sectoral Patterns of Interactive Learning" An empirical exploration using an extented resource based model

by

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Abstract

This paper pursues the development of a theoretical framework that explains interactive learning between innovating firms and external actors in the knowledge infrastructure and the production chain. The research question is: what kinds of factors explain interactive learning of innovating firms with external actors? In our theoretical framework we augment the resource-based perspective predominant in network theory with an activity based account and a structural account of interactive learning. We contend basically: that higher technological dynamics induce innovative activities with a higher complexity. More complex innovative activities increase the probability of internal resource deficits/shortages in the innovating firms. The higher the resource deficits/shortages and the lower the alignment of innovative activities the more likely the search for complementary resources externally, which increases the likeliness of external relationships.

In order to test the generality of our theoretical claims we analyse our models within four sectors with different technological dynamics as distinguished by Pavitt. Furthermore we estimate four models within each sector predicting: 1) the level of interactive learning of innovating firms with the public knowledge infrastructure (difficult to access, demands high internal competences to utilise scientific knowledge), 2) the level of interactive learning of innovating firms with the production chain (easy to access), 3) the level of interactive learning of innovating firms with their users (here the innovating firms are the producers), 4) the level of interactive learning of innovating firms with their suppliers (here the innovating firms are the users), 5) the level of interactive learning with competitors. These analyses allow for a comparison between interactive learning with different external actors and give deeper insights into the differentiated interaction patterns governing innovation.

Our findings show that patterns of interactive learning between sectors differ. Some are more resource based and others are more affected by the complexity of innovative activities. Particularly the interactive learning with the knowledge infrastructure differs from that with actors in the production chain.

Introduction

Interaction and learning are critical constituents of the innovation process. Innovation requires the ability of a firm to recognise the value of new, external information, assimilate it, and translate it into the procurement and allocation of facilities, materials, components and knowledge. The interaction with its environment determines a firm's access to a diversity of resources, whereas the learning enables firms to transform these resources into innovations. Both interaction and learning contrast sharply with notions of lonely innovators with invariable resource base and stress the dynamic features of innovating organisations.

Despite the theoretical importance of these dynamic features, if given the option, most organisations would prefer to establish a minimum number of interorganisational relationships inasmuch as these relations can constrain their subsequent action (Galaskiewicz, 1985: 282; Hage and Alter, 1993: ; Alter and Hage, 1994). Given managers' preference for autonomy and maximum discretionary power one could call this an autonomy – dependency dilemma. Moreover, Lam (1997) argues that a large part of human knowledge is context bound, highly firm specific and tacit in nature; and that there are limits to which knowledge can effectively articulated, transferred and utilised. Reasoning from a behavioural and a knowledge based perspective the triumvirate of innovation, interaction and learning is anything but automatic and raises the question, why networks and clusters are so important nowadays in the context of innovation.

In this paper we argue that particularly the complexity of innovative *activities* impels firms to exploit external knowledge and build external relations despite the stickiness, firm specificity, and social embeddedness of human knowledge, and despite the limited governance opportunities (Lam, 1997). Following Alter and Hage (1993), Hage and Alter (1994), and Lundvall (1992), the complexity of innovative activities is by and large determined by the discontinuous nature of social, sectoral, technological and market developments (Tushman and Anderson, 1990), to which firms try to respond, whether reactive or proactive. In such a context the preservation and structural alignment of an up to date internal knowledge base is virtually impossible, which on its turn explains the attractiveness of building external relationships. The organisational form of networks is considered as an effective organisational strategy because it enables firms to avoid risks and uncertainties (Håkansson, 1987, 1989; DeBresson, 1991) associated with innovative activities, either in the field of strategic positioning, or in the field of technical innovation (Boisot, 1995). Simultaneously networking allows firms to exploit heterogeneous external knowledge bases, and makes firms more aware of external capabilities, offers opportunities to adapt and learn and to develop new competences (Alter and Hage, 1993; Cohen and Levinthal, 1990; Lundvall, 1992).

In this paper we aim at developing a theoretical model for the interactive learning in networks extending the dominant view on learning and networks. Our theoretical accounts for flows of heterogeneous resources, the avoidance of uncertainties and risk sharing in networks pursue an extension of the resource based network approach in economics and sociology (Litwak and Hilton, 1962; Cooke, 1977; Pfeffer and Salançik, 1978; Cooke and Emerson, 1984; Håkansson, 1987; Nielsen, 1988; Hergert and Morris, 1988; Tyler and Steensma, 1995) as well as the knowledge based theories on learning (Smith, 1995, Jin and Stough, 1998). In contrast with the resource based theory of networks and learning where firms' activities are taken for granted we add the *complexity and structuration of innovative activities inducing the search and utilisation of external resources*. Both, the nature of innovative activities as well as the coherence of internal innovative activities determines the extent in which innovating firms have to draw upon external knowledge bases and hence develop external relations. The complexity perspective implies on the one hand that growth of knowledge yields more elaborate production and innovation processes, whereas on the other hand the growth of the number of monitored external environments exponentially augments information flows. In tandem this induces the rise of the awareness of both threats and opportunities. Inherent in complexity is the dilemma of co-ordination and co-operation, the need to build external linkages and control many discrete activities (Hage and Alter, 1994).

The advanced theoretical framework shall be explored at the level of firms within four sectors derived from Pavitt (1984), and the patterns of interactive learning within these sectors shall be explored for five different types of external actors (universities/research labs, the production chain, users, suppliers and competitors). Because the pace and level of technological dynamics largely determine the complexity of innovative activities it makes sense to explore interactive learning within sectors with distinct technological dynamics. Pavitt's sectors differ strongly as to the nature of technological change. Furthermore, Pavitt also suggests what type of actors (users, suppliers, universities etc) contribute to the innovations going in firms, whereas no other theory does.

Our paper adds to the growing body of literature on innovation systems, interactive learning and networks and performs several functions. First, whereas much empirical literature focuses on dyadic relations of innovating firms with its competitors, universities, or its customers or suppliers, we concentrate on the interaction of innovating firms with actors differing with respect to their accessibility. There are only a few empirical studies available that address regional patterns of interaction and relationship between innovating firms and a broad variety of actors (Håkansson, 1987/1989; van der Knaap & Tortike, 1991; Krolis & Kamann, 1991; Cooke et.al., 1997). Second, most network research applied in innovation studies does not make explicit theoretical accounts for the existence of networks, or the level of interactive learning (Meeus and Oerlemans, 1993). Hence we advance an alternative theoretical account for the external linkages between innovating firms and external actors based on several explicit theoretical frameworks.

The structure of our paper is as follows. First, we describe the components of our theoretical framework. Next we specify the moderator variable: sectoral technological dynamics and in addition divergent types of external actors with whom innovating firms can co-operate. This yields a research model and a set of hypotheses on the relation between levels of interactive learning and the complexity of innovative activities, the quality of the internal resource base and the structuration of innovative activities. The next section describes the research design including the sample, measurement and analyses. Subsequently, our results are described. Finally, we discuss these results and derive some theoretical and policy inferences, complemented with some ideas about future research.

Theoretical framework

Toward a research model

First we describe the elements of our research model separately and derive a number of propositions. Next we specify the conditions affecting the explanations for interactive learning. This yields our major hypothesis.

Interactive learning

The concept of learning is not new (Arrow, 1962; Chandler, 1992). Learning is conceived as a set of activities in which all kinds of knowledge are (re-) combined to form something new. Stough and Jin (1998: 1261) define the learning capability of an agent as its capacity to create, acquire, and transform knowledge and thereby upgrade its skills, expertise and competencies (...). Lundvall (1992) has introduced the notion of interactive learning in the innovation literature. The notion of interactivity performs several functions. First, it applies to the dependency of learning on the communication between people or organisations that possess different types of required knowledge. Second, it allows for feedback loops between 'upstream' activities like R&D and external actors like user communities or the basic science infrastructure (Morgan, 1997). The dependent variable in our research model is defined as the level of interactive learning between the innovating firms and external actors and is indicated with the frequency of external actors' active participation in or contribution of ideas to the innovation process of the innovating firm.[4]

Resources

Several researchers on learning convincingly showed the association between learning and resources. Post-Fordist conditions for competition, rest more on the superior capacity to learn rapidly to improve products and processes than simply on cost advantages in the production and distribution of standardised goods. The strategic definition of a business firms has shifted from being a profit maximiser, or transaction cost avoider, to being a learning organisation of knowledge creating company (Alter and Hage, 1993; Smith, 1995; Jin and Stough; 1998). Our research model includes three different knowledge based indicators for the quality of the internal resource base: R&D intensity (Cohen and Levinthal, 1990), percentage of higher educated workforce (Jin and Stough, 1998), size of the firm (Baldwin and Scott, 1987; Cohen & Levin, 1989; Vossen and Nooteboom, 1996)[5].

The innovation process draws on a large number of heterogeneous resources, which are not easily acquired (Håkansson, 1987). The acquisition of such resources is enabled by the interaction between the involved actors. In the context of innovation these resources are primarily defined in terms of money enabling investments, a physical and technological infrastructure, a stock of knowledge, information and human skills enabling an organisation to transform inputs into outputs and decision making.

The central tenet of the resource-based approach is that the higher the environmental dynamics, the more a firm has to draw on its internal and external environment to acquire all knowledge resources conducive to innovation. Consequently firms have to monitor actively their resource bases, particularly their knowledge base (embodied and disembodied) as well as their financial position and decide how to solve their resource deficits. In that context the intensification of existing relationships or the formation of new linkages with other firms, institutional actors like universities, or venture capitalists are considered as behavioural alternatives enabling innovation strategies. Each external actor can be evaluated with regard to its competencies to complement the resource base of the innovating firm. So the interaction between innovating firms and broad variety of firms and institutional actors is the corollary of their needs for heterogeneous resources (Håkansson, 1987; Lundvall, 1992, Hage and Alter, 1994, Tödtling, 1994). Cohen and Levinthal (1990: 128) argue that the ability to evaluate and utilise outside knowledge is largely a function of prior related knowledge. This implies that firm with a comparatively better internal resource base, are less inclined to develop external relations. This yields a first resource-based proposition:

P1a A *higher quality of the internal resource base reduces the probability of the emergence of external relationships, all else equal.*

However, the discontinuous nature of technological calls for a qualification of this resource-based argument and stresses that firms' abilities to sustain their internal knowledge base without incurring high costs are severely limited. Leonard-Barton and Doyle (1996) expect the occurrence of resource deficits particularly in case of disruptive or fast technological changes, when existing competencies become obsolete such that no firm can anticipate. Hence they suggest that although core competencies of a firm are often an aid to its innovative performance, the very same core technical capabilities that have made a company great can constitute core rigidities and hinder new product development in subtle ways. The second resource–based proposition on interactive learning reads as follows:

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[4] For the indicators used and the calculation and transformations of raw score see Annex 1, Table 1.

[5] For the indicators, the calculation and transformations of the raw scores see Annex 1, Table 2.

P1b *Higher environmental dynamics create a higher probability of internal resource deficits, which on its turn makes the emergence of external relationships more likely.*

A second qualification of the resource-based proposition is enhanced by clarifying the effects of the quality of the resource base on monitoring capacities. A higher quality of the internal resource base allows firms to monitor a larger set of external environments more in depth. This implies a rise of the probability of defining a larger number of opportunities that cannot be met with the internal resource base, which on its turn invokes a higher probability of developing external relations. Therefore the following proposition reads:

P1c *A higher quality of the internal resource base enables in depth monitoring of a larger number of external environments, increasing the chance of interactive learning.*

Complexity

Whereas resource dependency theorists take firms' activities for granted in their explanations of networks, several activity based theories emphasise firms' activities as the major cause for the emergence of external relationships (Lundvall, 1992; Alter and Hage, 1994). This allows for a further qualification and extension of the resource-based perspective of interaction and learning.

Lundvall (1992) explains levels of interactive learning primarily with the complexity of innovative activities. Lundvall conceptualises innovation as an informational commodity (Cohendet, Héraud & Zuscovitch, 1993), and he interprets innovation profits in a Schumpeterian way as transitory. Therefore the acquisition and protection of information is essential in order to innovate and profit from the innovation, which explains the emergence of linkages as well as the importance of control.

Lundvall's starting point is that a broader range of technological opportunities and a higher changeability of user needs cause a higher rate of innovation. Since innovation is by definition the creation of qualitatively different, new things and new knowledge, the chances and threats of technological opportunities, as well as changing user needs have to be evaluated in order to know whether they can be translated into new product/process features. Particularly when a firm intends process or product innovations, this feasibility check demands close co-operation between users and producers, because users provide the required information for the producers. This has two related consequences: 1) a higher rate of innovation causes more intense patterns of interaction between users and producers, and 2) a higher level of innovation (incremental/radical) affects the complexity of the knowledge exchange. It is especially radical innovations that erase existing communication codes between user and producers. New codes have to be developed on a trial and error basis, which requires intensive interactions between users and producers compared to incremental innovations. This implies basically that growth of knowledge yields more elaborate production and innovation processes. Inherent in complexity is the dilemma of co-ordination and co-operation, the need to build external linkages and control many discrete activities (Hage and Alter, 1994). The general proposition derived from Lundvall's theory is as follows: P2 *More complex innovative activities induce higher levels of interactive learning.*

In innovation research the nexus between complexity and external linkages is often indicated with the contrast between incremental and radical innovation[6]. Lundvall (1992/1993) and Maillat (1991) gave similar accounts for the relation between the level of innovation and the emergence of linkages. Maillat (1991) argues that the importance of the local environment for the innovation process is dependent on the type of innovation, on the one hand, and on the innovation strategies of the firms on the other. For incremental innovators, the local production environment is of little importance. According to Maillat, the resources necessary for incremental innovation can in many cases be found in the firm itself. Radical innovators, however, develop more relations with the local production environment if they have an insufficient supply of internal resources to realise this type of innovation. Therefore, we hypothesise that innovating firms implementing radical innovations have a higher probability of internal resource shortages and face higher uncertainties and therefore are more inclined to exploit external knowledge and build external relationships.

Complexity has different meanings in different stages of the innovation process, and also impacts in different ways on the formation of linkages. In the pre-innovation stage complexity pertains to innovative search activities (Mezias and Lant, 1994).[7] Firms' innovative search aims at the monitoring of innovation possibilities for their products or processes either looking at new technical findings, or at new market needs. Uncertainties exist as to markets and technologies. These uncertainties induced by both types of information trigger an internal and external assessment as to the capabilities needed to absorb these new technical findings into an efficient process or product. If the internal resource base is insufficient, the alternative option is to draw on external resources. Because innovative search deals with the processing of relatively new and unused knowledge, it probably evokes more processing problems, and therefore increases the chance of internal knowledge shortages, which in turns enlarges the probability of the emergence of external linkages. Hence, innovating firms with lower levels of innovative search activities interact less frequently with the actor set than firms with higher levels of innovative search activities.

With the start of the implementation of an innovation specific operational deficiencies are detected. This implies that problemistic search begins. The notion of problemistic search is derived from Cyert and March (1963: 79,

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[6] For the indicators, the calculation and transformation of raw scores see Annex 1, Table 2.

[7] For the indicators, the calculation and transformation of raw scores see Annex 1, Table 2.

120).[8] By problemistic search Cyert and March mean search that is stimulated by a problem (usually a rather specific one) and is directed toward finding a solution to that problem. Problemistic search increases with the amount by which performance is below aspiration level. Firms with this type of search consider those changes that alter the status quo only slightly. Since the solution of product deficiencies pertains to an existing product it probably regards codified knowledge. If the problems are well defined and the required knowledge is not internally available a higher level of interaction with external actors can be expected. However it is well known that the solution of operational technical problems is often very troublesome and relies on untraceable tacit knowledge and tinkering. If the problems are ill defined, knowledge deficits cannot be defined either. In that case we expect that problems be tackled in a trial and error mode internally, because building links outside the firm is not very effective. Hence we expect that innovating firms with lower levels of problemistic search activities interact less frequently with the actor set than firms with higher levels of problemistic search activities only under the condition that problems to be solved are well defined.

Structure of innovative activities

There are many structural accounts explaining the outcomes of innovation processes (Hage, 1980; Alter and Hage, 1993). The alignment and conduciveness of internal departments' innovative activities becomes more important in case of a higher complexity of innovative activities (Hage, 1980; Lawrence and Lorsch, 1967). It has become generally accepted that complementary functions or departments within organisations (e.g. R&D. sales and marketing, purchase, production) ought to be tightly intermeshed, recognising that some amount of redundancy in expertise may be desirable to create what can be called cross-function absorptive capacities (Cohen and Levinthal, 1990; 134). To the extent that an organisation develops a broad and active network of internal relationships, individual awareness of others' capabilities and knowledge will be strengthened. Inward (production, engineering) and outward looking (R&D, sales/marketing) departments enable a comparison of the internal and external opportunities for co-operation in innovation projects.[9] This yields the following proposition:

P3 *Higher integration of internal innovative activities creates a higher awareness of external as well as internal knowledge bases and therefore induces both lower and higher levels of interactive learning with external actors dependent on the evaluation of the quality of the internal resource bases.*

In our research model one structural variable is included indicating the integration of internal innovative activities.

Insert Figure 1 about here

Our major hypothesis is based on our finding that the level of interactive learning cannot be explained only with the quality of the internal resource base of innovating firms and needs to be extended with the complexity and structuration of a firm's innovative activities:

Higher levels of interactive learning are associated with the quality of the internal resource base, the complexity of innovative activities and the structuration of innovative activities.

The generality of theoretical claims

Nevertheless, we expect the relations advanced in our hypothesis to be contingent upon divergent sectoral technological dynamics as well as on the type of actors involved in the innovating firm's interactive learning. This assumption asks for a test of the generality of our theoretical claims.

To explore the generality of the theoretical claims derived from the advanced theoretical framework, we shall explore our hypotheses within four sectors derived from Pavitt (1984), within these sectors our hypotheses shall be specified for four different types of external actors (universities/research labs, the production chain, users and suppliers). The first specification of our hypothesis pertains to the external actors with which innovating firms interact.[10] The key interactions involved are between component and system producers, upstream and downstream firms, universities and industry, and government agencies and universities and industries (Nelson, 1993). Pavitt (1984), and Von Hippel (1976) stressed the role of suppliers and users. There is ample evidence that innovating firms co-operate with institutional actors in the knowledge infrastructure (Höglund & Person, 1987; Van Dierdonck, 1990; Mitchell, 1991), like universities and higher professional education. This also applies to relationships amongst competitors (Von Hippel, 1987; Kleinknecht & Reijnen, 1992; Hagedoorn & Schakenraad, 1992).

We distinguish external actors with respect to their accessibility for innovating firms, which is specified on one hand by the nature of the knowledge provided by external actors, and on the other hand by the capabilities of the innovating firm to assimilate such knowledge[11]. Universities and applied research laboratories produce complex, codified knowledge, though much of it has not been tested in industrial large scale or highly firm specific conditions. The utilisation of such scientific knowledge requires in innovation processes requires high engineering capabilities and production experience, which is unevenly distributed among firms. This implies that a number of firms are unable to assimilate such knowledge and consequently co-operation with universities is not likely. The empirical research of

[8] For the indicators, the calculation and transformation of raw scores see Annex 1, Table 2.

[9] For the indicators, the calculation and transformation of raw scores see Annex 1, Table 2.

[10] For the indicators, the calculation and transformation of Pavitt sectors see Annex 1, Table 2.

[11] For the indicators, the calculation and transformation of raw scores see Annex 1, table 2.

Nelson (1982b, 1985) stressed the linkage between basic science and innovation. The strength of the linkage between firms and other technology-generating institutions in the US appeared to be strongly differentiated. From the questioning of research managers in 650 firms it was found that all industries in the sample claimed a strong dependence on at least one field of basic or applied science while a small number of industries – drugs, semiconductors, instruments – were very dependent on a single science. However this did not mean that they had strong links with university located research. In fact, only nine industries claimed close links with academic science. Meeus, Oerlemans and Van Dijck (1999) found that the interaction frequency of innovating firms with the universities and applied research labs in the Netherlands was very low. However, in other research projects, we found that in specific technical fields (image processing, human-system interaction), Dutch universities were perceived as very important for the innovating firms, which also resulted in regular interaction (Meeus, Oerlemans and Faber, 1997; Oerlemans and Meeus, 1999).

External actors with a relatively low accessibility are customers, suppliers and competitors. There is ample evidence that innovating firms interact frequently with them in innovation projects and that they contribute significantly to innovation outcomes. In 1971 SPRU tested two hundred measures explaining the patterns of success of innovation projects in chemicals and instruments. The single measure which discriminated most clearly between success and failure was 'user needs understood' (Freeman and Soete, 1997). Teubal (1976a) found the same 'market determinateness' in the Israeli medical electronics industry. In the seminal paper of Von Hippel (1976) empirical findings were presented stressing the importance of external sources for innovation. Of a total of 44 innovation projects in scientific instruments 36 (81%) were user-dominated. He found that it was the user who: perceived that an advance in instrumentation is required; invents the instrument; builds a prototype; proves the prototype by applying it; diffuses detailed information on the value of his invention. Only when all of the above has transpired does the instrument manufacturer enter the innovation process. Typically, the manufacturer's contribution is then to: perform product engineering work on the user's device to improve its reliability, convenience of operation, etc.; manufacture, market and sell the innovative product. Interestingly, this user-dominated pattern appeared typical for innovations which were more 'basic', as well as for the minor and major improvement innovations. The user-dominated patterns described by Von Hippel also appeared to hold independent of the size - and thus, presumably, of the internal R&D potential - of the commercialising company. Finally, Von Hippel observed that the pattern of a user-dominated innovation process appears to be true for companies who are established manufacturers of a given product line - manufacturers who "ought to know" about improvements needed in their present product line and be working on them - as well as for the manufacturers for whom a given innovation represents their first entry into a new product line. Johnson (1992) reports that the Nordic Innovation Survey shows that customers are an important source of product-innovation ideas in Scandinavian firms. Universities and R&D-institutions are also frequently mentioned.

Pavitt (1984) extended the "customer active paradigm" to a broader actor set, inside and outside the firm. Compared to Von Hippel, Pavitt refined the ideas on linkages with customers to linkages within the firm stressing the role of internal departments, and between firms stressing the role of suppliers, public R&D etc. Pavitt (1984, 354) found that for supplier dominated sectors (e.g. agriculture, housing, private services, traditional manufacture) the sources of technology were suppliers, big users and research extension services. For the scale intensive sectors (e.g. bulk materials, assembly) he found that the production engineering department and (in-house) suppliers as well as the R&D department sourced innovation processes. Innovation among the specialised suppliers (e.g. machinery and instruments) was supported by the design and development department, in-house customers and users. Innovations in the science based industries (e.g. electronics/electrical, chemicals) originated in the R&D department, public science and production engineering and in-house suppliers. Over 40 percent of U.S. firms questioned claimed that suppliers of capital equipment and components were important sources of innovation inputs (Nelson, 1982). These empirical findings allow for a second qualification of hypothesis 1, which yields hypothesis 2: *effects of the quality of the internal resource base, the complexity and structuration of innovative activities on interactive learning differ dependent on the type of external actor(-s) involved.*

Pavitt's sectors differ strongly as to the nature of the process of technological change and the embeddedness of the innovation process. Pavitt (1984) showed convincingly that innovation rates differ strongly between different sectors due to distinct technological dynamics. Following Lundvall (1992) this implies a different level of complexity of innovative activities in these sectors. Pavitt also described the variety of relationships of the innovating firms with external actors as well as the contributions of internal departments to their innovative activities. His findings indeed confirm that the firms in the sector with the highest innovation rates had the largest variety of actors involved in their innovations. Empirical research confirmed the differences as to participation and R&D spending between Pavitt sectors in the Netherlands. The ranking from low to high is equal for both indicators: 1) the supplier dominated, 2) scale intensive, 3) specialised suppliers, and 4) science based industries (Vossen and Nooteboom, 1996: 165). Earlier research (Oerlemans, Meeus, Boekema, 1998) suggest that patterns of interaction with distinct external actors yield different innovation outcomes between Pavitt's sectors. In other words technological innovation is a process which occurs differently across industries and over times (Pavitt, 1984).

The *supplier dominated firms* can be found in traditional sectors of manufacturing, and in agriculture, construction and many professional, financial and commercial services. They are generally small, and their in-house R&D and engineering capabilities are weak. Consequently these sectors make only a minor contribution to their process or product technology and have relatively low innovation rates. Especially linkages with their suppliers are important sources of technology, as well as big users. The *scale intensive producers* are found in food products, metal manufacturing, shipbuilding, motorvehicles, and glass and cement. They produce a relatively high proportion of their own process technology, to which they devote a high proportion of their innovative resources. Innovating firms are relatively big and have a relatively high level of vertical technological diversification into equipment related to their own process technology. Scale intensive firms acquire their technology from external and in-house suppliers and some internal departments. The *specialised suppliers* – mechanical and instrument engineering firms – produce a relatively high proportion of their own process technology too, but the main focus of their innovative activities is the manufacturing of product innovations for use in other sectors. Innovating firms are relatively small. Specialised suppliers acquire their technology from their users and product design. The *science based industries* can be found in chemicals, oil, and electronics. These firms are relatively large, have a high R&D intensity, which is done in-house. They produce a high proportion of their own process technology, as well as a high proportion of product innovations that are used in other sectors. Science based firms have their internal R&D, production engineering, in-house suppliers and public science as technology sources. Empirical research in the chemical industry revealed that radical innovations indeed improve market success. Radical innovation has been identified as the kingpin for the evolution of technologies in both the micro- and macro-economic context, not only because it provides a model for imitation, but also because it turns out to be more profitable (Achilladelis, Schwarzkopf and Cines, 1990). These empirical findings allow for a second qualification of hypotheses 1, which yields hypothesis 3: *effects of the quality of the internal resource base, the complexity and structuration of innovative activities on interactive learning are moderated by sectoral differences in technological dynamics.*

Research design

Sample

A survey was administered to industrial firms with five or more employees in North Brabant (a province in the southern part of the Netherlands). The data gathering took place between December 1992 and January 1993.

The data gathering was performed in a region with typical features. This region is one of the most industrialised regions in the Netherlands. In 1992 the total number of jobs in manufacturing was roughly 210,000, i.e. the manufacturing sector share of employment in the region was 28.8% (The Netherlands, 19.5%). The population of firms in the region consists of a mix of small, medium-sized and large enterprises. At about 84% of the responding firms have hundred or less employees. Furthermore, the manufacturing sector has shown a relatively high R&D and export performance (Meeus & Oerlemans,1995). Because technological activity is an important issue in this article, industrial firms were grouped according to Pavitt's taxonomy (Oerlemans, 1996).

Our sample is a reliable representation of the population of industrial firms in North Brabant, in which sample strata and population strata deviated within 8% boundaries. The mean deviation between the percentages in the sample and in the response is 6.4%-points.

Insert table 1 about here

Analyses

In this paper we restrict our analyses to descriptive, exploratory analyses. Four models, within four different economic sectors, were estimated. In order to test our hypotheses OLS (Ordinary Least Square) regression analyses were applied. Because our empirical model contains dichotomous (size) as well as numeric operationalisations (R&D intensity) for resource indicators as predictor variables, the interpretation of our findings deviates from standard models containing numerical variables only.[12]

The interpretation of our findings is straightforward. For the dummy coded variable 'size'a significant positive beta of, for instance, means that large firms interact more frequently with an external actor, than the small- and medium-sized firms. A negative implies the opposite. For the numerical variables the interpretation of research findings is slightly different. Positive betas for the complexity indicators imply that higher scores - so higher levels of radicalness of innovations - co-vary with higher levels of interactive learning. Significant negative betas would mean that higher levels of complexity are associated with lower levels of interactive learning.

In our analyses we controlled for collinearity which means that different variables provide very similar information. The consequence is that the effects of individual variables are difficult to separate, which causes interpretation problems. Where collinearity occurred in the analyses, variables were excluded from the regression equation or deleted from the analysis. Control on collinearity was done using the variance inflation factor.[13]

Results

First we shall review the outcomes of our descriptive analyses. Next the results as to hypotheses 1-3 shall be reviewed for the total sample of innovating firms supplying industrial users. Subsequently the outcomes of analyses within Pavitt sectors are reviewed separately. By comparing the outcomes of five models within one sector, the differences between modes of interactive learning can be revealed. Subsequently a cross-sectoral comparison is made between interactive learning with users, suppliers, universities and the production chain. This allows for an assessment of the moderating effects of sectoral dynamics on the relation of complexity, resource base and structure of innovative activities with the level of interactive learning.

Descriptive statistics

Insert figure 2 about here

As a general result (Figure 2) the innovation process of the local firms seems to be affected most by internal departments, customers and suppliers. Neither the intermediary organisations, nor the public knowledge infrastructure have strong relations with the innovating firms.

Interactive learning in the total sample

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[12]The least-square regression model can easily be extended to accommodate dichotomous predictors, including sets of dummy variables (Menard,1995: 5; Harnett, 1982: 571-575). With the dichotomous predictors for size, the intercept and the slope have a special interpretation compared to numerical variables measured at interval, or ratio level. It is still true that the intercept is the predicted value of the dependent variable when the independent variable is coded 1 (<=100 employees) but with only two groups the intercept now is the mean innovation outcome for the group coded as 1. The slope is still the change in the dependent variable associated with one-unit change in the independent variable, but with only two categories; that value becomes the difference in the mean scores in the criterion variable (level of interactive learning) between the first (sme's <=100 employees) and second group (large firms > 100 employees.). The sum of the slope and the intercept is therefore the mean score the level of interactive learning for the second group (large firms).

[13]This quantity is called the variance inflation factor (VIF) since the term is involved in the calculation of the variance of the i^{th} regression coefficient (Norusis 1990). The formula is: $VIF_i = 1/(1-R_i^2)$

Table 2[14] displays the findings on hypothesis 1 and 2 for the total sample of innovating firms. Hypothesis 1 is not supported by our findings in Table 2. The explained variances of the five estimated models are relatively low (.07-.22). Whereas no model contained significant bèta's for every type of independent variable (complexity, resource base and structuration indicators). By and large, resource indicators in combination with the structuration of innovative activities predicted the level of interactive learning.

Hypothesis 2 is confirmed partially. Interactive learning of innovators with their customers and suppliers did not differ and was significantly affected only by the structuration of innovative activities (Table 2, model 3 and 4). Model 1, 2 and 5 yielded a different set of indicators with significant bèta's. The interactive learning of innovating firms with the universities and applied research centres (Table 2, model 1) is induced by higher levels of problemistic search, a higher percentage of higher educated employees and large size firms. The number of innovation problems and the structuration of innovative activities affect the level of interactive learning within the production chain (Table2, model 2). A higher level of integration of innovative activities, and a lower number of higher educated employees affected the level of interactive learning of innovators with their competitors.

Moderating effects of Pavitt sectors on levels of interactive learning

The overall results displayed in Table 3 to 6 show that hypothesis 3 is strongly confirmed. Sectoral technological dynamics indeed moderated the relation between complexity, the quality of the internal resource base, the level of integration and the levels of interactive learning. First, the R^2 in Table 3 to 6 for the cross sectoral OLS regression analyses are largely higher than in Table 2 displaying the analyses for the total sample. We estimated twenty models, and in fifteen models the explained variance was higher. Second, compared to the predictors significantly contributing to the explanation of interactive learning for the total population (Table 2, model 1-5), the predictors affecting the levels of interactive learning differed in seventeen of the twenty estimated models.

A closer inspection of the differences of sectoral patterns of *interactive learning with different actors* revealed the following patterns. The *level of interactive learning of innovators, universities and research centres (Table 3 to 6, model 1)*, was affected by three resource based indicators and two complexity indicators. In the supplier dominated industries, size positively affected interactive learning with the knowledge infrastructure. The R^2 had a range between .08 (science-based firms) and .29 (scale intensive firms). We expected that this model fitted best with Pavitt's findings on the science-based industries, which was not the case.

The level of interactive learning within the production chain (forward with customers/users, backward with suppliers and horizontal with competitors) was affected significantly by resource indicators (size, number of innovation problems, percentage higher educated employees), the complexity of innovative activities (twice radicalness of innovations, level of problemistic search), and the level of integration of innovative activities (four times) (Table 3-6, model 2). The highest R^2 was found in the supplier-dominated firms (.42), which fits the logic of Pavitt's findings. Though supplier dominated firms are generally low-tech, they are strongly oriented towards their big users and suppliers (Pavitt, 1984: 355).

The level of interactive learning between innovating firms and their customers (Table 3-6, model 3) was associated with a higher quality of resource bases (twice the percentage higher educated employees), with more complex innovative activities (radicalness of innovation, problemistic search) and tight integration of innovative activities. The highest proportion of explained variance (.43) was found in the specialised suppliers, which is indeed a sector where firms have to be specialists in customisation. The lowest proportion explained variance (.09) was found in the scale intensive firms producing bulk products, which does not rely on close and intensive contacts with customers, because customers are predominantly price sensitive.

Interactive learning between innovating firms and their suppliers (Table 3-6, model 4) turned out to be associated with the quality of the resource base (percentage of higher educated employees), the complexity (twice radicalness of innovation) and structuration of innovative activities (three times). The models for the supplier-dominated and the science-based firms yielded the highest explained variance, an R^2 of .34. This is not consistent with Pavitt's findings, which suggests that this model should perform the best in the supplier- dominated industries.

Interactive learning of innovating firms and their competitors (Table 3-6, model 5) was determined by firms' resource base (size), the complexity of innovative activities (radicalness of innovation twice) and the structuration of innovative activities (twice). The range of the R^2 of these models varied between .11 (science-based firms) and .21 (specialised suppliers).

The comparison of the interactive learning with distinct external actors shows some interesting differences. The integration of innovative activities had no impact on interactive learning with universities and research centres, whereas it turned out to be the most consistent impact in the interactive learning with the other actors. The indicators predicting the levels of interactive learning between innovators and universities and research labs turned out to differ strongly from those in the other four models.

The extended resource based model turns out to predict best the interaction of innovating firms with their production chain. It yielded the largest number of significant predictors, and the highest R^2's. Whereas the interactive learning of innovating firms with their competitors was predicted worst with our predictors. It yielded the smallest

[14] See Annex 2 for Tables 2 – 6.

number of significant predictors, one insignificant model (science-based firms, Table 6, model 5) and the lowest R^2's. Compared to the results achieved with the estimation for the total sample, the cross sectional analyses for Pavitt sectors refined our ideas about interactive learning with different actors.

A comparison of Pavitt sectors

The most remarkable differences between the Pavitt sectors are:

1. that the interactive learning of specialised suppliers is determined the most by the quality of the internal resource base (three times the % higher educated employees, and size one time).
2. that the interactive learning of scale intensive firms is negatively affected by the radicalness of innovation, whereas it impacted positively on interactive learning in the other sectors.
3. that the impacts of the quality of the internal resource base are very scarce in the science-based industries.

Discussion and conclusions

Despite the numerous publications on networks, learning and interactive learning, the review studies of technological collaboration this study clearly shows that interactive learning is anything but automatic. The main conclusion from our exploratory analyses for the total sample is that:

- our results showed that the resource- and structure based perspective were confirmed for interactive learning with most actors, whereas the complexity-based perspective was only confirmed for the interactive learning between innovators and the knowledge infrastructure. So hypothesis 1 was weakly confirmed.
- the comparison of interactive learning with distinct external actors revealed that patterns of significant predictors differed except for suppliers and customers. This implied a partial confirmation for hypothesis 2.

Our decomposition of the total sample in Pavitt sectors, controlling for divergent technological dynamics by and large confirmed hypothesis 3:

- the explanatory power of our models in general improved. This implies that at the sectoral level we found stronger support for hypothesis 1 than at the level of the total sample. Except for R&D intensity and innovative search, all the indicators included in the model contributed to the explanation of the level of interactive learning.
- patterns of predictors explaining levels of interactive learning differed with distinct external actors involved. This implies that at the sectoral level we found stronger support for hypothesis 2 than at the level of the total sample.

Our findings indicate convincingly: 1) that the augmented resource-based model of interactive learning performed well, but 2) that the explanation of interactive learning should be done at the sectoral level, for distinct types of external actors. Controlling for differences in technological dynamics and divergent patterns of embeddedness enhances interpretation of the results and improves results as well.

In general it is interesting that our findings confirm Cohen and Levinthal's (1990) ideas on absorptive capacity. Firms with external linkages tend to have more prior related knowledge, a higher quality of internal resources in our terms. Conversely, resource deficits in general did not account for the level of interactive learning of innovating firms. It is interesting that interactive learning in some sectors (specialised suppliers) is determined particularly by the quality of internal resources, whereas interactive learning in the science-based firms is determined more by their problemistic search.

Our findings indicate several things. First, since moderation effects of Pavitt's sectors were prevalent future research should continue to make cross-sectional analyses. Second, except R&D intensity and innovative search, all the indicators included in the model contributed to the explanation of the level of interactive learning. It might be the case that these variables were excluded because there are non-linear relations with interactive learning. Future research should pursue non-linear analyses. Third the mixed signs of radicalness of innovation shows – negative in the scale intensive firms, positive in specialised suppliers – that particularly lower levels of complexity invoke interactive learning in specific sectors. Fourth, similar indicators explain the interactive learning between innovating firms and customers, suppliers, and competitors within sectors. This suggests that there is a general logic underlying the interactive learning within the production chain. Here it would be helpful to include the reasons for choosing specific types of co-operation, which would allow for a further qualification of patterns of interactive learning. Fifth the indicators predicting interactive learning with universities and research laboratories are distinct from those in the other four models. This implies that interaction within the production chain follows a different logic, compared to the interactive learning with universities and research labs. Again, our augmented resource-based model would need further extension, particularly with respect to the types of knowledge needs that led to the search for and utilisation of external knowledge bases.

Another important research direction is to compare regions with respect to their connectivity. By comparing external linkages of innovating firms within several comparable regions, we may tease out the effects of networking on regional competitiveness. Furthermore, given the low utilisation of regional resources in this specific region, we suggest research focusing on the comparison of strategies for the acquisition of distinct resources and their relative contributions to innovative performance. This allows us to support the efficiency of network strategies, as well as the efficacy of regional innovation systems more solidly.

Although we contend that the results of this study provide a valuable addition to the micro-foundations of innovation and organisation theory, several cautions should be noted. First, because we studied a specific region, with a specific population of predominantly small- and medium sized firms. Second, because the way we controlled for sectoral differences is multidimensional (size, embeddedness, technological dynamics) it is unclear how this precisely affects our outcomes. So, this demands further specification of control variables. Finally, we did not control for so-called interaction effects, and concentrated on the main effects of our independent variables. Hence, our analyses don't allow us to trace interaction effects between the independent variables.

References

Achilladelis, B., A. Schwarzkopf, M. Cines, 1990, The dynamics of technological innovation: the case of the chemical industry. Research Policy, 19, pp. 1-34.

Alter, C., J. Hage, 1993, Organizations working together. Newbury Park: Sage Publications.

Arrow, K.J., 1962, The economic implications of learning by doing. Review of Economic Studies, 29, pp. 155-173.

Baldwin, W.L., Scott, J.T., 1987, Market structure and technological change. London: Harwood Academic Publishers.

Boisot, M.H., 1995, Is your firm a creative destroyer? Competitive learning and knowledge flows in the technological strategies of firms. Research Policy, 24, pp. 489-506.

Cohen, W.M., Levin, R.C., 1989, Empirical studies of innovation and market structure, in: Schmalensee, R., Willig, R.D. (eds.), Handbook of industrial organisation, Amsterdam: Elsevier Science Publishers, pp. 1060-1170.

Cohen , W.M., D.A.Levinthal, 1990, Absorptive capacity. Administrative Science Quarterly, 35, pp. 128-152.

Cohendet, P., J.A. Héraud , E. Zuscovitch, 1993, Technological learning, economic networks and innovation appropriability. In: Foray, D., C. Freeman, 1993, Technology and the wealth of nations. The dynamics of constructed advantage. London: Pinter Publishers, pp. 66-76.

Cooke, P., M. Gomez Uranga, G. Extebarria (1997), 'Regional innovation systems: Institutional and organisations dimensions'. In: Research Policy, 26, pp. 475-491.

Cook, K.S., R.M. Emerson, 1984, Exchange networks and the analysis of complex organizations. Research in the sociology of organizations, 3, pp. 1-30.

Cook, K.S., 1977, Exchange and power in networks of interorganizational relations. Sociological Quarterly, 18, pp. 66-82.

Cyert, R.M., March, J.G., 1963, A Behavioral Theory of the Firm. Englewood Cliffs, New Jersey: Prentice Hall Inc.

DeBresson, C., F. Amesse, 1991, Networks of innovators: a review and introduction to the issue. Research Policy, 20, pp. 363-379.

Dierdonck, R. van , 1990, University - industry relationships: How does the Belgian Academic community feel about it ? In: Research Policy, 19, pp. 551 - 566

Freeman, C., L.Soete, 1997, The economics of innovation (London: Pinter).

Galaskiewicz, J., 1985, Interorganizational relations. Annual Review of Sociology, 11, pp. 281-304.

Gregersen, B., B. Johnson, 1997, Learning Economies, Innovation Systems and European Integration. *Regional Studies*, 31, pp. 479-490.

Hage, J., C. Alter, 1994, A typology of interorganizational relationships and networks. In: J.R. Hollingsworth, R. Boyer, Contemporary capitalism. The embeddedness of institutions. Cambridge: Cambridge University Press, pp. 94-126.

Hagedoorn, J., J. Schakenraad. - Leading companies and networks of strategic alliances in information technologies. - In: Research Policy 21 (1992), P. 163-190

Håkansson, H., 1987, Industrial technological development: A network approach. London: Croom Helm.

Håkansson, H., 1989, Corporate Technological Behavior: Co-operation and Networks. London : Routlegde.

Hergert, M., D. Morris, 1988, Trends in international collaborative agreements. In: Contractor, F., P. Lorange, (Eds.), Cooperative strategies in international business. Lexington, MA: Lexington Books, pp. 99-109.

Höglund, L and O. Persson., 1987, Communication within a national R&D - system: A study of iron and steel in Sweden. In: Research Policy 16, pp. 29 - 37

Jin, D.J., R.R. Stough, 1998, Learning and learning capability in the Fordist and post-Fordist age: an integrative framework. Environment and Planning A, 30, pp. 1255-1278.

Kleinknecht, A., J.O.N. Reijen., 1992, Why do firms cooperate on R&D? An empirical study. -In: Research Policy 21, pp. 347-360

Knaap, G.A. van der, B.J.L. Tortike, 1991, Regional economic interaction patterns between enterprises; a case study of the Northern Netherlands. - In: - Complexes, formations and networks / Eds.: M. de Smidt, E. Wever. - Netherlands Geographical Studies, 132. - Utrecht: Faculty of Geographical Sciences University of Utrecht, 1991. pp. 111-124

Krolis, H.P., D.J.F. Kamann., 1991, Economic growth potential of an industrial complex: the case of the Dutch Flemish Canal.. In: Complexes, formations and networks / Eds.: M. de Smidt, E. Wever. - Netherlands Geographical Studies, 132. - Utrecht: Faculty of Geographical Sciences University of Utrecht, 1991. - P. 53-67

Lam, A., 1997, Embedded firms, embedded knowledge: problems of collaboration and knowledge transfer in global cooperative ventures. Organization Studies, 18, pp. 973-996.

Lawrence, P.R., J.W. Lorsch, 1967, Organization and environment: managing differentiation and integration. Cambridge, Mass.: Harvard Graduate School of Business Administration.

Litwak, E., L.F. Hylton, 1962, Interorganizational analysis: a hypothesis on co-ordination agencies. Administrative Science Quarterly, 5, pp. 217-256.

Lundvall, B.A., 1992, User-producer relationships, national systems of innovations and internationalisation. In: Foray, D., C. Freeman, 1993, Technology and the wealth of nations. The dynamics of constructed advantage. London: Pinter Publishers, pp. 277-300.

Lundvall, B.A., 1993, User-producer relationships, national systems of innovation and internalization. In: Lundvall, B.A., 1993, National systems of innovation. Towards a theory of innovation and interactive learning.London: Pinter Publishers, pp. 45-67.

Maillat, D. (1991), 'The Innovation Process and the Role of the Milieu.' In: E. Bergman, G. Maier, F. Tödtling (eds.), *Regions Reconsidered: Economic Networks, Innovation and Local Development in Industrialized Countries*, pp. 103-117. London/New York: Mansell Publishing Limited.

Meeus, M.T.H., L.A.G. Oerlemans, 1993, Economic Network Research: a methodological state of the art. In: Beije, P., J. Groenwegen, O. Nuys (eds.), Networking in Dutch Industries, 1993, Leuven/Apeldoorn: Garant.

Meeus, M.T.H., L.A.G. Oerlemans, 1995, The competitiveness of firms in the region of North-Brabant. In: Beije, P., O. Nuys (eds.) , 1995, The Dutch Diamond. The usefulness of Porter in analyzing small countries. Leuven/Apeldoorn: Garant/Siswo, pp. 223-256.

Meeus, M.T.H., L.A.G. Oerlemans, J.J.J. van Dijck, 1999, Interactive learning within a regional system of innovation. A case study in a Dutch region. In: Boekema, F., K. Morgan, S. Bakkers, R. Rutten, Knowledge, innovation and economic growth. The theory and practice of learning regions. Cheltenham: Edward Elgar Publishers Ltd. (forthcoming).

Mezias, S.J., T.K. Lant , 1994, Mimetic learning and the evolution of organizational populations. In: Baum, J.A.C., J.V. Singh (eds.), Evolutionary dynamics of organizations, New York: Oxford University Press, pp. 179-198.

Mitchell, W. - Using academic technology: Transfer methods and licensing incidence in the commercialization of American diagnostic imaging equipment research, 1945 - 1988. -In: Research Policy 20 (1991), P. 203 - 216

Morgan, K. (1997), 'The Learning Region: Institutions, Innovation and Regional Renewal'. In: Regional Studies, vol. 31.5, pp. 491-503.

Nelson, R., 1982, The role of knowledge in R&D efficiency, Quarterly Journal of Economics, 97, pp. 453-470.

Nelson, R. (ed.), 1993, National Innovation Systems. A comparative analysis. New York: Oxford University Press.

Nielsen, R., 1988, Cooperative strategy. Strategic Management Journal, 9, pp. 475-492.

Oerlemans, L.A.G., M.T.H. Meeus, F. Boekema, 1998, Do networks matter for innovation. Journal of Social and Economic Geography, 3, pp. 298-309.

Oerlemans, L.A.G., 1996, De ingebedde onderneming: innoveren in industriële netwerken. Tilburg: Tilburg University Press. [The embedded firm. Innovation in industrial networks.]

Pavitt, K., 1984, Sectoral patterns of technical change. Towards a taxonomy and a theory. Research Policy, 13, pp. 343-373.

Pfeffer, J., G.R. Salançik, 1978, The external control of organizations: A resource dependence perspective. New York: Basic Books.

Smith, K. (1995), 'Interactions in knowledge systems: foundations, policy implications and empirical methods'. In: STI Review, no. 16, OECD, pp. 69-102.

Tushman, M.L., P. Anderson, 1986, Technological discontinuities and organizational environments. Administrative Science Quarterly, 31, pp. 439-465.

Vossen, R.W., B. Nooteboom, 1996, Firm size and participation in R&D. In: Kleinknecht, A., 1996, Determinants of innovation. The message form new indicators. London: MacMillan Press Ltd., pp. 155-168.

Von Hippel, E., 1976, The dominant role of users in the scientific instrument innovation procees, in: Research Policy, 5, pp. 212-239.

Von Hippel, E., 1987, Cooperation between rivals: Informal know-how trading. In: Research Policy, 16 (1987), pp. 291 – 302.

Figures

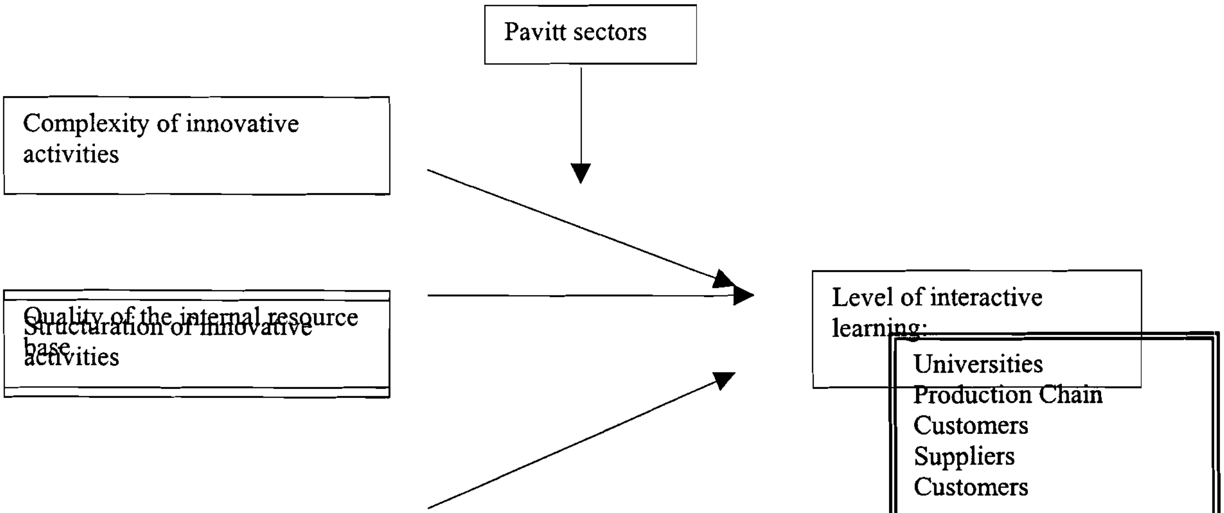
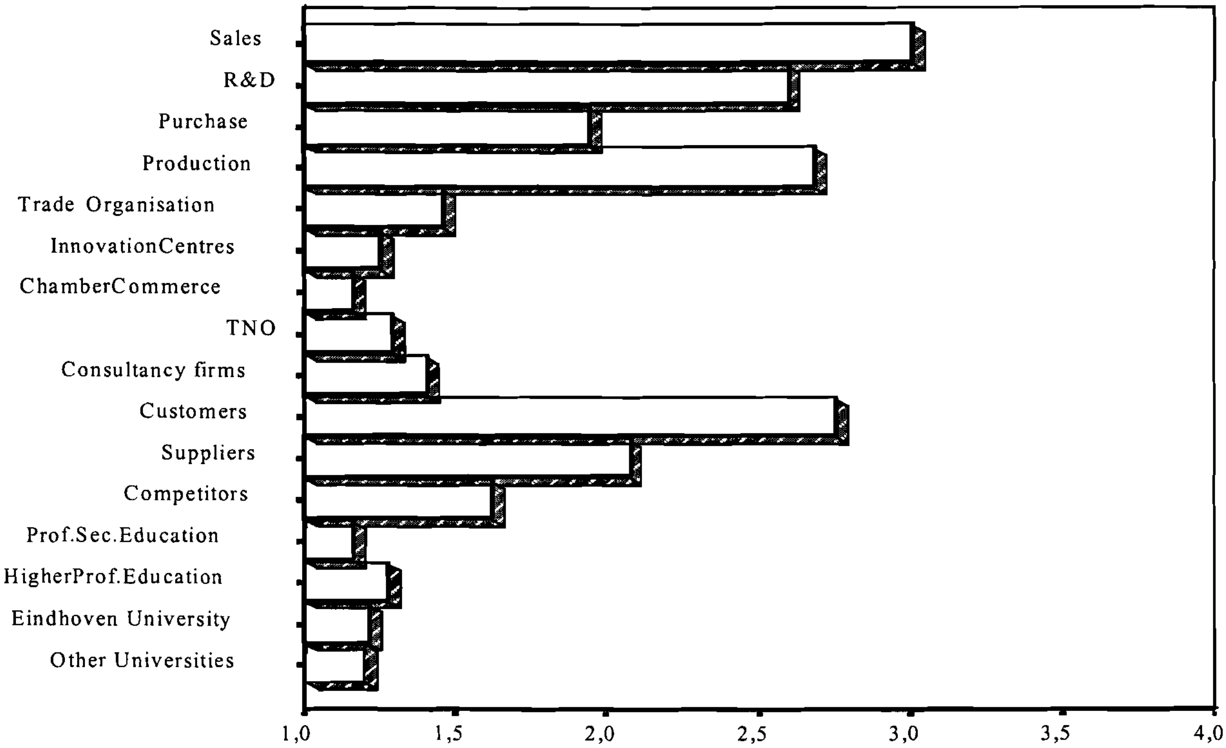


Figure 1 A research model of the relation between interactive learning of innovating firms with divergent actors, the complexity of innovative activities, the quality of the internal resource base and the structuration of innovative activities and the moderator effects of sectoral technological dynamics.


Sales
R&D
Purchase
Production
Trade Organisation
InnovationCentres
ChamberCommerce
TNO
Consultancy firms
Customers
Suppliers
Competitors
Prof.Sec.Education
HigherProf.Education
Eindhoven University
Other Universities
1,0
1,5
2,0
2,5
3,0
3,5
4,0

f

Annex 1

Table 1 Measurement of the dependent variable: level of interactive learning

Definition, name of variable	**Indicators, range of scores**
Level of interactive learning: the frequency in which external actors contributed to the innovation proces(-ses) of the responding firm.	The innovating firms were asked to report whether the following actors contributed to their innovation processes by bringing up ideas, or participate actively. The respondents could score their contribution in terms of frequencies ranging from 1) never, 2) sometimes, 3) regularly, 4) often, 5) always. Trade Organisations, Regional Innovation Centres, Chambers of Commerce, National Centre for Applied Research (TNO), Consultancy Firms, Professional Secundary Education, Higher Professional Education, Eindhoven University of Technology, Other Universities, Important Buyers, Important Suppliers, Competitors. *Interactive learning with universities and research laboratories* pertained to: Eindhoven University of Technology, Other Universities, and the National Centre for Applied Research. *Interactive learning within the production chain* pertained to: Important buyers, important suppliers and competitors. Raw scores were averaged. Range 1-5. Subsequently the average score were standardised into z-scores. *Interactive learning with customers* pertained to "important buyers". *Interactive learning with suppliers* pertained to "important suppliers". *Interactive learning with competitors* pertained to "competitors". Raw scores were standardised into z-scores.

Table 2 Measurement of one control variable (Pavitt sectors) and the independent variables (complexity of innovative activities, the quality of the internal resource base, the structure of the innovative activities).

Definitions, name of variables		**Indicators, calculation of scores, range**
Sector in which firm is active:	*Pavitt sectors*	1. Supplier-dominated :agriculture, housing, private services, traditional manufacture 2. Scale intensive: bulk materials, assembly 3. Specialised Suppliers: machinery and instruments 4. Science-based: electronics, electrical, chemicals
Complexity of innovative activities	*Problemistic search* : the extent into which firms innovate due to deficiencies in products and processes	Reasons to innovate were: 1. to solve technical product deficiencies 2. to solve technical production problems Firms could respond to a 5-point Likert scale of frequencies ranging from: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. Raw scores were averaged. Range 1-5.
	Innovative search: the extent into which firms innovate due to technical or market opportunities	Reasons to innovate were: 1. discovery of new market needs 2. technical idea, invention Firms could respond to a 5-point Likert scale of frequencies ranging from: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. Raw scores were averaged. Range 1-5.
	Radicalness of innovations the extent into which firms alter product and/or process features	Firms could answer: 1. incremental improvement of product features 2. radical change of product features Range is 1 (incremental) – 2 (radical). Firms could answer: 1. incremental improvement of production features 2. radical change of production features. Range is 1 (incremental) – 2 (radical).
The quality of the internal resource base	*R&D intensity*	The number of employees working full-time on R&D as a percentage of the total workforce. Range 0 –100.
	% higher educated employees	The percentage of higher educated employees of the total workforce. Range 0-100.
	Size	We applied a dummy coded variable: (1) small- and medium sized firms <=100 employees, (2) large firms >100 employees.
	Number of innovation problems	A count of confirmative answers was made to items as to different types of innovation problems: exceeding time planning, product deficiencies, technical production deficiencies, exceeding budgets, bad timing, wrong partners, reaction of competitors, insufficient market introduction efforts. Range 0-8.
Structure of the innovative activities	*The level of integration of internal innovative activities*	An average score of the extent into which internal departments contributed to the firm's innovation projects. It concerned: the R&D, marketing and sales, purchase and production department. Firms could respond to a 5-point Likert scale of frequencies ranging from: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. Raw scores were averaged. Range 1-5.

Tables

Table 1 Population and sample divided in Pavitt sectors

Pavitt sector	Population (%, N)	Total Sample (%, n)	Sample of Innovating Respondents
Supplier Dominated	33.5% (1.028)	25.7% (149)	22.9% (92)
Scale Intensive	41.1% (1.261)	36.1% (209)	34.1% (137)
Specialised Suppliers	13.6% (478)	21.4% (124)	22.1% (89)
Science Based	11.8% (363)	16.8% (97)	20.1% (84)
Total	100% (3.069)	100% (579)	100% (402)

Annex 2

Table 2 OLS regression of Interaction Frequency of innovating firms with external actors on indicators of complexity of innovative activities (radicalness of innovation, innovative search, problemistic search) , indicators of the firms knowledge base (R&D intensity, % higher educated employees, size, learning problems) and one structural variable (the level of integration) for the total sample of firms supplying industrial users.

Dependent variableΨ Independent variables ∴		Model 1 Interaction frequency with Universities and Centre for Applied Research	Model 2 Interaction frequency with Production Chain	Model 3 Interaction frequency with Customers	Model 4 Interaction frequency with Suppliers	Model 5 Interaction frequency with competitors
Complexity of innovative activities	Radicalness of innovation	-.03	.01	.01	.04	.04
	Level of innovative search	.10	.04	.05	-.00	.10
	Level of problemistic search	.19***	.09	.06	.05	.04
Quality of the resource base	R&D intensity	-.02	.01	.12	.00	-.04
	%higher educated employees	.16**	.03	.12	.00	-.14**
	Size	.14**	-.14	-.11	-.12	-.01
	Number of innovation problems	.00	.14**	.07	.05	.13
Structure of innovation	Level of integration of inn. act.	.10	.40****	.37****	.38****	.19***
	R^2	.08	.22	.18	.16	.07
	F- value	5.77	18.99	15.45	19.79	5.39
	Sign.	.001	.000	.000	.000	.001
	D.f.	3, 204	3, 205	3, 212	2, 211	2, 205
	Listwise N	208	209	216	214	207

*p #.10, ** p# .05, *** p#.01, **** p#.001

Table 3 OLS regression of Interaction Frequency of innovating firms with external actors on indicators of complexity of innovative activities (radicalness of innovation, innovative search, problemistic search) , indicators of the firms knowledge base (R&D intensity, % higher educated employees, size, learning problems) and one structural variable (the level of integration) in Supplier Dominated firms.

Dependent variableΨ Independent variables ∴		Model 1 Interaction frequency with Universities and Centre for Applied Research	Model 2 Interaction frequency with Production Chain	Model 3 Interaction frequency with Customers	Model 4 Interaction frequency with Suppliers	Model 5 Interaction frequency with competitors
Complexity of innovative activities	Radicalness of innovation	.05	.36****	.48****	.26*	.00
	Level of innovative search	.21	.11	.01	-.06	.20
	Level of problemistic search	.12	.04	.01	.15	-.04
Quality of the resource base	R&D intensity	-.02	-.09	.06	-.03	-.12
	%higher educated employees	-.11	-.13	-.11	-.06	-.12
	Size	.35**	-.01	-.07	-.12	.24*
	Number of innovation problems	.02	.05	-.09	-.01	.08
Structure of innovation	Level of integration of inn. act.	.06	.43***	.17	.35**	.32**
	R^2	.12	.42	.23	.34	.19
	F- value	5.18	14.53	13.17	7.32	4.72
	Sign.	.021	.000	.001	.000	.014
	D.f.	1, 42	2, 40	1, 44	3, 42	2, 40
	Listwise N	44	43	46	46	43

*p #.10, ** p# .05, *** p#.01, **** p#.001

Table 4 OLS regression of Interaction Frequency of innovating firms with external actors on indicators of complexity of innovative activities (radicalness of innovation, innovative search, problemistic search) , indicators of the firms knowledge base (R&D intensity, % higher educated employees, size, learning problems) and one structural variable (the level of integration) in Scale Intensive firms.

Dependent variableΨ Independent variables ∴		Model 1 Interaction frequency with Universities and Centre for Applied Research	Model 2 Interaction frequency with Production Chain	Model 3 Interaction frequency with Customers	Model 4 Interaction frequency with Suppliers	Model 5 Interaction frequency with competitors
Complexity of innovative activities	Radicalness of innovation	-.13	-.25**	-.13	-.25**	-.27**
	Level of innovative search	.17	.04	-.08	.06	.10
	Level of problemistic search	.22**	.14	.03	.14	.20*
Quality of the resource base	R&D intensity	-.05	-.03	-.04	-.03	-.12
	%higher educated employees	.47****	-.13	-.11	-.14	-.11
	Size	.07	-.30***	-.21	-.19	-.11
	Number of innovation problems	.05	.31***	.16	.12	.24*
Structure of innovation	Level of integration of inn. act.	.19	.40****	.30***	.30***	.26**
	R^2	.29	.35	.09	.16	.14
	F- value	12.31	7.92	6.33	5.89	5.19
	Sign.	.000	.000	.014	.005	.008
	D.f.	2, 61	4, 60	1, 63	2, 62	2, 62
	Listwise N	64	65	65	65	65

*p #.10, ** p# .05, *** p#.01, **** p#.001

Table 5 OLS regression of Interaction Frequency of innovating firms with external actors on indicators of complexity of innovative activities (radicalness of innovation, innovative search, problemistic search) , indicators of the firms knowledge base (R&D intensity, % higher educated employees, size, learning problems) and one structural variable (the level of integration) in Specialised Suppliers.

Dependent variableΨ Independent variables ∴		Model 1 Interaction frequency with Universities and Centre for Applied Research	Model 2 Interaction frequency with Production Chain	Model 3 Interaction frequency with Customers	Model 4 Interaction frequency with Suppliers	Model 5 Interaction frequency with competitors
Complexity of innovative activities	Radicalness of innovation	.28**	.14	-.14	.14	.46****
	Level of innovative search	.06	-.11	.01	-.02	-.04
	Level of problemistic search	.13	-.09	.01	.02	-.01
Quality of the resource base	R&D intensity	-.15	.03	.07	.02	.20
	%higher educated employees	.01	.32**	.32***	.35***	-.22
	Size	.31**	-.22	-.06	-.17	-.16
	Number of innovation problems	-.01	.08	.01	-.03	.21
Structure of innovation	Level of integration of inn. act.	.05	.41***	.66****	.23	.08
	R^2	.27	.31	.43	.12	.21
	F- value	8.80	6.79	19.53	6.99	12.53
	Sign.	.001	.001	.000	.011	.001
	D.f.	2, 48	3, 46	2, 52	1, 50	1, 48
	Listwise N	51	50	55	53	50

*p #.10, ** p# .05, *** p#.01, **** p#.001

Table 6 OLS regression of Interaction Frequency of innovating firms with external actors on indicators of complexity of innovative activities (radicalness of innovation, innovative search, problemistic search) , indicators of the firms knowledge base (R&D intensity, % higher educated employees, size, learning problems) and one structural variable (the level of integration) in Science Based firms.

Dependent variableΨ Independent variables ∴		Model 1 Interaction frequency with Universities and Centre for Applied Research	Model 2 Interaction frequency with Production Chain	Model 3 Interaction frequency with Customers	Model 4 Interaction frequency with Suppliers	Model 5 Interaction frequency with competitors
Complexity of innovative activities	Radicalness of innovation	-.27	-.11	-.18	-.15	.05
	Level of innovative search	.15	.18	.17	.07	.11
	Level of problemistic search	.28**	.40***	.42****	.16	.24
Quality of the resource base	R&D intensity	.23	.10	.09	.07	-.04
	%higher educated employees	.03	.07	.32***	-.07	-.16
	Size	-.25	-.15	.01	-.17	-.05
	Number of innovation problems	-.03	.05	.01	.08	-.01
Structure of innovation	Level of integration of inn. act.	.17	.30**	.20	.51****	-.10
	R^2	.08	.33	.29	.34	.11
	F- value	4.52	11.86	9.70	12.76	.616
	Sign.	.045	.000	.000	.000	.759
	D.f.	1, 49	2, 48	2, 48	2, 49	8, 42
	Listwise N	51	51	51	51	51

*p #.10, ** p# .05, *** p#.01, **** p#.001