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Patterns of interactive learning in a high-tech region

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Patterns of Interactive Learning in a high-tech Region

An empirical exploration of an extended resource-based model.

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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 public knowledge infrastructure and the production chain. Our research question is: Why do innovating firms engage in interactive learning? 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 induces higher levels of interactive learning.

In order to test the generality of our theoretical claims we estimate four models predicting: 1) the level of interactive learning of innovating firms with the public knowledge infrastructure (universities and research centres), 2) the level of interactive learning of innovating firms with their customers (here the innovating firms are the producers), 3) the level of interactive learning of innovating firms with their suppliers (here the innovating firms are the customers), 4) the level of interactive learning with competitors. These analyses allow for a comparison of the antecedents of interactive learning with different external actors. We control for linear as well as non-linear effects of the complexity of innovative activities, and for the effects of sectoral technological dynamics.

Our findings show that antecedents of patterns of interactive learning differ widely and are contingent upon the type of actors and sectoral technological dynamics. A highly differentiated pattern of interaction between the quality of the resource base and the complexity of innovative activities was found.

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.

The objective of this paper is to study interactive learning building on the work in the national systems of innovation literature (Lundvall 1993; Nelson 1993: 15; Edquist 1997: 21). Edquist (1997) contends that '...it is important to be able to capture the interdependencies in empirical work – which includes the development of concepts and indicators that relate elements to each other. Quantification is important. This is needed for the development of a more sophisticated, systemic and interactive view of the innovation process.' And this what this paper intends to do.

In addition we want to broaden the theoretical discussion of the antecedents of interactive learning, because it is anything but automatic. First, if given the option, most organisations would prefer to establish a minimum number of inter-organizational relationships inasmuch as these relations can constrain their subsequent action (Galaskiewicz 1985: 282; Alter and Hage 1993; Hage and Alter, 1997). Given managers' preference for autonomy and maximum discretionary power one could call this a autonomy – dependency dilemma. Second, it is well known 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 be effectively articulated, transferred and utilised (Von Hippel 1987; Lam 1997). Third, interactive learning implies knowledge transfer between organisations, which encourages imitation and diminishes the rents of innovation (Kogut and Zanders 1992). Why would innovating firms engage in interactive learning?

In this paper we develop a theoretical model for the interactive learning synthesizing the resource-based organisation theory in economics and sociology (Pfeffer and Salançik 1978; Håkansson 1987; Wernerfelt 1991; Barney 1991), with elements of the knowledge based theories on networks and learning (Cohen and Levinthal 1990; Lundvall 1992; Kogut and Zander 1992; Grant 1996; Edquist 1997; Hage and Alter 1997; Jin and Stough 1998; Teece and Pisano 1998). In contrast with the resource based theory where firms' internal activities, as well as the structuring of innovative activities are conflated with resources we add the *complexity and structuring of innovative activities inducing the search and utilisation of external resources*. Both, the nature of innovative activities as well as the integration and embeddedness of internal innovative activities determine the extent to which innovating firms have to draw upon external knowledge bases and hence develop external relations. The complexity perspective argues that growth of knowledge yields more elaborate production and innovation processes, and also the growth in the number of monitored external environments, both of which exponentially augment 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 Powell 1992; Hage and Alter, 1997). The extended theoretical framework shall be explored at the level of firms for four different types of external actors (universities/research labs, users, suppliers and competitors).

Our theoretical effort adds to the growing body of literature on innovation systems, interactive learning and organizations and performs several functions. First, whereas much empirical literature focuses on dyadic relations of innovating firms with either its competitors, or universities, or its customers or suppliers, we include them all in our analyses. 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 in the innovation literature does not make an explicit theoretical argument for the level of interactive learning (Meeus and Oerlemans, 1993).

The structure of our paper is as follows. First, we describe the components of our theoretical framework. This yields a research model, a clarification of the measurement of levels of interactive learning, the complexity of innovative activities, the quality of the internal resource base and the structuring of innovative activities, and a set of testable propositions. The next section describes the research design including the sample and the analytical procedures. Subsequently, our results are described. Finally, we discuss these results and derive some theoretical and policy inferences.

Theoretical framework

We begin with an elaboration of the distinct dimensions of interactive learning. Next our basic premise with respect to the explanation of levels of interactive learning is developed. It builds on an important deficit of resource-based organization theories, because they conflate resources, the nature and structuring of innovative activities.

Interactive learning

Although the notion of user-producer interaction had been introduced in the seventies (Von Hippel 1976; Teubal 1976), the concept of interactive learning – the dependent variable in our research model - was introduced by Lundvall (1985, 1992) in the innovation literature. The level of interactive learning between the innovating firms and external actors focuses on the access to and acquisition of knowledge from external actors in order to innovate products and/or processes to sustain firms' competitiveness. We concentrate on the processual aspects of innovation networks because it lacks a theoretical explanation, and because we reported on the structural aspects of the relations between innovating firms and external actors like e.g. proximity, formalization, and the longevity of the relation elsewhere (Oerlemans and Meeus, 1995: 99-104, Oerlemans et. al. 1999).

Three related, but distinct dimensions of interactive learning, namely the actor-set, interaction and learning are the focus of our discussion.

Whereas Lundvall (1985) restricted the interactive learning to user-producer interaction, we expect that the process of interactive learning is contingent on the type of actors involved. Therefore we extend the actor-set engaged in interactive learning. The focal actor is specified as innovating firms in a Dutch high-tech region, who were asked to report on their levels of interactive learning with four distinct external actors: universities and centres for applied research, customers, suppliers and competitors. This extension of the actor-set allows for a further qualification of the process of interactive learning because the access to resources of universities, research centres and competitors compared to the access to suppliers and customers demands distinct monitoring and absorptive capabilities on the part of the innovating firms. Our dependent variable – level of interactive learning – determines to what extent innovating firms obtained information from these distinct external actors.

Social interaction is defined as a sequence of situations where the behaviours of one actor are consciously reorganized by, and influence the behaviours of another actor and vice versa (Turner 1988: 14). In the context of innovation these reciprocal impacts of actor's behaviours are specified in two ways (Lundvall 1992). 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 level of interaction was measured by asking the innovating firms to rate the contact frequency between the innovating firms and the external actors. Furthermore the measure captures the level of reciprocity between innovating firms and external actors, indicating on the one hand the contacts initiated by external actors, and on the other hand the contacts initiated by the innovating firms.

The learning dimension of interactive learning was measured in terms of the contents of the transferred knowledge that supplement the innovating firm's knowledge base (Dodgson 1993) and augments the range of its potential behaviours (Huber 1991; Stough and Jin 1998). The indicators fit these learning definitions and measured the extent into which external actors actively contributed to the innovating firms' innovations, either by external actors' active participation in or by their contribution of ideas to the innovation process of the innovating firm (for the items see Annex, Table 1). Another dimension of learning - the output of the learning process - is left out of the analyses, because in Oerlemans et. al. (1998) we already reported a positive impact of learning in networks and innovation results.

Resources

Theoretical explanations for the emergence of business networks, innovation networks, and accordingly interactive learning are dominated by resource based theories (Pfeffer and Salançik 1978; Håkansson 1987; Cohen and Levinthal 1990). The basic premise of resource dependence theory is that organizations are open systems. From this it follows that organization (1) are not self-sufficient; (2) cannot generate all the necessary resources internally; and (3) must mobilize resources from other organizations in their environments if they are to survive. To acquire the necessary resources involves interacting with other organizations that control these critical resources (Pfeffer and Salançik 1978: 25-28).

The central tenet of the resource-based approach is that performing product or process innovations, induces firms to draw on its internal and external environment and is forced to pool all knowledge resources conducive to innovation. The heterogeneity of the resources involved in innovation urges firms to monitor actively their resource bases, particularly their knowledge base 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, 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 as well as the ability of external actors to supplement there resource deficits or shortages (Håkansson, 1987; Lundvall, 1992, Hage and Alter, 1997, Tödtling, 1994).

With regard to the resources involved in innovation, scholars have different opinions. Håkansson (1987) and Smith (1995) defined resources broadly 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. Hage and Alter (1997) and Cohen and Levinthal (1990) argue that the ability to evaluate and utilise outside knowledge – firms' absorptive capacity - is largely a function of prior related knowledge. In our research model we restrict the measurement of the quality level of the resource-base to knowledge-based indicators and a size indicator. The quality of the resource base contains three different knowledge-based indicators for the quality of the internal resource base: R&D intensity (Baldwin and Scott 1987; Cohen and Levinthal 1990), percentage of higher educated workforce (Kleinknecht and Reijnen 1992; Jin and Stough 1998). The third indicator measures the number of problems firms experienced during their innovation projects (Meeus et. al. 1996). The fourth indicator - size of the firm (Baldwin and Scott, 1987; Cohen & Levin, 1989; Vossen and Nooteboom, 1996) – is a proxy for the a firm's ability to invest in innovation (See Annex, Table 2 for the items and calculations of resource indicators).

The quality of the resource base can be related in several ways to the level of interactive learning with external actors. The most straightforward resource based proposition is that an innovating firm detects resource deficits and therefore searches access to complementary resources through interaction with external actors (Aiken and Hage 1968: 930).

P1a A lower quality of the internal resource base increases the level of interactive learning with external actors, all else equal.

This proposition can be qualified in several ways, for the quality of the resource base enables more in depth monitoring of internal and external deficits and opportunities, which can counteract in multiple ways. For example, a higher quality allows firms to solve specific resource deficits more easily, and it augments its monitoring capacity, allowing a more in depth analysis of the internal resource base, as well as a more in depth analysis of external resource stocks. This implies that despite a relatively high quality of the internal resource base, a firm can be pushed toward interactive learning because specific opportunities are detected.

An important issue is whether there are thresholds in a firm's ability to detect and solve specific resource deficits, as well as to the detection of external opportunities for complementing their resource deficits. The reasoning is as follows: firms with a moderate quality of their resource base are more likely to detect knowledge deficits, they are also more likely to be unable to solve these problems themselves, and they have a higher chance of detecting external opportunities extending their behavioural repertoire. This yields the second and non-linear resource-based proposition:

P1b Firms with a moderate quality of their resource base are probably more inclined toward higher levels of interactive learning than firms with a low or high quality resource base.

Complexity of innovative activities

The first reason to extend the resource-based explanation on interactive learning is that resource dependency theorists disregard firms' activities, because resources and activities are conflated. Wernerfelt (1984: 172) defines a resource as 'anything which could be thought of a strength or weakness of a given firm'. Barney (1991: 101) defines firms' resources as including all assets, capabilities, organizational processes, firm attributes, information, knowledge, etc. controlled by a firm that enables the firm to conceive of and implement strategies that improve its efficiency and effectiveness. Theoretically resources have a dual function as enablers of strategies, and as organizational practices and strategies. Although the deployment of strategic planning, training, controlling and co-ordinating systems can be considered as a resource compared to a situation in which such systems are absent, this analytical conflation of activities and resources hampers the explanation of resource utilisation and the detection of resource deficits. Our contention is that firms' entrepreneurial activities enable the utilisation of resources, and the disclosure of specific resources' strategic value e.g. more intelligent training systems, co-ordination systems, systems of strategic planning , innovative activities are geared to utilise its resources better and add strategic value to a firm's resource stock.

Both Lundvall (1992), and Alter and Hage (1997) advanced an explanation for interactive learning in which especially the complexity of innovative activities is the key variable. Lundvall (1992) defines innovation as an informational commodity that is transitory (Cohendet, Héraud & Zuscovitch 1993). This makes the acquisition and protection of information essential in order to profit from the innovation, which explains the emergence of linkages as well as the importance of control. Particularly when a firm intends process or product innovations, this demands close co-operation between users and producers, because users provide the required information for the producers. 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. In tandem with the growth of scientific and applied knowledge this 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, 1997).

We distinguished three dimensions of complexity of innovative activities, which were combined in one compound independent variable. Following Lundvall, the first dimension of complexity was radicalness of innovation, because of its enormous impacts on the existing communication codes and patterns of expectation of users and producers. Two other dimensions we discern pertain to search behaviours in different stages of the innovation process. In the pre-innovation stage complexity pertains to innovative search activities (Mezias and Lant, 1994). 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 (for the items see Annex, Table 2). Uncertainties exist with respect 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.

In 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, 120); they 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 of a product or process is below aspiration level (for the items, see Annex Table 2). These three dimensions of complexity of innovative activities induce the monitoring of resources and as such enlarge the chance of finding resource deficits, which on its turn affects the likelihood of interactive learning. The general proposition derived from the complexity argument is as follows:

P2a More complex innovative activities induce higher levels of interactive learning (Evan 1993: 230).

As was the case with resource based propositions, the relation between complexity and interactive learning could be either linear or non-linear. The non-linear analysis tests whether there is curvilinear relation - U-shaped or inverted U-shaped – between complexity of innovative activities and interactive learning. The argument is that innovative activities with low complexity probably do not require high levels of interactive learning, because mutual expectations remain stable. Firms are more inclined to perform extremely complex innovative activities within organizational boundaries because a firm's reputation might get damaged if external actors would find out, or because interaction increases the risk of imitation. Hence, in this case the level of interactive learning is probably not increased. The firms initiating innovations with moderate levels of complexity comparatively are more likely to detect problems they cannot solve themselves, simultaneously the risk of damaging reputations is lower than with extremely high complexity levels, which induces a comparatively high level of interactive learning. This yields the following proposition:

P2b Firms performing innovation projects with moderate levels of complexity are more inclined to higher levels of interactive learning than firms performing innovative activities with low or high levels of complexity.

The interaction between complexity of innovative activities and the quality of the resource base.

Actually a synthesis of the resource-based and the activity-based explanation for interactive learning yields a more comprehensive theoretical argument. We contend that the complexity of the innovative activities determines whether the quality of the internal resource base is sufficient and therefore determines the level of interactive learning. More complicated innovative activities draw more heavily on a firm's resource base than routine distribution activities with lower complexity, hence they reveal resource deficits or shortages and affect the level of interactive learning. This yields the following proposition:

P3a The effect of the quality of the resource base on the level of interactive learning is moderated by the complexity of the innovative activities.

Also for this proposition the issue of linearity or non-linearity is explored. We expect that moderate levels of complexity and moderate quality of the resource base in tandem are associated with highest levels if interactive learning. The argument runs parallel with the arguments pertaining to proposition 1b, and proposition 2b.

P3b Firms combining moderate levels of complexity of innovative activities with a moderate quality of their resource base are more inclined to interactive learning than firms with low or high scores on the interaction term.

Structure of innovative activities

A final extension of the resource-based perspective on interactive learning concerns the conflation of resources and structures. This conflation of resources with the structuring of organizations contrasts strongly with the newer versions of the resource-based theories like the knowledge-based theory of Cohen and Levinthal (1990), Kogut and Zander (1992), Grant (1996) and Teece and Pisano (1998). Without exception these authors stress the significance of organizational structuring enhancing relationships between knowledge sharing and knowledge diversity across individuals and departments and plants. The pooling of internal departments' innovative activities becomes more important in case of a higher complexity of innovative activities (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; Teece and Pisano 1998: 198-200; Dougherty 1992: 179). In the systems of innovation literature a new aspect of the organizational structuring of knowledge resources is advanced: the embeddedness of innovating firms in so-called bridging institutions. These organisations are interfacing units that link innovating firms to external actors and facilitate information and technology transfer, as well as technological collaboration (Galli and Teubal 1997: 356-357).

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. To the extent that an innovating firm has developed linkages with bridging institutions their external monitoring capacity grows considerably. For instance technology centres (innovation centres in the Netherlands) link industry to the outside world and to the university providing both information services. The promoting agents may be the central government, but also new agents like regional authorities, trade or industrial associations, chambers of commerce, etc.

Following this line of reasoning the structuring of innovative activities has an internal and an external dimension. Accordingly, we measured integration of internal innovative activities with the extent that internal department contribute to firm's innovation process. The external dimension - the level of support by bridging institutions – was measured with the frequency in which chambers of commerce, industry associations and innovation centres contributed to the innovating firms' innovation process (for the items see Annex, Table 2).

P4 *Both, a higher integration of internal innovative activities, and more support of bridging institutions induce a higher awareness of external as well as internal knowledge bases and therefore increase the chance of higher levels of interactive learning.*

Insert Figure 1 about here

The generality of our claims

The theoretical model we have developed is probably contingent on several factors one would like to control for, because they limit the generality of our claims.

The first contingency is the type of actors engaged in interactive learning. For example universities differ with respect to their accessibility, as well as their organizational structures, and their relations within the production chain compared to customers. So we expect that the antecedents of interactive learning differ between innovating firms and universities, customers, suppliers and competitors. Accordingly we discerned four types of actors and estimate separate models for each of them. The second contingency is the enormous difference between sectoral technological dynamics. The discontinuous nature of technological change indeed calls for a qualification of our 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. 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 when technological dynamics alter. Therefore, we control for sectoral technological dynamics by distinguishing between high-tech sectors – the so-called science based industries (e.g. electronics, chemical industry) and the specialised suppliers (instruments) – and low-tech sectors (the so-called supplier dominated and scale intensive industries e.g. building and construction, textile and leather) which are dominated by economies of scale. Pavitt's (1984) research revealed that the technological change between the high-tech and low-tech sectors differs significantly. 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 et. al. 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).

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 region of North Brabant has features that differ widely from agricultural regions (Zeeland Groningen and Drente), and service oriented regions like Zuid- en Noord-Holland. For example this region is in the Dutch context considered as a high-tech region where multinational enterprises Philips, DAF trucks, Royal Dutch Shell, Akzo Chemical, DSM, former Fokker (aircrafts) and Fuji have plants, and which contains important medium-sized niche international players like ASM Litography, OCE and Rank Xerox (copiers), ODME (optical discs equipement), Ericsson, EMI (cd's), General Plastics etc. Brabant's industrialization started in ca. 1850 and was based on traditional industries like dairy industries, textile and wool industry. Also the Brabant region has two universities, and three innovation centres. A strong group of key players in internationalized industries and its location near important distribution centres like Rotterdam and Antwerpen make this region highly attractive for foreign direct investment.

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 and 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. Because there is no empirical research that developed the same models one has to be cautious with generalizing the findings. In order to test our hypotheses OLS (Ordinary Least Square) hierarchical regression analysis was applied in four models. Model 1 explores the antecedents of the interactive learning with the Public knowledge infrastructure; model 2 pertains to the interactive learning with customers; model 3 pertains to the interactive learning with suppliers and model 4 pertains to the interactive learning with competitors.

In order to test the moderating effects of complexity on the relation between the quality of the resource base and the level of interactive learning, in each separate model the independent variables were added in four steps (Cohen and Cohen 1975; Miller and Droge 1986; Stone and Hollenbeck 1989). We checked for change in variance and F-values. In order to find main effects of the resource based and complexity variables we included complexity and complexity squared in the first step. In the second step we included the quality of the resource base and resource base squared. In the third step the cross-product term of complexity and the quality of the resource base and its square were included in the model. In the final step the structuring variables were included in the model. In order to check for the non-linearity we included in each model squared terms for complexity, quality and their interaction term.

The interpretation of our research findings differs for the linear and the non-linear hypothesis. The variables interactive learning, complexity of innovative activities, the quality of the resource base, the cross-product term of complexity and the quality of the resource base, and the structuring of innovative activities were coded from low scores to high. So positive betas signify that higher scores on the independent variables are associated with higher levels of interactive learning. E.g. positive betas for the complexity indicators imply that higher complexity of innovative activities 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.

To control for non-linearity we included squared terms for the quality of the resource base, the complexity of innovative activities and their cross-product term. For the squared variables the interpretation is as follows. A beta with a positive sign means that the relation between that independent variable and the level of interactive learning is U-shaped. So, low and high scores on the independent variable are associated with high levels of interactive learning, and the moderate score on that independent variable is associated with low levels of interactive learning. A negative beta signifies an inverted U-shaped relation between independent and the level of interactive learning. In this case moderate scores on the independent variable are associated with high levels of interactive learning, and low and high scores on the independent variable are associated with low levels of interactive learning.

Finally, it is important to notice that if the linear proposition is confirmed and the control for non-linearity yields significant betas, than the findings on the linear hypothesis become irrelevant. The same goes for the identification of moderating effects. If one or two of the main effects are significant and the test of moderation is also significant, that would support our theory that higher complexity of innovative activities would affect the magnitude of the relation between the quality of the resource base and the level of interactive learning.

Results

First we shall review the outcomes of our descriptive analyses. Next the results as to hypotheses 1-4 shall be reviewed for the total sample of innovating firms. Subsequently the contingencies affecting the antecedents of interactive learning are reviewed to test the generality of our claims.

Descriptive statistics

Insert table 2 about here

Table 2 shows that the focal firms are engaged in interactive learning most with customers and suppliers, whereas the public knowledge infrastructure and the competitors seem to be involved only incidentally (Meeus et.al. 1999a). The quality of the internal resource base varies strongly. Its frequency distribution is skewed to the right, which indicates an overrepresentation of small- and medium sized firms, with relatively low R&D intensity, and low percentages of higher educated employees. The complexity of innovative activities has a moderate level. In general the level of integration of internal innovative activities is moderate. The support of bridging institutions to the focal firms' innovations is relatively low.

A test of the extended resource-based model of interactive learning.

Insert Table 3 about here

Table 3 presents the results of our hierarchical regressions testing for the main effects – linear and non-linear – of the complexity of performed innovations, the quality of the resource base, their interaction effects and the effects of structuring of innovative activities on levels of interactive learning. We consider confirmation or rejection of the linear propositions 1a to 4a only if there are no indication for non-linearity.

Since support was found for a non-linear relation our findings as to proposition 1a – a higher complexity of innovative activities induces higher levels of interactive learning – yields no relevant information. Proposition 1b - moderate levels of complexity of innovative activities induce relatively higher levels of interactive learning – is never supported by our findings and in one case it is rejected (Table 3, model 4). The beta for complexity squared is negative which means that higher and lower levels of complexity induce higher levels of interactive learning than moderate levels of complexity. These results show that the main effects of the complexity of innovative activities on the levels of interactive learning were opposite to proposition 1b. Accordingly propositions 1a and 1b must be rejected.

Proposition 2a –lower quality of the internal resource base induces higher levels of interactive learning -is confirmed for the competitors (Table 3, model 4) and rejected for the interactive learning with suppliers (Table 3, model 3). Higher levels of interactive learning with suppliers turned out to be induced by a higher quality of the internal resource base. Proposition 2b – a moderate quality of the internal resource base induces higher levels of interactive learning – is confirmed (beta for quality of internal resource base squared is 3.22, p. # .001). Our findings provide only partial support for proposition 2b. There is more support for the linear than for the non-linear resource-based proposition, although the association between the quality of the resource base and the level of interactive learning is double-edged. These findings reject Cohen and Levinthal's (1990) linear ideas on absorptive capacity. Firms with external linkages can have more prior related knowledge as well as extremely low levels of prior related knowledge, a higher and a lower quality of internal resources in our terms.

Our findings revealed that proposition 3a – effects of the resource base on the level of interactive learning are moderated by the complexity of the innovative activities - is confirmed for the interactive learning with the public knowledge infrastructure (b = .97, p # .10). For the other external actors (Table 3, model 2-4) the interaction of complexity of the innovative activities and the quality of the internal resource base has a non-linear relation with the level of interactive learning. Proposition 3b is rejected for the suppliers. So, moderate levels of the squared cross-product of complexity and quality of resources are associated with lower levels of interactive learning (b = 1.03, p# .05). For the interactive learning with the customers and the competitors proposition 3b is confirmed. The betas are negative, which means that compared to low and high levels of the squared cross-product of complexity and quality of the resource base moderate levels have significantly higher levels of interactive learning. For the customers (b = -3.37, p # .01) the effect is stronger than for the competitors (b = -1.10, p # .10), but for both external actors the moderate scores on the squared cross-product of the interaction effects are associated with higher levels of interactive learning.

Overall, these findings provide support for the linear version of our proposition about the moderating effects of complexity on the relation between the quality of the internal resource base and the level of interactive learning. Again, however, the support for the non-linear proposition 3b is ambiguous. This suggests that firms are pulled into interactive learning by other firms because of their complementary resources and activities, or by the monitoring of external opportunities.

Our findings revealed partial support for proposition 4 – better structuring of innovative activity induces higher levels of interactive learning. The effect of the level of integration of innovative activities and the level of interactive learning is only supported for interactive learning with the competitors (b = .15, p # .05). The effect of the level of support by bridging institutions on the level of interactive learning are significant in three of four models (interactive learning with public knowledge infrastructure, suppliers and competitors) but was not confirmed for the interactive learning with customers (Table 3, model 2).

These results show that internal pooling of resources impacts less on the level of interactive learning than the support given by bridging institutions. The signs of the significant betas were as expected. It is interesting that in case of interactive learning with competitors both the integration of innovative activities (b = .15, p # .05) and the support of bridging institutions (b = .16, p # .01) impacted significantly. Whereas in case of the interactive learning with the customers neither of these variables had significant impacts. This finding suggests that interactive learning with customers is more routinized and nested in economic transactions, in contrast to interactive learning with competitors which is out of the realm of routinized behaviour.

The generality of our claims.

The relations we proposed between the complexity of innovative activities, the quality of the internal resource base, the structuring of innovative activities and the level of interactive learning turned out to be very actor-specific. Some striking differences are highlighted. The level of interactive learning with the Public knowledge infrastructure was neither affected by the quality of the resource base, nor by the complexity of innovative activities, or by their squared terms, whereas these factors did affect interactive learning with other external actors. For the customers, suppliers and competitors, we found a non-linear effect of complexity*quality of the knowledge base, whereas it was linear for the public knowledge infrastructure. A comparison of interactive learning with customers and suppliers yields striking contrasts. For the customers, a non-linear relation was found between the quality of the resource base, while it was linear for the suppliers. As to the interactive learning with customers an inverted U-shaped relation was found for the cross-product of complexity and quality of the resources, whereas this relation was U-shaped for the suppliers. For the interactive learning with the customers the bridging institutions were irrelevant, whereas they significantly affected the interactive learning with the suppliers.

In the regression analyses we controlled for *direct* effects of sectoral technological dynamics. The Pavitt-dummy significantly affected the level of interactive learning with competitors (b = -.14, p #.01). This means that the supplier-dominated industries and the scale intensive industries have significantly higher levels of interactive learning than specialized suppliers and science based firms.

In other analyses, not included here (Tables are with the authors), we controlled for *indirect* effects of sectoral technological dynamics, by estimating levels of interactive learning for the supplier-dominated industries, the scale intensive industries, the specialized suppliers and science based industries separately. We found strong indications for large sectoral differences, some of which we will discuss. The antecedents of interactive learning with customers diverged strongly between the scale intensive industries and the specialised suppliers. The squared term of complexity of innovative activities significantly affected the level of interactive learning with customers among specialized suppliers (b = 2.91, p #.10), whereas it had no effects in the scale intensive industries. For the specialized suppliers the level of interactive learning was positively affected by the quality of the internal resource base (b = 4.96, p # .05), while for innovating firms in the scale intensive industries the level of interactive learning was negatively affected by the quality of the internal resource base (b = -5.62, p # .10). The moderating effects of complexity of innovative activities on the relation between the quality of the resource base and the level of interactive learning also were the exact opposite in the two industries (b = 6.47, p # .10 for the scale intensive industries, and b = -7.12, p # .01 for the specialized suppliers). The same contrast between the scale intensive industries and the specialised suppliers was found for the interactive learning with the public knowledge infrastructure. Again, however some of the significant betas for the squared terms were positive, contrary to our expectations. This finding suggests that there are not only push-effects that motivate firms to interactive learning, but also pull-effects in which case interactive learning is initiated by external actors, or by the detection of external business opportunities.

Overall these findings provide strong support for effects of contingencies – type of external actor and sectoral technological dynamics – on the explanation of levels of interactive learning.

Discussion and conclusions

This study provides evidence suggesting that a singular resource-based explanation for the level of interactive learning is insufficient. Including the complexity argument in our theoretical model improved the theoretical argument to some extent. Yet, three significant main effects of the quality of the internal resource base and one significant main effect of complexity on interactive learning suggest that the empirical confirmation for our expanded theoretical argument is rather poor. Stronger support for the flaws in the resource-based account for interactive learning can be derived from the repeated occurrence of significant effects of the cross-product of the complexity of innovative activities and the quality of the resource base on levels of interactive learning and the significant effects of structuring of innovative activities on interactive learning.

In particular, our data show that the impacts of the quality of the resource base on the level interactive learning is moderated by the complexity of innovative activities. These moderating effects were found in different modes – linear and non-linear, U-shaped and inverted U-shaped – and were prevalent in the interactive learning with all external actors. This yields the unique situation that we can make a general conclusion as to the moderating effects of complexity of innovative activities on the relation between the quality of the resource base and interactive learning. While simultaneously we have to stress the variability of these moderating effects because of its distinct forms contingent on the type of external actor involved and the sectoral technological dynamics. Our findings indicate convincingly: 1) that the augmented resource-based model of interactive learning performed well, but 2) that the explanation of interactive learning vary as a function of sectoral technological dynamics as well as on the type of external actors involved in the interactive learning.

The strong variety in the level of interactive learning with distinct external actors observed in our data and the contingency of patterns of interactive learning upon sectoral technological dynamics (Meeus et. al. 1999b), contrasts heavily with the generality of the notion of interactive learning in the systems of innovation literature (Edquist 1997). Our findings suggest that there is not one avenue for initiating interactive learning between the enormous variety of actors involved in the innovation process. Practically speaking, it may be possible to change levels of interactive learning by investing in a highly skilled workforce and in pooling social and technical disciplines by means of intelligent organizational designs and project management. Yet, this will probably yield other effects on the level of interactive learning with the customers, than on the interactive learning with the public knowledge infrastructure, and it will work out differently in distinct industrial sectors. For future research this implies that interactive learning should be qualified by including a broad variety of actors, and by distinguishing industrial sectors.

In assessing the contribution of our study, caution is needed because there is no comparable research available that empirically tested levels of interactive learning. Also caution should be exercised because an important control variable - regional economic difference - was not included here. As described in our sample section this region has specific features, that in tandem with a consensus driven Dutch regulatory style might induce very distinct patterns of interaction between business partners. A strategy for dealing with this problem might be a comparison of external linkages of innovating firms within several comparable regions. 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.

One of the puzzles revealed by our findings is the multiple effects of resource bases, the complexity of innovative activities, and the structuring of innovative activities. Additionally, future research should develop direct measures for monitoring capacity, the detection of external business opportunities to enable a differentiation between the multiple impacts of the quality of the resource base and to untangle the way they counteract each other’s effects on the level of interactive learning. For the complexity of innovative activities it would be useful to develop measures indicating the variety of disciplines involved in innovation projects. The measurement of the structuring of innovative activities could also be specified in terms of distinct types of project management with distinct ways of pooling resources.

The findings reported here highlight the importance of theory comparison and of an integrative approach to interactive learning as a fruitful avenue to develop the theoretical foundations for systems of innovations. Researchers engaged in organizational studies of innovation may no longer unintendedly ignore one class of variables at the expense of other important variables like sectoral technological dynamics, or the complexity and structuring of innovative activities.

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Annex

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

Definition, name of variable	**Indicators, range of scores**
Level of interactive learning with universities and research laboratories	The sum of two items for Eindhoven University of Technology, Other Universities, and the National Centre for Applied Research: (1) the firms were asked to report if they actively acquired information from these external actors, and (2) the firms were asked to report how often the external actors contributed to their innovation processes by bringing up ideas, or participate actively. For item 1 the respondents could score (0) no (1) yes. For item 2 answers were coded (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. The range of the variable was between 3-18.
Level of interactive learning with customers	The sum of scores on three items: (1) the firms were asked how often their customers contributed to their innovation processes by bringing up ideas, or active participation, (2) the firms were asked to rate the contact frequency with customers, and (3) the firms were asked how often they transferred knowledge to customers. For item 1 answers were coded: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. For item 2 the answers were coded: (1) daily, (2) weekly, (3) monthly, (4) once per quarter, (5) once per six months. For item three the answers were coded in the same way as for item 1. The range of the variable was between 3 and 15.
Interactive learning with suppliers	The sum of scores on three items: (1) the firms were asked how often their suppliers contributed to their innovation processes by bringing up ideas, or active participation, (2) the firms were asked to rate the contact frequency with their suppliers, and (3) the firms were asked how often their suppliers transferred knowledge to them. For item 1 answers were coded: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. For item 2 answers were coded: (1) daily, (2) weekly, (3) monthly, (4) once per quarter, (5) once per six months. For item three the answers were coded in the same way as for item 1. The range of the variable was between 3 and 15.
Interactive learning with competitors	The score on one item. The firms were asked to report whether their competitors contributed to their innovation processes by bringing up ideas, or active participation. For this item the answers were coded: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. The range of the scores varied between 1 and 4.

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 structuring of innovative activities).

Definitions, name of variables		**Indicators, calculation of scores, range**
Sector technological dynamics	*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: the sum of scores on problemistic search, innovative search and radicalness of innovation. Range 2-14.	*Problemistic search* : the extent into which firms innovate due to deficiencies in products and processes	How often did your firm innovate: 1. to solve technical product deficiencies 2. to solve technical production problems Answers were coded: (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	How often did your firm innovate, because of: 1. discovery of new market needs 2. technical idea, invention Answers were coded: (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	The sum of product and/or process innovations. For process and product innovations answers were coded: (0) no innovations, (1) incremental improvement production or process features, (2) radical change of production of process features. Range 0-4.
The quality of the internal resource base: the sum of four indicators. Range 3-2006.	*R&D intensity*	The percentage of employees working full-time on R&D.
	% higher educated employees	The percentage of higher educated employees of the total workforce.
	Size	The number of full-time 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.
Structuring of the innovative activities. Here the separate indicators were used.	*The level of integration of internal innovative activities*	The sum of the frequency with which the R&D, marketing and sales, purchase and production department contributed to the firm's innovation projects. Answers were coded: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. Range 4-20.
	The level of support by Bridging Institutions	The sum of the frequency with which trade association, innovation centres and chambers of commerce contributed to the firm's innovation projects. Answers were coded: (1) never, (2) sometimes, (3) regularly, (4) often, (5) always. Range 3-15.

Figure

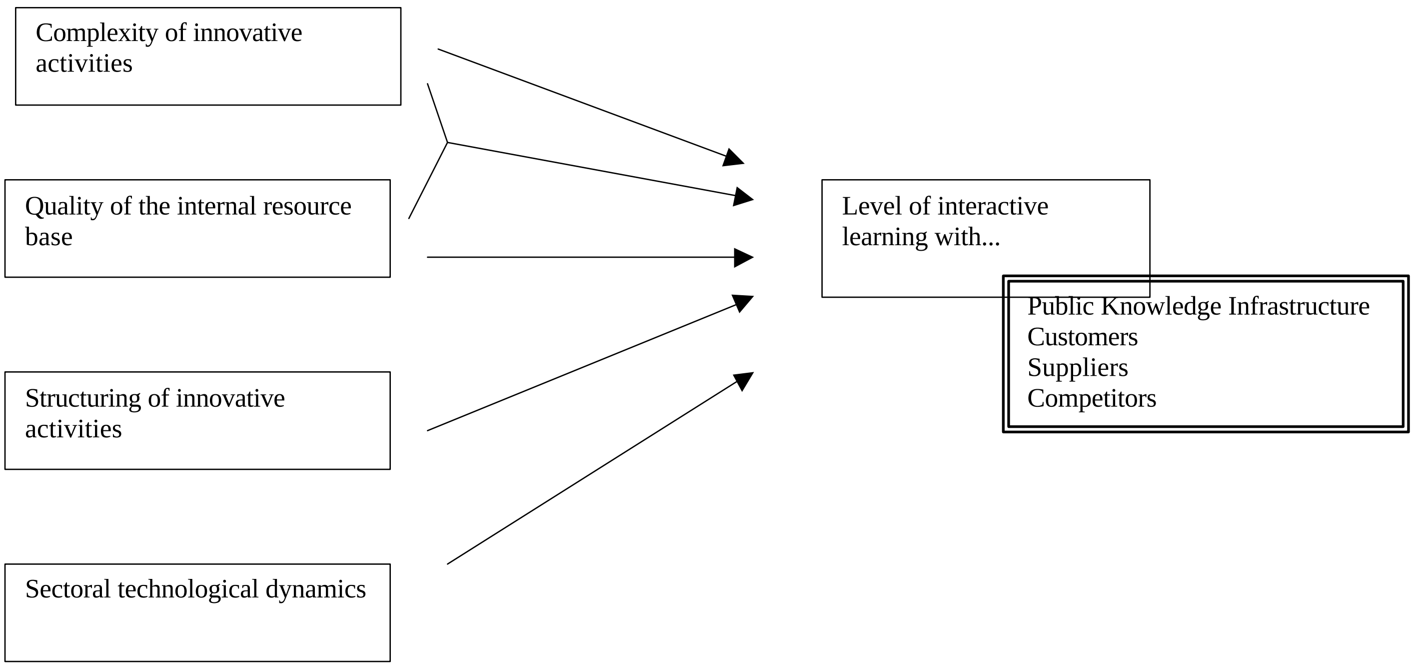

Figure 1 A research model of the relation between interactive learning of innovating firms with divergent actors, the complexity of innovative activities, the quality of the internal resource base and the structuring of innovative activities and the moderator effects of sectoral technological dynamics.

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)
Specialized 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)

Table 2 Descriptive statistics

Variables		Mean Scores	s.d.	Correlation of independent variables with distinct dependent variables			
Level of interactive learning with:				1 Public Knowledge Infrastructure	2 Customers	3 Suppliers	4 Competitors
1	Public Knowledge Infrastructure	4.76	1.95				
2	Customers	7.90	1.80				
3	Suppliers	8.47	1.83				
4	Competitors	2.59	0.71				
5	Quality of the internal resource base	87.42	152.08	.40****	.14***	.12**	-.00
6	Complexity of innovative activities	7.55	2.13	.23****	.22****	.10*	.18****
7	Cross-product term of quality of resources and complexity	837.09	1441.86	.32****	.15***	.16***	.05
8	Level of integration of internal innovative activities	10.30	2.63	.14****	.15***	.13**	.21****
9	Level of support by bridging institutions	3.83	1.19	.20****	.01	.24****	.19****

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

Table 3 OLS regression of Interactive Learning of Innovating Firms with external actors on complexity of innovative activities, the firms internal resource base and the structuring of the innovation process..

Dependent variable Ψ	Interactive learning of innovating firms with ….	Model 1 Public Knowledge Infrastructure	Model 2 Customers	Model 3 Suppliers	Model 4 Competitors
Independent variables ∴					
Complexity of innovative activities	Complexity	.16	-.10	-.10	.59*
		(.55)	(-.28)	(-.28)	(1.91)
	Complexity^2	-.11	.10	.44	-.66*
		(-.39)	(.27)	(1.25)	(-2.20)
Quality of the internal resource base	Quality internal resource base	-.31	-2.29****	2.19****	-1.50***
		(-.57)	(-3.28)	(3.73)	(-2.51)
	Quality internal resource base^2	.01	3.22****	-.58	.87
		(.03)	(4.27)	(-1.12)	(1.33)
Interaction effects	Complexity*Quality Internal resource Base	.97*	2.34***	-2.55****	1.60***
		(1.64)	(2.96)	(-3.68)	(2.70)
	Complexity*Quality Internal resource Base^2	-.52	-3.37***	1.03**	-1.10*
		(-.97)	(-4.20)	(2.24)	(-1.76)
Structuring of innovative activities	Level of integration of innovative activities	.04	.11	.07	.15**
		(.67)	(1.55)	(.93)	(2.44)
	Level of support by Bridging Institutions	.28****	-.08	.20***	.16***
		(5.21)	(-1.41)	(2.87)	(2.88)
Sector	Pavitt dummy	-.06	.06	-.07	-.14***
		(-1.20)	(.94)	(-.99)	(-2.57)
	R^2	.20	.12	.14	.14
	F- value	8.26	3.25	3.52	5.14
	Sign.	.000	.001	.000	.000
	D.f.	9, 299	9, 215	9, 201	9, 290
	Listwise N	309	225	211	300

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