Patterns of Interactive Learning in a High-tech Region*

Marius T.H. Meeus, Leon A.G. Oerlemans, Jerald Hage

Marius T.H. Meeus, Leon A.G. Oerlemans
ECIS, Faculty of Technology Management, Eindhoven University of Technology, The Netherlands

Jerald Hage
University of Maryland, Washington, USA

Abstract

This paper aims at developing a theoretical framework that explains levels of interactive learning. Interactive learning is defined as the exchange and sharing of knowledge resources conducive to innovation between an innovator firm, its suppliers, and/or its customers. Our research question is: Why do levels of interactive learning of innovator firms, their customers, and/or suppliers vary? Our theoretical framework combines a resource-based perspective with an activity-based account of interactive learning. It starts with a resource-based argument, which is specified by introducing competing and complementary theoretical arguments such as the complexity and structuring of innovative activities, and sectoral technological dynamics. The strength of internal knowledge resources can either hamper or facilitate levels of interactive learning. We assume that more complex innovative activities urge firms to co-ordinate and exchange information between users and producers, which implies a higher level of interactive learning. The structuring of innovative activities, as well as sectoral technological dynamics can foster interactive learning.

To test our theoretical claims, we estimated six models predicting the level of interactive learning of innovator firms with: (1) their customers (here the innovating firms are the producers); (2) their suppliers (here the innovating firms are the customers); (3) with customers and suppliers split by size (four separate models). These analyses allow a comparison of the antecedents of interactive learning of innovator firms performing dual roles, and having a different size. Both monotonic and non-monotonic effects of the complexity of innovative activities, the strength of the internal knowledge base, and monotonic effects of the structuring of innovative activities are tested.

Our findings suggest that our theoretical model best fits the interactive learning of small- and medium-sized innovator firms. Interactive learning with customers is positively associated with the complexity and structuring of innovative activities, and with moderate scores of the cross-product term of 'complexity of innovative activities and the strength of knowledge resources'. Interactive learning with customers is positively affected by higher technological dynamics. Stronger internal knowledge resources yield positive effects on interactive learning with suppliers up to a threshold point. Once this threshold is crossed, the effects of stronger knowledge resources become negative. Interactive learning with suppliers as well as with customers is positively associated with internal and external structuring of innovative activities, but is not affected by sectoral technological dynamics.

Descriptors: interactive learning, resource dependence, absorptive capacity, complexity of innovative activities, structuring of innovative activities, monotonic and non-monotonic relations

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Introduction

A number of empirical studies have shown how interactions of innovator firms with external actors are intensified during innovation projects (Teubal 1976; Von Hippel 1976, 1988; Pavitt 1984; Coombs et.al. 1996; Freeman and Soete 1997; Meeus et. al. 2000a; Cooke et. al. 2000). This increased level of interaction is due to the nature of innovation. Innovations represent qualitatively new artefacts or knowledge that can cause all kinds of problems, either in production or in use. Thus mutual interests between innovator firms, their suppliers and customers evolve. The signalling and solution of product deficiencies by users affect the direction of producers' innovation efforts, because they inform producers about product viability and opportunities for improvement. Users' inputs in the innovative activities of producers are also beneficial for the users, because improved product performance potentially fosters the users' efficiency. The interaction with external actors determines a firm's access to a diversity of resources; the learning enables firms to transform these resources into innovations. Lundvall (1985) labelled this phenomenon 'interactive learning'.

Although the notion of interactive learning is intuitively appealing and a lot of descriptive evidence is available, it remains a phenomenon in search of a theory (Fagerberg 1998: 209). The discussion on interactive learning initiated by Lundvall (1988) concentrated more on the institutional effects of innovation and on agenda setting for technology policy than on a substantial explanation. The issue of interactive learning became important because it described the implications of innovative activities for the functioning of economic institutions such as industrial organizations, sectors and markets. Innovation and technological development mitigate the functioning of pure markets and temporarily replace competition with co-ordination. The generation and diffusion of innovations throughout an economy require the coordination and fine-tuning of the needs and opportunities of users and producers. This fine-tuning is based on the formation of linkages and knowledge transfer.

So far, interactive learning has either been largely ignored or touched upon only slightly in the literature on technological collaboration (Tyler and Steensma 1995) or alliances (Mowery et. al. 1996). First, because the discussion on interactive learning started in the economics of technical change as a critique of a neo-classical conception of markets, and, second, because the issues of learning and interaction have been dealt with in largely detached organization literatures. Interaction is dealt with in studies about networks focusing on structure and governance (e.g. Grandori 1997; Jones et al. 1997). Oliver and Ebers (1998: 566–567) conclude from their review of the network literature that, although innovation and learning represent 'eminent practical problems', these problems were only poorly related to other antecedents or theories, and received scant attention. In the literature on organizational learning, interaction has been neglected due to its bias towards individual learning, which in turn has hampered the linking of the individual and organizational level. This made inter-organizational learning a bridge too far. Learning approaches focus primarily on organizational change, adaptation and competence development; they have a behavioural focus (Jin and Stough 1998; Kogut and Zander 1992) in which the issue of interaction is recognized, but remains unproblematic. Although innovation is often considered as an instance of learning, the specific nature of knowledge exchange and sharing in the context of innovation is overlooked (Dodgson 1993: 387; Simon 1991: 127–131). Although many researchers have made significant efforts to understand when and why firms interact and learn, they have left relatively unexplored the question of the intensity of interaction and learning in the context of innovation.

This paper aims at contributing to a more complete and theoretical understanding of *levels* of interactive learning of users and producers in the context of innovation. Therefore we move from the economics of technological change (Lundvall 1988; Edquist 1997; Cooke et al. 1996) to organization theory, because the latter has a longer research tradition and a richer set of approaches to explain the interdependencies of firms (for a review, see Galaskiewicz 1985; Grandori 1997). We specify Lundvall's (1992: 58) activity-based account for interactive learning by including the structuring of innovative activities, in addition to the complexity of innovative activities. Levels of interactive learning are considered to depend on the way in which innovator firms integrate their innovative activities. Internal integration is achieved by linking activities of internal departments (Cohen and Levinthal 1990; Grant 1996; Teece and Pisano 1998). External integration consists of the formation of linkages to so-called bridging institutions like innovation centres or trade organizations (Edquist 1997; Cooke et al. 2000). Furthermore, we have built our theoretical argument on a resource-based account, more specifically on a knowledge-based account of interactive learning. On the one hand, because the complexity argument implicitly refers to the occurrence of knowledge deficits, without elaborating that issue. On the other hand, because the acquisition of complementary knowledge resources is a key driver of technological collaboration (Aiken and Hage 1968). Finally, we argue that innovator firms have dual roles; they are simultaneously customer/user and producer. This raises an interesting comparative issue: Do levels of interactive learning of innovator firms with their users have the same antecedents as the level of interactive learning of innovator firms with their suppliers? To our knowledge, this issue has never been dealt with. The associated research question is: To what extent do the strength of internal knowledge resources, the complexity of innovative activities, and the structuring of innovative activities affect the levels of interactive learning of innovator firms with their suppliers, and their customers?

Our theoretical effort performs several functions in innovation and organization studies. First, it fills a lacuna in network theory (Oliver and Ebers 1998) by adding a substantial theoretical explanation for processes channelled by networks, namely the exchange and sharing of complementary knowledge resources or interactive learning between innovative producers and users. Second, it explores the complementarity of activity- and resource-based organization theories in the explanation of interactive learning. Third, whereas much empirical literature focuses on the dyadic relations of innovator firms with either their customers or suppliers, we focus on the dual role of innovator firms. We analyze the interactive learning of the innovator firms in their dual role as a supplier co-operating with customers, and as a buyer co-operating with suppliers. This allows for a comparison that has never been made before. Third, neither network research in the innovation literature nor the learning literature makes 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, and a clarification of our propositions. Next we describe the research design including the sample, the measurement of our variables — levels of interactive learning, the complexity of innovative activities, the strength of internal knowledge resources, the structuring of innovative activities, and technological dynamics — and the statistical procedures. Subsequently, we describe our results. Finally, we discuss these results and derive some theoretical and policy conclusions.

Theoretical Framework

Interactive Learning

Although Lundvall (1988: 352–353) gives a broad description of interactive learning in the innovation process, a succinct formal definition of interactive learning is missing. Building on Lundvall, we define interactive learning of a firm as the (in-)formal exchange and sharing of knowledge resources with suppliers and/or customers that is conducive to the innovation of the firm. We discuss three dimensions of interactive learning that determine the level of interactive learning: the level of formalization of the relation, the contact frequency, and the frequency of exchange and sharing of knowledge conducive to the innovation of the innovator firm.

Theoretically, Lundvall's notion of interactive learning specifies the resource dependence argument in the context of innovation. The basic premise of resource dependence theory is that organizations are open systems. From this it follows that organizations (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 regular interaction with other organizations that control these critical resources (Pfeffer and Salançik 1978: 25–28).

However, given the nature of innovation, this control assumption has to be relaxed due to counteracting forces. On the one hand, the non-exclusive and transitory nature of technical knowledge (Cohendet et. al. 1993) makes the acquisition and protection of information a core competence enabling firms to profit from the innovation. On the other hand, the stickiness of technical knowledge (Von Hippel 1987; Senker and Faulkner 1996;

Szulanski 1996; Lam 1997), its range and significance is so difficult to assess that any contractual arrangement pursuing a specification of knowledge transactions would become an unworkable strait-jacket.

The control of resource flows is also put in perspective by the uncertain outcomes of knowledge exchange and knowledge sharing. Several authors have pointed towards the loss of autonomy and increased dependence between collaborating firms (Galaskiewicz 1985: 282; Alter and Hage 1993; Saxenian 1994: 148–149). Huber (1991: 98) listed the reluctance to initiate external knowledge acquisition due to potential negative reputation effects. Kogut and Zander (1992) stressed the enhanced imitation risks, which potentially diminish the rents of innovation. Finally, the level of control of critical resources also depends on the role of the innovator firm. In routine economic exchange, the discretionary power of buyers often supersedes that of suppliers. This power asymmetry probably pervades the functioning of partners in interactive learning as well. There is a good chance that if the innovator firm has the role of buyer/user, it has more possibilities to control knowledge flows compared to the situation where the innovator firm has the role of a supplier.

Firms often deal with the control problem by means of formalizing relations. Formalization is achieved with contracts to supply resources. The terms of the contract define the mutual interest of partners. It specifies resources volumes and features, and stabilizes resource flows. In this way, a context for the institutionalization of interaction, and contacts between firms is formed. Especially long-term supply contracts motivate partners to invest in each other's innovative activities. Empirical research showed that most innovative relations emerge as spin-offs of market-based exchanges (Oerlemans and Meeus 1995). Although one should be aware of the fact that the formalization of business relations is contingent on regulatory systems and national cultures, it is an important relational feature that determines the access of partners to each other's costly-to-copy resources. Hence, the extent in which mutual knowledge transactions between interacting firms are embedded in formalized relations determines their mutual learning impacts.

Although the control of resource flows in routine market-based exchanges is intricate, the control of resource flows in innovation processes is even more complex. This leads to the question: Is there a specific logic that explains why innovation is associated with high levels of interactive learning? Lundvall's main assumption is that the very nature of innovation generates a mutual interest for the user and the producer of innovation to interact and learn. A producer of innovation will have a strong incentive to monitor what is going on in user units. First, process innovations within user units might be appropriated by producers or represent a potential competitive threat. Second, product innovations at the user level may imply new demands for process equipment. Third, the knowledge produced by learning-by-using can only be transformed into new products if the producers have a direct contact to users. Fourth, bottlenecks and technological interdependencies observed within user units, will represent potential markets for the innovating producer. Finally, the producer might be interested in monitoring the competence and learning potential of users in order to estimate their respective capability to adopt new products. The user, on the other hand, needs information about new products. This information also involves quite specific information about the relation between new use-value characteristics and specific user needs. When new user needs develop (for example, in the case of bottlenecks or new technical opportunities) the user might be compelled to involve a producer in the analysis of the problem. This can only be done successfully if the user has a detailed knowledge of the competence and reputation of different producers. The more customers and suppliers are aware of the mutual benefits of the sharing and exchange of knowledge, the higher the level of interactive learning.

Resources

The central tenet of the resource-based approach is that firms select actions that best capitalize on their unique endowments of resources, and that they focus on the production and maintenance of strategic resources in order to remain competitive (Combs and Ketchen jr. 1999). Performing product or process innovations induces firms to draw on their internal and external environment and forces them to pool all resources conducive to innovation. In the context of innovation, technical knowledge is the primary strategic resource to be acquired and developed (Cohen and Levinthal 1990; Hage and Alter 1997; Kogut and Zander 1992). Without technical knowledge, new technical opportunities would not be recognized, and hence neither product nor process innovations can be achieved. The heterogeneity of the resources needed in innovation — specialized skills, facilities, and money — urges firms to monitor actively their resource base as well as their financial position and decide how to solve their resource deficits. The strength of internal knowledge resources determines the ability to cope with this heterogeneity. If resources are fully utilized and hence unavailable, a search for complementary resources starts. In that context, existing relationships are intensified or new linkages evolve with other firms, or institutional actors such as universities, public R&D labs and innovation centres. Each external actor can be evaluated with regard to its competencies to complement the resource base of the innovating firm. The interaction, therefore, between innovating firms and a broad variety of external actors is a consequence of their needs for heterogeneous resources on the one hand. Patterns of interaction, on the other hand, indicate the ability of external actors to supplement the resource deficits or shortages of innovator firms (Aiken and Hage 1968: 930; Håkansson 1987; Lundvall 1992; Combs and Ketchen Jr. 1999: 868). In summary, therefore, interactive learning of innovator firms with either their buyers or suppliers permits firms to share resources and thereby overcome resource-based constraints for innovative activities. This yields the following proposition:

P1: The stronger the innovator firm's internal knowledge resources, the lower the level of interactive learning with buyers and suppliers.

While Proposition 1 suggests a negative monotonic relationship between the level of interactive learning and the innovator firm's internal knowledge base, there are two arguments for alternative propositions. The first argument is derived from Cohen and Levinthal (1990), and Gulati (1995), who argue that the ability to evaluate and utilize outside knowledge — the absorptive capacity of firms — is largely a function of prior related knowledge. There are few direct tests of the influence of absorptive capacity, but the results of such tests are broadly supportive of this argument (Gambardella 1992; Mowery et. al. 1996). This yields a competing resource-based hypothesis:

P2: The stronger the innovator firm's internal knowledge resources, the higher the level of interactive learning with buyers and suppliers.

The second argument pertains to the nature of the empirical relation suggested in Propositions 1 and 2. Both suggest a monotonic relationship between levels of interactive learning and the strength of the internal knowledge base. However, there are two arguments for a non-monotonic relationship. Both arguments suggest that a stronger internal knowledge base only leads to higher levels of interactive learning up to a certain point; after this point, stronger internal knowledge bases are associated with relatively lower levels of interactive learning. On the one hand, there is the marginal information value argument (Gulati 1995; Chung et. al. 2000), which suggests that if knowledge resources are stronger, the probability of diminishing returns of knowledge exchange and knowledge-sharing grows, which, in turn, decreases levels of interactive learning. On the other hand, there is the monitoring–reassessment argument, which suggests that firms are myopic, and hence have limited capabilities to value their internal knowledge base. Innovator firms simultaneously reassess their internal knowledge resources when monitoring the knowledge bases of external actors. Especially for firms with stronger internal knowledge bases, this reassessment diminishes the potential complementarity of external knowledge because of the identification of slack resources. This decreases the levels of interactive learning. Therefore we propose that:

P3: Firms with knowledge resources of moderate strength are more inclined towards higher levels of interactive learning than are firms with weak or strong knowledge resources.

Complexity of Innovative Activities

In general, complexity is defined in rather abstract terms. Boisot (1998: 5–6) defines complexity in terms of the number of elements in interaction and the number of different states to which those interactions can give rise. The greater the number of elements one has to deal with, and the more varied the interactions, the more complex one's task. Kogut and Zander (1992: 388) define the complexity of a task as the number of operations required to solve it. Jones et. al. (1997: 921) stress another dimension of task complexity by referring to the number of specialized inputs needed to complete a product or service. Building on these abstract notions, we define the complexity of innovative activities in terms of the innovator firm's learning and problem-solving efforts induced by the external innovation pressures and innovative activities implemented. Both significantly enlarge this number of learning and problem-solving operations. The higher the heterogeneity and intensity of perceived innovation pressures, the stronger the impetus to adapt. Examples of innovation pressure are: changes in perceived customer needs, competitor behaviour (Lundvall 1992), proliferation of new technical knowledge, new technical findings (Hage and Alter 1997), legal requirements, emergence of new markets, standardization (Anderson and Tushman 1990), and cost reduction (Duncan 1972). More heterogeneous innovation pressures imply that more divergent, and probably less compatible criteria have to be met in the product or process innovation, which requires additional specialized skills and knowledge (Jones et. al. 1997; Dewar and Hage 1978), or makes existing competencies obsolete (Leonard-Barton and Doyle 1996). The higher the likelihood of incompatible innovation pressures, and the higher the required capacity for problem solving, the more firms must go beyond the incremental improvement of existing competencies associated with learning by doing and learning by using (Windrum 1999: 1539). If innovation pressures are more heterogeneous, the number of innovation opportunities grows, and this, in turn, demands more interaction with external actors, primarily buyers and suppliers (Lundvall 1992; Hage and Alter 1997; Pfeffer and Salançik 1978).

The rate of innovation measures the actual innovative behaviour of the innovator firms. The higher the number of implemented product and process innovations, the higher the actual intensity of the problem solving and associated (un-)learning (Dodgson 1993; Henderson and Clark 1989; Rosenbloom and Christensen 1998). High innovation rates erase existing communication codes between users and producers. Compared to lower innovation rates, new codes have to be developed on a trial and error basis, and this requires intensive interactions between users and producers (Lundvall 1992: 58).

In summary, therefore, both the heterogeneity of innovation pressures and the rate of innovation generate a higher complexity of innovative activities (Evan 1993: 230; Hage and Alter 1997). A higher complexity of innovative activities increases the information needs of innovator firms. Innovator firms build forward and backward external linkages to satisfy these information needs. The general proposition derived from the complexity argument is therefore as follows:

P4: More complex innovative activities induce higher levels of interactive learning.

As was the case with the resource-based propositions, the relation between complexity and interactive learning is either monotonic or non-monotonic. The argument for a non-monotonic relation is that innovative activities with low complexity probably do not require much problem solving. Due to low innovation pressures and low innovation rates, firms do not need complementary knowledge. Innovator firms are also inclined to perform extremely complex innovative activities within organizational boundaries. This relation can be interpreted with a reputation effect, and with a matching effect. The reputation effect applies, should external actors find out that the innovator firm cannot solve its own innovation problems. A damaged reputation will cause partners to be less eager to collaborate (Huber 1991). The matching effect explains the decline of the likelihood of finding partners willing to offer complementary resources after a certain threshold of complexity of innovative activities. Firms initiating innovations with moderate levels of complexity are less bothered by matching and reputation effects in their partnering behaviour. They are more likely to detect problems they cannot solve themselves, than in the case of low complexity, and the risk of damaging reputations is lower than when the levels of complexity are extremely high. Finally, the likelihood of finding partner firms that can offer complementary resources is larger with innovative activities of moderate complexity. Together, these effects increase the chance that moderate complexities of innovative activities induce comparatively high levels of interactive learning. This yields the following proposition:

P5: 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.

Interaction between Complexity of Innovative Activities and the Strength of the Knowledge Resources

Our research explicitly aims at extending the resource-based view of the firm, with an activity-based view of the firm. The reason is that the resource-based view conflates resources and activities. Wernerfelt (1984: 172) defines a resource as 'anything, which could be thought of as a strength or weakness of a given firm'. Barney (1993: 101) defines resources of firms as including all assets, capabilities, organizational processes, firm attributes, information, knowledge, etc. controlled by a firm that enables it to conceive of and implement strategies that improve its efficiency and effectiveness. Because this conceptual conflation of organizational features hampers an analytical approach to interactive learning, we advance an activity-based and a resource-based explanation of interactive learning.

A synthesis of the resource-based and the activity-based explanation for interactive learning yields a more comprehensive theoretical account of interactive learning. It is the complexity of the innovator firms' innovative activities, which determines whether the strength of the internal knowledge resources is sufficient, and therefore determines the level of interactive learning. More complicated innovative activities draw more heavily on a firm's resource base than do routine production and distribution activities with lower complexity. Hence, they reveal resource deficits or shortages and affect the level of interactive learning. This yields the following proposition:

P6: The effect of the strength of internal knowledge resources on the level of interactive learning is moderated by the complexity of the innovative activities.

Also for this proposition, a non-monotonic version is explored. We expect that moderate levels of complexity and the moderate quality of the resource base are associated with the highest levels of interactive learning. The argument runs parallel with those pertaining to Propositions 3 and 5.

P7: *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.*

The 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, such as the knowledge-based theories of Cohen and Levinthal (1990), Kogut and Zander (1992), Grant (1996) and Teece and Pisano (1998). These authors stress the significance of organizational structuring enhancing relationships between knowledge sharing and knowledge diversity across individuals, departments and plants. The pooling of innovative activities of internal departments becomes more important when innovative activities are more complex (Lawrence and Lorsch 1967). It has become generally accepted that complementary functions or departments within organizations (e.g. R&D, sales and marketing, purchase, production) ought to be tightly intermeshed. After all, 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). To the extent that an organization 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.

P8: A higher integration of internal innovative activities induces a higher awareness of external as well as internal knowledge bases, and therefore affects the level of interactive learning.

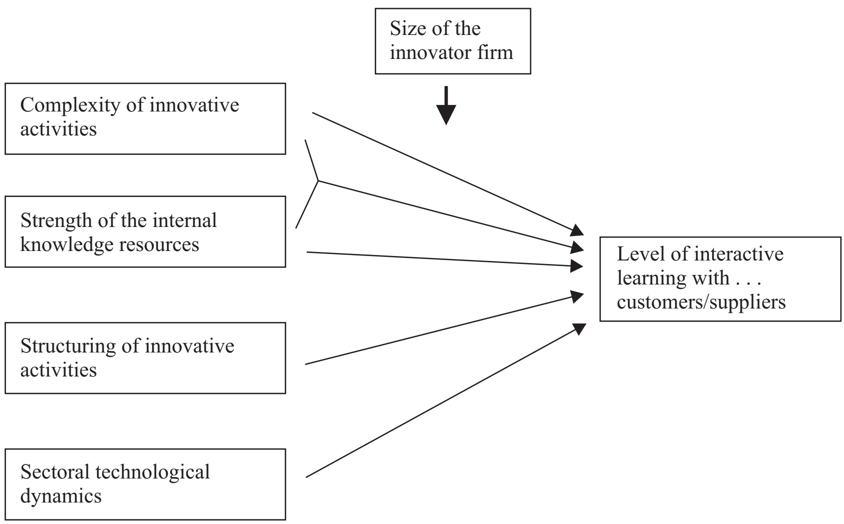
In the systems of innovation literature, a new aspect of the organizational structuring of innovative activities is advanced: the embeddedness of innovating firms in so-called bridging institutions (Midgley et al. 1992; Edquist

1997). This may be the national government, but it could also be agents like technology centres responsible for local knowledge transfer, regional development authorities, trade or industrial associations, chambers of commerce, etc. These organizations 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). Because European and Dutch technology policies are geared towards clustering and networking (Cooke et. al. 2000), in many EC countries, technology subsidies are assigned only if the innovation projects submitted induce (international) collaboration. Many bridging institutions operate in this technology subsidy niche and are rewarded for their 'network' activities, and this is conducive to their legitimacy. This yields the final proposition:

P9: Stronger links with bridging institutions induce higher levels of interactive learning.

This conceptual model summarizes our general theoretical claims as to the explanation of levels of interactive learning between innovator firms, their suppliers and customers.

Figure 1
A Research Model of the Relation between the Level of Interactive Learning of Innovator Firms with Customers and/or Suppliers, the Complexity of Innovative Activities, the Strength of the Internal Knowledge Resources, the Structuring of Innovative Activities, and Sectoral Technological Dynamics with Size as a Control Variable



The Generality of Our Claims

The theoretical model we have developed is probably contingent on several factors. We check the effects of two important control variables, because potentially they limit the generality of our claims. The first variable we control for is firm size, which is often considered as a proxy for resource strength. A review of the empirical research by Cohen and Levin (1989: 1072) revealed that firm size has dual effects. On the one hand, the resource availability tends to grow when firms grow. Large firms have qualitatively and quantitatively more comprehensive resource bases and are therefore better equipped to innovate successfully and to compete proactively and aggressively. Compared to small- and medium-sized firms, large firms are favoured by the availability of internal funds in a world of capital market imperfections. For instance, cash flow (a measure of internal financial capabilities) is empirically associated with higher levels of R&D intensity. Simultaneously, slack resources buffer firms from competition and promote insularity, and this affords economies of scale that capitalize on inertial routines (Miller and Chen 1994). On the other hand, large firms are more bureaucratic than small and medium-sized enterprises. The rigid rules and routines that so profoundly permeate many larger companies may hamper resource utilization (Tushman and Romanelli 1985; Miller and Friesen 1982).

The second contingency is the enormous difference between sectoral technological dynamics. Many researchers reported significant differences between patterns of technological change in high-tech and low-tech sectors. High-tech sectors have higher R&D spending, and patterns of collaboration in the high-tech sectors are more elaborate (Pavitt 1984; Vossen and Nooteboom 1996; Oerlemans 1996; Freeman and Soete 1997; Meeus et. al. 2000b).

Research Design

Much recent empirical research (Kleinknecht and Reijnen 1992; Vossen and Nooteboom 1996) on innovation in Europe is based on data acquired in the Community Innovation Survey (CIS). This survey was performed in 15 Member States of the European Union. Although the CIS questionnaire contains 200 questions related to the innovative behaviour of firms, it contains only a limited number of items about innovation networks and learning. To deepen our knowledge about these issues, we combined case studies with survey research. First we analyzed networks in 23 innovation projects of 18 local firms. This helped us to develop a questionnaire allowing a full treatment of theoretical issues related to innovative behaviour in innovation networks.

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 specific characteristics. Brabant's industrialization started in ca. 1850 and was based on traditional industries like dairy industries, textile and wool industry. The Brabant region also has two universities and three innovation centres. A strong group of key players in internationalized industries and the location of these companies near important distribution centres such as Rotterdam and Antwerp make this region highly attractive for foreign direct investment.

This is one of the most industrialized regions in the Netherlands. In 1992, the total number of jobs in manufacturing was roughly 210,000, i.e. the manufacturing sector's share of employment in the region was 28.8 percent (cf. the Dutch average of 19.5 percent). The population of firms in North Brabant differs widely from agricultural regions (e.g. Zeeland, Groningen, and Drente), and service-oriented regions (e.g. Utrecht, Zuid- and Noord-Holland). In the Dutch context, North Brabant is considered as a high-tech region. It accommodates plants of multinational enterprises such as Philips, DAF trucks, Royal Dutch Shell, Akzo Chemical, DSM, former Fokker (aircraft) and Fuji. Some examples of important medium-sized international niche players in Brabant are ASM Lithography, OCE and Rank Xerox (copiers), ODME (optical disc equipment), Ericsson, EMI (CDs), and General Plastics, etc.

The population of firms in the region consists of a mix of small, medium-sized and large enterprises. About 84 percent of the responding firms have a hundred or less employees. Furthermore, the manufacturing sector has shown a relatively high R&D and export performance (Meeus and Oerlemans 1995).

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 percent boundaries. The mean deviation between the percentages in the sample and in the response is 6.4 percentage points. The sample of industrial firms is classified according to Pavitt's taxonomy (Oerlemans 1996). In this paper, we focus on innovator firms as the focal firms whose innovative behaviour is related to patterns of interactive learning.

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 (3.130)	100 (579)	100 (402)

Measurement

Interactive learning is measured as a multi-dimensional construct that combines a learning dimension, an interaction dimension, and a control dimension (for the items, see Table 2).

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; Jin and Stough 1998). Our indicators measured the

Table 2. Measurement of the Dependent Variable 'Levels of Interactive Learning'

Variable	Indicators
Level of interactive learning with customers	Four items were included in this variable: (1) firms were asked how often their customers contributed to their innovation processes by bringing up ideas, or participate actively; (2) firms were asked to rate the contact frequency with customers; (3) firms were asked how often they transferred knowledge and information to their customers; (4) firms were asked to rate the level of formalization of relationships with customers. For items 1 and 3 answers were coded: (1) never; (2) sometimes; (3) regularly; (4) often; (5) always. For item 2 the answers were coded: (1) once per six months; (2) once per quarter; (3) monthly; (4) weekly; (5) daily. Item 4 had a 4-point scale, (1) indicating low levels of formalization, and (4) indicating high levels of formalization. Every item was standardized and an average sum score was computed.
Level of interactive learning with suppliers	Four items were included in this variable: (1) firms were asked how often their suppliers contributed to their innovation processes by bringing up ideas, or participate actively; (2) firms were asked to rate the contact frequency with suppliers; (3) firms were asked how often suppliers transferred knowledge and information to them; (4) firms were asked to rate the level of formalization of the relationships with suppliers. For items 1 and 3 answers were coded: (1) never; (2) sometimes; (3) regularly; (4) often; (5) always. For item 2 the answers were coded: (1) once per six months; (2) once per quarter; (3) monthly; (4) weekly; (5) daily. Item 4 had a 4-point scale, (1) indicating low levels of formalization, and (4) indicating high levels of formalization. Every item was standardized and an average sum score was computed.

extent to which suppliers and customers actively contributed to innovations of the focal firm, either by active participation or by their contribution of ideas to the innovation process of the focal firm.

The level of interaction was measured by asking the innovating firms to rate the contact frequency between the innovating firms and the external actors. Social interaction is defined as a sequence of situations where the behaviours of one actor are consciously re-organized by, and influence, the behaviours of another actor, and *vice versa* (Turner 1988: 14). The measure captures the level of reciprocity between innovator firms and external actors, indicating, on the one hand, the frequency of knowledge transfer initiated by external actors, and, on the other, the frequency of knowledge transfer initiated by the innovator firms.

The level of formalization of contracts is a proxy for the level of control on the knowledge exchange between innovator firms and the suppliers and customers most conducive to the innovative activities of the focal firms. If levels of formalization are higher, firms have more control on knowledge exchange and sharing during the innovation process.

Resources

With regard to the resources involved in innovation, scholars have divergent opinions. Håkansson (1987) and Smith (1995) broadly defined resources in

Table 3. Measurement of the Independent Variables, and Control Variables

Variable	Indicators	Calculation of Scores
Complexity of innovative activities: A sum score was computed using 'the percentage of new processes and products' and 'heterogeneity of innovative pressures'	*Percentage of new processes and products in a 5-year period*	Firms were asked to indicate to what extent (1) their machines/processes and/or (2) their line of products changed in a 5-years period. Each item was coded: (1) 0–20%; (2) 20–40%; (3) 40-60%; (4) 60–80%; (5) 80–100%. An average sum score was computed and the resulting variable was standardized.
	Heterogeneity of innovative pressures	Firms were asked to indicate how often the items mentioned below, were pressures to innovate. Items included were: (1) customers asked for specific new product; (2) customers asked for specific operation method; (3) competitor had comparable new product; (4) competitor had comparable machine/process; (5) improvement of product quality; (6) maintain market share; (7) increase market share; (8) reduction of cost price; (9) improved production time; (10) new market need discovered; (11) technical idea/invention; (12) solve technical product deficiencies; (13) solve technical production problems; (14) improve delivery time; (15) react to regulation; (16) technical standardization. Items were coded: (1) never; (2) sometimes; (3) regularly; (4) often; (5) always. An average sum score was computed and the resulting variable was standardized.
Strength of the internal knowledge resources: A sum score was computed using 'R&D intensity', 'percentage of higher educated employees', and 'resource deficits'	*R&D intensity*	The percentage of employees working full-time on R&D. The variable was standardized.
	Percentage of higher educated employees	The number of higher educated employees as a percentage of the total workforce of the firm. The variable was standardized.
	Resource deficits	Firms were asked to indicate whether or not the following issues hampered their innovative activities: (1) lack of financial resources; (2) lack of time; (3) lack of skilled workers; (4) lack of technical know how. If an issue hampered innovative activities the item was coded 1, else it was coded 0. A sum score was computed and the resulting variable was *recoded* and standardized. Low scores indicate high levels of resource deficits, and high scores indicate low levels of resource deficits.
Structuring of innovative activities The separate variables were used in the estimations	*Level of integration of internal innovative activities*	The sum of the frequency with which the R&D, marketing and sales, purchase, and production function of the firm contributed to the firm's innovation projects. Answers were coded: (1) never; (2) sometimes; (3) regularly; (4) often; (5) always. After the sum score was computed, the variable was standardized.
	The level of support by bridging institutions	The sum of the frequency with which trade associations, 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. After the sum score was computed, the variable was standardized.
Pavitt sector (control variable)	*Pavitt dummy*	Firms were coded 0 if they belonged to the supplier dominated or the scale intensive sector (traditional manufacturing, bulk material, assembly); Firms were coded 1 if they belonged to the specialised suppliers or science based sector (machinery, instruments, electronics, chemicals)
Size (moderator variable)	*Size dummy*	Firms were coded 0 if they had less then 100 employees Firms were coded 1 if they had 100 employees or more

terms of money-enabling investments, a physical and technological infrastructure, a stock of knowledge, information and human skills enabling an organization to transform inputs into outputs and decision making. Hage and Alter (1997) and Cohen and Levinthal (1990) argue that the ability to evaluate and utilize outside knowledge — firms' absorptive capacity — is largely a function of prior related knowledge.

In our research model, we restrict the measurement of the strength of the knowledge resources to three different knowledge-based indicators (see Table 3). First, R&D intensity (Baldwin and Scott 1987; Cohen and Levinthal 1990); second, the percentage of higher educated workforce (Kleinknecht and Reijnen 1992; Jin and Stough 1998); third, the number of problems that firms experienced during their innovation projects (Meeus et. al. 1996). A large number of innovation problems indicate large resource deficits. In order to align the meaning of the resource indicators the raw scores for the number of innovation problems were recoded. Consequently, high scores on this indicator mean few innovation problems and hence a high problem-solving capability of the innovator firm.

Complexity of Innovative Activities

We have distinguished two dimensions of complexity of innovative activities, which were combined in one compound independent variable (for separate items, see Table 3). The first dimension is the heterogeneity and intensity of perceived innovation pressures, which defines the diversity of environmental pressures pushing firms to innovation (Duncan 1972). The items pertain to customer demands, innovative behaviour of competitors, new market needs and technical findings, as well as to institutional developments. Due to these pressures, existing skills and capabilities can become obsolete and shift the locus of technical expertise from industry incumbents to newly formed ventures and firms from other industries (Schumpeter 1975: 83; Pisano 1990; Tushman and Anderson 1989). The second dimension of complexity of innovative activities is the rate of innovation. It is measured by the percentage of products and processes that were innovated between 1988–1993. The rate of innovation measures the extent in which the innovator firm has responded to innovation pressures. Jointly, these indicators represent the degree of difficulty of the innovator firms' learning efforts, which is higher in the case of intense, and more heterogeneous, innovation pressures and high innovation rates.

The Structuring of Activities

The structuring of innovative activities is measured by two separate variables: the level of integration of internal innovative activities, and the level of support of bridging institutions. The integration of internal innovative activities is measured as the frequency with which internal departments contributed to the innovation process of the innovator firm. The external dimension — the level of support by bridging institutions — was measured by the frequency in which chambers of commerce, industry associations and innovation centres contributed to the innovating firms' innovation process (for the items, see Table 3).

Control Variables

The size of the firm (Baldwin and Scott 1987; Cohen and Levin 1989; Vossen and Nooteboom 1996) — is a proxy for a firm's ability to invest in innovation (see Table 3). For the measurement of technological dynamics, we used a dummy variable. We discern traditional industries (supplier-dominated and scale-intensive industries), and modern industries (specialized suppliers and science-based industries). R&D spending of Dutch industries classified as Pavitt sectors has the following order: (4) the supplier dominated, (3) scale intensive, (2) specialized suppliers, and (1) science-based industries (Vossen and Nooteboom 1996: 165). Earlier research (Oerlemans et. al. 1998) suggests that patterns of interaction with distinct external actors yield different innovation outcomes between Pavitt's sectors.

Analyses

In this paper, we restrict our investigation to exploratory analyses. After all, there is no empirical research that developed the same models, hence one has to be cautious about generalizing the findings. In order to test our propositions, we used stepwise OLS regression (Ordinary Least Square). Six separate models were estimated, exploring the level of interactive learning of the focal firms with: (1) customers, (2) suppliers, (3) customers for small- and medium-sized focal firms with less than 100 employees, (4) customers for focal firms with 100 employees or more, (5) suppliers for small- and medium-sized focal firms with less than 100 employees, and (6) suppliers for focal firms with 100 employees or more.

The interpretation of our research findings differs for the monotonic and non-monotonic propositions. All the variables in our research model (the level of interactive learning, the complexity of innovative activities, the strength of the knowledge resources, the cross-product term 'complexity — strength of the knowledge resources', and the structuring of innovative activities) were coded from low to high scores. Positive betas signify, therefore, that higher scores on the independent variables are associated with higher levels of interactive learning. For example, a positive beta for complexity of innovative activity implies that a higher complexity of innovative activities co-varies 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-monotonic effects, we included squared terms for the strength of the internal knowledge 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. In that case, 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 variables and the level of interactive learning. This means that 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.

Results

Table 4 reports descriptive statistics and Spearman Rho correlations among measures used in the study. These findings give a first indication that especially the resource-based explanation is not supported.
Table 5 displays the results relevant to our propositions. Propositions 1 and 2 predicted that the strength of internal knowledge resources has either a negative or a positive monotonic relation with levels of interactive learning. Neither the resource deficit argument, nor the absorptive capacity argument is supported by our findings. Proposition 3 predicted an inverted U-shaped relation between the strength of the innovator firm's internal knowledge resources and levels of interactive learning. This proposition is supported for interactive learning with suppliers (Model 4 and 5, b = –0.12[a]), but was not supported for the interactive learning with customers.

Table 4. Descriptive Statistics

Variables	Mean	S.D.	Minimum	Maximum	Correlations of Independent Variables with Levels Interactive Learning with …	
					Customers	Suppliers
Level of interactive learning with customers	–0.002850	0.5856	–1.67	1.48		
Level of interactive learning with suppliers	+0.005315	0.5665	–1.28	1.52		
Complexity of innovative activities	–0.001240	1.5837	–3.92	4.83	**0.31**[d]	**0.20**[c]
Strength of the internal knowledge resources	–0.003950	1.6851	–2.15	9.44	0.02	0.02
Cross-product term of complexity of innovative activities and the strength of the internal knowledge resources	+0.32920	2.4511	–9.93	9.87	0.09	0.04
Level of integration of internal innovative activities	+0.004650	1.0190	–2.40	3.69	**0.30**[d]	**0.42**[d]
Level of support by bridging institutions	+0.002430	1.0301	–0.69	6.01	**0.13**[b]	**0.20**[c]

Legenda:
le = less than or equal to
[a]p le 0.10, [b]p le 0.05, [c]p le 0.01, [d]p le 0.001

Table 5. OLS Regression of Levels of Interactive Learning with Customers or Suppliers as the Dependent Variable, and Complexity of Innovative Activities, the Strength of the Internal Knowledge Resources, the Structuring of the Innovation Process, and Pavitt Sectors as the Independent Variables Divided by Size (Stepwise Model)

Independent Variables	Indicators	Customers: Model 1 (total sample)	Customers: Model 2 (less than 100 employees)	Customers: Model 3 (100 employees or more)	Suppliers: Model 4 (total sample)	Suppliers: Model 5 (less than 100 employees)	Suppliers: Model 6 (100 employees or more)
		Levels of Interactive Learning with.....					
Strength of the internal knowledge resources	P1/2 SIKR	–0.02	0.03	–0.05	0.01	0.01	0.17
		(–0.30)	(0.31)	(–0.39)	(0.21)	(0.10)	(0.69)
	P3 SIKR (Sq.)	0.02	0.10	–0.10	**–0.12**[a]	**–0.12**[a]	–0.13
		(0.23)	(1.20)	(–0.70)	**(–1.68)**	**(–1.57)**	(–0.52)
Complexity of innovative activities	P4 COMP	**0.23**[d]	**0.28**[c]	**0.50**[d]	0.03	–0.01	0.28
		(3.26)	**(2.90)**	**(3.65)**	(0.44)	(–0.02)	(1.07)
	P5 COMP (Sq.)	–0.10	0.00	0.01	0.00	0.01	–0.01
		(–1.28)	(–0.01)	(0.07)	(0.01)	(0.16)	(–0.01)
Interaction effects	P6 COMP * SIKR	0.05	0.06	0.03	0.01	0.03	0.01
		(0.67)	(0.68)	(0.18)	(0.10)	(0.39)	(0.04)
	P7 [COMP * SIKR] Sq.	**–0.14**[a]	**–0.19**[b]	0.03	0.02	0.03	–0.08
		(–1.84)	**(–2.16)**	(0.18)	(0.24)	(0.33)	(–0.22)
Structuring of innovative activities	P8 LIIA	**0.22**[d]	**0.23**[c]	0.16	**0.40**[d]	**0.42**[d]	0.13
		(3.13)	**(2.90)**	(0.98)	**(5.72)**	**(5.49)**	(0.50)
	P9 LSBI	0.08	**0.14**[a]	–0.12	**0.15**[b]	**0.18**[b]	0.00
		(1.11)	**(1.78)**	(–0.90)	**(2.22)**	**(2.38)**	(0.00)
Pavitt sectors	PAVITT (dummy)	**0.12**[a]	**0.19**[b]	–0.01	–0.01	–0.01	–0.09
		(1.82)	**(2.43)**	(–0.08)	(–0.17)	(–0.11)	(–0.47)
	R square	0.14	0.17	0.25	0.20	0.22	0.18
	F-value	15.014	7.261	13.33	20.726	19.509	0.650
	Sign. F	0.000	0.000	0.001	0.000	0.000	0.745
	Listwise N	190	147	43	174	138	36

[a]p le 0.10, [b]p le 0.05, [c]p le 0.01, [d]p le 0.001

Standard errors are in parentheses.

Legenda:
le: less than or equal to.
SIKR = Strength of the internal knowledge resources; SIKR (Sq.) = Strength of the internal knowledge resources squared; COMP = Complexity of innovative activities; COMP (Sq.) = Complexity of innovative activities squared; COMP*SIKR = Cross–product of complexity of innovative activities and Strength of the internal knowledge resources; [COMP*SIKR] Sq. = Squared term of the cross–product of complexity of innovative activities and Strength of the internal knowledge resources; LIIA = Level of integration of internal innovative activities; LSBI = Level of support by Bridging Institutions; PAVITT = Pavitt sectors.

Proposition 4 predicted that the complexity of innovative activities is positively related to the level of interactive learning. As displayed in Table 5, this proposition is supported for interactive learning with customers (Model 1: b = 0.23[d]; Model 2: b = 0.28[c]; Model 3: b = 0.50[d]), but not for interactive learning with suppliers. Proposition 5, that predicted a non-monotonic relation between levels of interactive learning and the complexity of innovative activities is not supported by our findings.

Proposition 6, predicting a monotonic and positive effect of 'complexity of innovative activities and strength of knowledge resources' on the levels of interactive learning, is not supported by our findings. Proposition 7 predicted an inverted U-shaped relation between the cross-product term 'complexity of innovative activities and strength of knowledge resources' and the level of interactive learning. This non-monotonic interaction effect is supported for interactive learning with customers (Model 1: b = –0.14[a]). Furthermore, the non-monotonic interaction effects turned out be sensitive for the size and role effects of the focal firm. Table 5 shows that this U-inverted relation applied only to interactive learning between small- and medium-sized innovator firms and their customers (Model 2: b = –0.19[c]). Proposition 7 was not supported for interactive learning with their suppliers.

The results with respect to the effects of the structuring of innovative activities — P8 and P9 — confirmed the contingent nature of patterns of interactive learning. The level of integration of innovative activities turns out to be positively associated with levels of interactive learning between innovator firms, customers and suppliers (Model 1: b = 0.22[d]; Model 4: b = 0.40[d]). However, a sample split by size revealed that more integration of internal innovative activities occasions higher levels of interactive learning with suppliers and customers among small- and medium-sized innovator firms (Model 2: b = 0.23[c]; Model 5: b = 0.42[d]). This effect is absent among larger firms. Our findings as to Proposition 9 show the same pattern. The positive effects of the support of bridging institutions on levels of interactive learning are limited to small- and medium-sized firms and are absent among larger firms (Model 2: b = 0.14[a]; Model 5: b = 0.18[b]). Finally, technological dynamics affected the level of interactive learning with customers for small- and medium-sized innovator firms (Model 1: b = 0.12[a]; Model 2: b = 0.19[b]). Technological dynamics did not affect the level of interactive learning with suppliers.

Discussion and Conclusions

In several ways, this study sheds new light on the effects of innovation on the link between firm behaviour and markets. Our theoretical model brings interactive learning from the economics of technological change and policy-oriented studies (Lundvall 1988; Cooke et. al. 2000) within the realm of organization theory. The exploration of levels of interactive learning with a theoretical model that combines resource dependence, resource-based and activity-based arguments enables the comparison of the explanatory value of competing and complementary theoretical perspectives. To our knowledge, we are the first researchers that advanced an operational measure for levels of interactive learning, which synthesizes interaction and learning in the context of innovation. New measures for the complexity of innovative activities and interactive learning are introduced. This enhanced, at least partially, the opening of the black box of external (Dodgson 1993) or collective learning (Huber 1991) occasioned by innovation, which has been neglected so far in the network literature (Oliver and Ebers 1998). Our analyses revealed that the innovation process transforms the economic exchange between producers and buyers into a co-ordinated alignment of mutual interests framed in a process of reciprocal knowledge transfer.

The relations we proposed in our research model proved to be very sensitive to the contingencies — size and the dual roles of focal firms and technological dynamics — we have specified. First, our findings revealed that our theoretical model applies to the patterns of interactive learning of small- and medium-sized firms. Second, a comparison of interactive learning with customers (the innovator firm is supplier) and suppliers (the innovator firm is a customer) yields striking contrasts. Expected effects of knowledge resources were partially confirmed (only the non-monotonic effects), but only for levels of interactive learning with suppliers, not for the interactive learning with customers. The predicted monotonic effects of the complexity of innovative activities were also partially confirmed, but this time, only for interactive learning with customers. The predicted non-monotonic effects of the interaction between complexity and knowledge resources were confirmed only for customers. Third, the effects of the structuring of innovative activities were significant only for small- and medium-sized innovator firms' interactive learning with both customers and suppliers. Finally, levels of interactive learning with customers proved to be positively associated with technological dynamics, which is consistent with Pavitt's results (Pavitt 1984).

These empirical findings allow for a first outline of a theory of interactive learning. It appears to be a type of innovative behaviour that applies, in particular, to SMEs. Small- and medium-sized innovator firms cannot deal with their environment in the same way as larger firms. First of all, SMEs are in a continuous process of building reputation, and gaining trust. Second, SMEs do not have the possibility of engaging in take-overs. Therefore, their survival chances depend on a close interaction with their backward and forward linkages. Third, SMEs have less time and money to monitor market and technological environments than larger firms. Smaller firms' search for complementary knowledge therefore fluctuates with the complexity of innovation projects on the one hand, and with their embeddedness in business and innovation networks, on the other. For larger firms, this dependency is relatively different, and seems to be more loosely coupled with resource and activity features.

Stronger internal knowledge resources occasion higher levels of interactive learning with suppliers up to a certain threshold. This suggests that the marginal value of information transferred between suppliers and the focal firm decreases after a certain threshold. Our findings also suggest that levels of interactive learning with customers are independent of the strength of internal knowledge resources. Consequently, knowledge deficits as such do not affect interactive learning with customers.

The complexity of innovative activities increases levels of interactive learning with customers, but in no way affects levels of interactive learning with suppliers. This finding confirms the importance of customer feedback in determining the feasibility of complex innovative activities of innovator firms. Whereas the alignment of innovative activities with customer needs and preferences turns out to be very sensitive for fluctuations in the complexity of the innovations performed, the interactive learning with suppliers is on a constant and high level (Oerlemans and Meeus 1995). The non-monotonic effect of complexity of innovative activities on levels of interactive learning was not supported.

The interaction effects of the strength of the knowledge base and the complexity of innovative activities turned out to have a non-monotonic relation with levels of interactive learning of small- and medium-sized innovator firms and their customers. This finding points at a self-reinforcing dynamic in which stronger knowledge resources induce more complicated innovative activities, which in turn boost the strength of the knowledge resources. The part of the inverted U-curve up to the inflection point shows that this dynamic also occasions higher levels of interactive learning with customers. The effect of stronger knowledge resources is pulled by the complexity of innovative activities. However, after a certain threshold, higher complexity and stronger knowledge resources are associated with lower levels of interactive learning. This finding allows for an important qualification of the absorptive capacity argument, which is moderated by the complexity of innovative activities performed by small- and medium-sized firms. It also yields an important direction for future research. A direct measurement of the marginal information value effect, the matching, and reputation effect would allow the exploration of alternative interpretations of the U-inverted relations reported here.

Our study has several theoretical implications. We combined variables building on divergent theoretical strands in our models and tested three of them in both a monotonic and non-monotonic way, and included interaction effects. The fact that levels of interactive learning with suppliers are empirically associated with a resource-based variable, whereas the interactive learning with customers is associated with an activity-based variable, shows that it makes sense to include divergent theoretical perspectives in the analysis of patterns of interactive learning. The differences between customer and supplier models, representing the dual roles of innovator firms, would have been inexplicable had one of these variables been omitted from the analysis. The findings reported here highlight the importance of theory comparison and of an integrative approach to interactive learning as a fruitful avenue for theorizing on the link between innovation, firm behaviour and institutions.

The confirmation of, on the one hand, significant non-monotonic effects of the strength of knowledge resources, and, on the other, the significant non-monotonic effect of the cross-product term of knowledge and complexity allows for an important specification of the knowledge-based account for levels of interactive learning. First, in contrast to earlier findings on R&D collaboration and alliances, a monotonic version of the resource deficiency argument does not apply to interactive learning, whereas the non-monotonic relation between the strength of internal knowledge resources and levels of interactive learning with suppliers, does. This yields an important refinement for resource dependency theory. Second, the monotonic relation between the strength of knowledge resources and levels of interactive learning — the authentic absorptive capacity argument — is not supported by our findings. Cohen and Levinthal (1990) suggested that higher levels of prior related knowledge enhance the absorption of external knowledge. The significant non-monotonic effect of knowledge resources on levels of interactive learning reveals that the absorptive capacity argument is valid up to a certain threshold, after which the association is inverted. After this threshold, stronger knowledge resources occasion lower levels of interactive learning. This can have two related reasons. One is that the external monitoring of other firms encourages innovator firms to reassess their own knowledge base and identify formerly unidentified knowledge resources. The other reason is that, beyond a certain threshold of knowledge exchanges, the informational value decreases (Gulati 1995). Furthermore, the significant non-monotonic interaction effect of the 'knowledge resource-complexity of innovative activities' on levels of interactive learning with customers is the most convincing argument for the value of combining theoretical perspectives. Moderate levels of complexity of innovative activities, combined with moderate levels of resources, are associated with the highest levels of interactive learning. If innovator firms perform simple innovative activities with a weak stock of knowledge, there is a high probability of low levels of interactive learning, as is the case if firms perform highly complex innovative activities and have a strong knowledge base.

Of all the variables in our research model, the structuring of innovative activities had the most consistent impact, in the sense that it explains higher levels of interactive learning with both suppliers and customers. Again these variables make the theoretical explanation of interactive learning richer, and allow a more elaborate analytical view, compared to the resource-based approach in which every aspect of organizational reality is considered as a resource. The distinction between internal and external integration shows that small- and medium-sized innovator firms enhance their monitoring capacity by internal integration, as well as by external embeddedness.

Our findings add to the argument that interactive learning is a very complex process influenced by multiple contingencies. Our results support the idea that firms learn from customers as well as from suppliers, but that the factors driving them differ strongly. Interactive learning seems to be a phenomenon that can be explained for small- and medium-sized firms, but our results also suggest that our theoretical model cannot explain the interactive learning of larger firms with their suppliers and customers.

In assessing the contribution of our study, caution is needed, because there is no comparable research available that has empirically explored the antecedents of levels of interactive learning. Although there is no significant sampling bias in our population, we think that the relatively small number of larger firms impacted on our findings. Caution should also be exercised, because an important control variable — regional economic difference — was not included here. As described in our sample section, this region has specific characteristics, that together 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 to compare the external linkages of innovating firms within several comparable regions.

Notes

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1. NIAS (Netherlands Institute for the Advanced Studies in the Humanities and Social Sciences) Royal Netherlands Academy of Arts and Sciences, Meijboomlaan 1, 2242 PR, Wassenaar, The Netherlands.

References

Aiken, Michael, and Jerald Hage
1968 'Organizational interdependence and intra-organizational structure'. *American Sociological Review* 33: 912–929.

Alter, Catherine, and Jerald Hage
1993 *Organizations working together*. Newbury Park: Sage.

Anderson, Philip, and Michael L.Tushman
1990 'Technological discontinuities and dominant designs: a cyclical model of technological change'. *Administrative Science Quarterly* 35: 604–633.

Baldwin, William L., and John T. Scott
1987 *Market structure and technological change*. London: Harwood Academic.

Barney, Jay
1993 'Firm resources and sustained competitive advantage'. *Journal of Management Studies* 17: 99–120.

Boisot, Max
1998 *Knowledge assets. Securing competitive advantage in the information economy*. Oxford: Oxford University Press.

Chung, Seangwha, Harbir Singh, and Kyungmook Lee
2000 'Complementarity, status similarity and social capital as drivers of alliance formation'. *Strategic Management Journl* 21: 1–22.

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

Cohen, Wesley M., and Daniel. A. Levinthal
1990 'Absorptive capacity: A new perspective on learning and innovation'. *Administrative Science Quarterly* 35: 128–152.

Cohendet, Patrick, Jean-Alain A. Héraud, and Ehud Zuscovitch
1993 'Technological learning, economic networks and innovation appropriability' *in Technology and the wealth of nations. The dynamics of constructed advantage*. D. Foray, and C. Freeman (eds.), 66–76. London: Pinter.

Combs, James, G., and David J. Ketchen, jr.
1999 'Explaining interfirm cooperation and performance: toward a reconciliation of predictions from the resource-based view and organizational economics'. *Strategic Management Journal* 20: 867–888.

Cooke, Phil., Mikel Gomez Uranga, and Goio Extebarria
1997 'Regional innovation systems: institutional and organisations dimensions'. *Research Policy* 26: 475–491.

Cooke, Philip, Patries Boekholt, and Franz Tödtling
2000 *The governance of innovation in Europe. Regional perspectives on global competitiveness*. London: Pinter.

Coombs, Rod, Albert Richards, Pier Paolo Saviotti, and Vivian Walsh
1996 'Introduction: technological collaboration and networks of alliances in the innovation process' in *Technological collaboration: the dynamics of cooperation in industrial innovation.* R. Coombs, A. Richards, P.P. Saviotti, and V. Walsh (eds.), 1–17. Cheltenham: Edward Elgar.

Dewar, Robert, and Jerald Hage
1978 'Size, technology, complexity and structural differentiation: Toward a theoretical synthesis'. *Administrative Science Quarterly* 23: 111–136.

Dodgson, Mark
1993 'Organizational Learning: A Review of Some Literatures'. *Organization Studies* 14/3: 375–394.

Dougherty, Deborah
1992 'Interpretive barriers to succesful product innovation in large firms'. *Organization Science* 3: 179–202.

Duncan, Robert B.
1972 'Characteristics of organizational environments and perceived environmental uncertainty'. *Administrative Science Quarterly* 17: 313–327.

Edquist, Charles (ed.)
1997 *Systems of innovation: technologies, institutions and organizations*. London: Pinter.

Evan, William
1993 *Organization theory. Research and design.* New York: Maxwell Macmillan.

Fagerberg, Jan
1998 'User-producer interaction, learning and comparative advantage' in *Trade, growth and technical change.* D. Archibugi, and J. Michie (eds.), 208–225. Cambridge: Cambridge University Press.

Freeman, Christopher, and Luc Soete
1997 *The economics of innovation.* London: Pinter.

Galaskiewicz, Joseph
1985 'Interorganizational relations'. *Annual Review of Sociology* 11: 281–304.

Galli, Ricardo, and Morris Teubal
1997 'Paradigmatic shifts in national innovation systems' in *Systems of innovation: technologies, institutions and organizations.* C. Edquist (ed.), 343–370. London: Pinter.

Gambardella, Alfonso
1992 'Competitive advantages from in-house scientific research: The U.S. pharmaceutical industry in the 1980s'. *Research Policy* 21: 391–407.

Grandori, Anna
1997 'An organizational assessment if interfirm coordination modes'. *Organizations Studies* 18/5: 897–925.

Grant, Robert
1996 'Prospering in dynamically-competitive environments: organizational capability as knowledge integration'. *Organization Science* 7: 375–387.

Gulati, Ranjay.
1995 'Social structure and alliance formation: A longitudinal analysis'. *Administrative Science Quarterly* 40: 619–652.

Hage, Jerald, and Catherine Alter
1997 'A typology of interorganizational relationships and networks' in *Contemporary capitalism. The embeddedness of institutions*. J.R. Hollingsworth, and R. Boyer (eds.), 94–126. Cambridge: Cambridge University Press.

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

Henderson, Rebecca M., and Kim B. Clark
1989 'Architectural Innovation: the reconfiguration of existing products and the failure of established firms'. *Administrative Science Quarterly* 35: 9–30.

Huber, George.P.
1991 'Organizational Learning; the contributing process and the literatures'. *Organizational Science* 2/1: 88–115.

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

Jones, Candace, William S. Hesterly, and Stephen P. Borgatti
1997 'A general theory of network governance: exchange conditions and social mechanisms'. *Academy of Management Review* 22: 911–945.

Kleinknecht, Alfred, and Jeroen. O.N. Reijen
1992 'Why do firms cooperate on R&D? An empirical study'. *Research Policy* 21: 347–360.

Kogut, Bruce, and Udo Zander
1992 'Knowledge of the firm, combinative capabilities, and the replication of technology'. *Organization Science* 3: 383–397.

Lam, Alice
1997 'Embedded firms, embedded knowledge: problems of collaboration and knowledge transfer in global cooperative ventures'. *Organization Studies* 18/6: 973–996.

Lawrence, Peter. R., and Jay W. Lorsch
1967 *Organization and environment: managing differentiation and integration*. Cambridge, MA: Harvard Graduate School of Business Administration.

Leonard-Barton, Dorothy, and John L. Doyle
1996 'Commercializing technology: imaginative understanding of user needs' in *Engines of innovation. U.S. industrial research at the end of the era.* R.S. Rosenbloom and W.J. Spencer (eds.), 177–208. Boston, MA: Harvard Business School Press.

Lundvall, Bengt-Åke.
1985 *Product innovation and user–producer interaction*. Aalborg: Aalborg University Press.

Lundvall, Bengt-Åke.
1988 'Innovation as an interactive process' in *Technical change and economic theory*. G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds.), 349–369. London: Pinter.

Lundvall, Bengt-Åke
1992 'User–producer relationships, national systems of innovation and internationalization' in *National systems of innovation. Towards a theory of innovation and interactive learning*. B. A. Lundvall (ed.), 45–67. London: Pinter.

Meeus, Marius T.H., and Leon Oerlemans
1993 'Economic network research: a methodological state of the art' in *Networking in Dutch industries.* P. Beije, J. Groenwegen and O. Nuys (eds.), 37–68. Leuven, Apeldoorn: Garant.

Meeus, Marius T.H., and Leon Oerlemans
1995 'The competitiveness of firms in the region of North-Brabant' in *The Dutch diamond. The usefulness of Porter in analyzing small countries.* P. Beije, and O. Nuys (eds.), 223–256. Leuven, Apeldoorn: Garant/Siswo.

Meeus, Marius T.H., Leon Oerlemans, and Frans Boekema
1996 'Knowledge indicators and innovative performance' (in Dutch) in *Technology and the regional labour market*. O. Atzema, and J. van Dijk (eds.), 144–161. Assen: Van Gorcum.

Meeus, Marius T.H., Leon Oerlemans, and Jules van Dijck
2000a 'Interactive learning within a regional system of innovation. A case study in a Dutch region' in *Knowledge, innovation and economic growth. The theory and practice of learning regions*. F. Boekema, K. Morgan, S. Bakkers, and R. Rutten (eds.), 192–216. Cheltenham: Edward Elgar.

Meeus, Marius T.H., Leon Oerlemans, and Jerald Hage
2000b 'Sectoral patterns of interactive learning. An empirical exploration of a case in a Dutch region'. *Technology analysis and strategic management* (in press).

Midgley, David F., Pamela D. Morisson, and John H. Roberts
1992 'The effect of network structures in industrial diffusion processes'. *Research Policy* 21: 533–552.

Miller, Danny, and Ming-Jer Chen
1994 'Sources and consequences of competitive inertia. A study of the U.S. airline industry'. *Administrative Science Quarterly* 39: 1–23.

Miller, Danny, and Peter H. Friesen
1982 'Innovation in conservative and entrepreneurial firms: Two models of strategic momentum'. *Strategic Management Journal* 3: 1–25.

Mowery, David C., Joan E. Oxley, and Brian S. Silverman
1996 'Strategic alliances and interfirm knowledge transfer'. *Strategic Management Journal* 17: 77–91.

Oerlemans, Leon, and Marius T.H. Meeus
1995 'Innovations and economic networks in Noord-Brabant (in Dutch)' in *Clusters and competitiveness. Towards new practices in Dutch business*. D. Jacobs, and A-P. de Man (eds.), 79–108. Alphen a/d Rijn/Zaventem: Samsom.

Oerlemans, Leon
1996 *The embedded firm: innovation in industrial networks* (in Dutch). Tilburg: Tilburg University Press.

Oerlemans, Leon, Marius T.H. Meeus, and Frans Boekema
1998 'Do networks matter for innovation'. *Journal of Social and Economic Geography* 3: 298–309.

Oliver, Amalya L., and Mark Ebers
1998 'Networking network studies: an analysis of conceptual configurations in the study of inter-organizational relationships'. *Organization Studies* 19/3: 549–583.

Pavitt, Keith
1984 'Sectoral patterns of technical change. Towards a taxonomy and a theory'. *Research Policy* 13: 343–373.

Pfeffer, Jeffrey, and Gerald R. Salançik
1978 *The external control of organizations: A resource dependence perspective*. New York: Basic Books.

Pisano, Gary P.
1990 'The R&D boundaries of the firm: an empirical analysis'. *Administrative Science Quarterly* 35: 153–176.

Rosenbloom, Richard S., and Clayton M. Christensen
1998 'Technological discontinuities, organizational capabilities, and strategic commitments' in *Technology, organization, and competitiveness. Perspectives on industrial and corporate change*. G. Dosi, D.J. Teece, and J. Chytry (eds.), 215–247. Oxford: Oxford University Press.

Saxenian, Annalee
1994 *Regional advantage. Culture and competition in Silicon Valley and Route 128*. Cambridge: Harvard University Press.

Schumpeter, Joseph
1975 *Capitalism, socialism and democracy*, 3rd. Ed. New York: Harper & Row (Originally published in 1942 by Harper & Row).

Senker, Jacqueline, and Wendy Faulkner
1996 'Networks, tacit knowledge and innovation' in *Technological collaboration: the dynamics of cooperation in industrial innovation.* R. Coombs, A. Richards, P.P. Saviotti and V. Walsh (eds.), 76–97. Cheltenham: Edward Elgar.

Simon, Herbert
1991 'Bounded rationality and organizational learning'. *Organization Science* 2: 125–134.

Smith, Keith
1995 'Interactions in knowledge systems: foundations, policy implications and empirical methods'. *STI Review* 16: 69–102.

Szulanski, Gabriel
1996 'Exploring internal stickiness: impediments to the transfer of best practice within the firm'. *Strategic Management Journal* 17: 27–43.

Teece, David, and Gary P. Pisano
1998 'The dynamic capabilities of firms' in *Technology, organization, and competitiveness. Perspectives on industrial and corporate change*. G. Dosi, D.J. Teece, and J. Chytry (eds.), 193–212. Oxford: Oxford University Press,

Teubal, Morris
1976 'On user needs and need determination: aspects of the theory of technological innovation'. *Research Policy* 5: 266–289.

Tyler, Beverly B., and H. Kevin Steensma
1995 'Evaluating technological collaboration opportunities: a cognitive modelling perspective'. *Strategic Management Journal* 16: 43–70.

Turner, Jonathan
1988 *A theory of social interaction.* Stanford: Stanford University Press.

Tushman, Michael L., and Philip Anderson
1989 'Technological discontinuities and organizational environments'. *Administrative Science Quarterly* 31: 439–465.

Tushman, Michael L., and Elaine Romanelli
1985 'Organizational evolution' in *Research in organizational behavior. An annual series of analytical essays and critical reviews,* Vol. 7. L.L. Cummings and B.M. Staw (eds.), 171–222. Greenwich, CT: JAI Press.

Vossen, Robert W., and Bart Nooteboom
1996 'Firm size and participation in R&D' in *Determinants of innovation. The message from new indicators*. A.H. Kleinknecht (ed.), 155–168. London: Macmillan.

Von Hippel, Eric
1976 'The dominant role of users in the scientific instrument innovation process'. *Research Policy* 5: 212–239.

Von Hippel, Eric
1987 'Cooperation between rivals: Informal know-how trading'. *Research Policy* 16: 291–302.

Wernerfelt, Birger
1984 'A resource-based view of the firm'. *Strategic Management Journal* 5: 171–180.

Windrum, Paul
1999 'Simulation models of technological innovation'. *American Behavioral Scientist* 42: 1531–155.