Interactive learning between industry and knowledge infrastructure in a high-tech region

Meeus, M.T.H.; Oerlemans, L.A.G.; Hage, J.

Published in:
Economic Geography of Higher Education

Publication date:
2003

Citation for published version (APA):
Meeus, M. T. H., Oerlemans, L. A. G., & Hage, J. (2003). Interactive learning between industry and knowledge infrastructure in a high-tech region: an empirical exploration of competing and complementary theoretical perspectives. In R. P. J. H. Rutten, & F. W. M. Boekema (Eds.), *Economic Geography of Higher Education: Knowledge, Infrastructure and Learning Regions.* (pp. 145-170). Routledge.

8 Interactive learning between industry and knowledge infrastructure in a high-tech region

An empirical exploration of competing and complementary theoretical perspectives

Marius Meeus, Leon Oerlemans and Jerald Hage

Introduction

In the last decade, there has been an ongoing debate on the role of universities and the broader knowledge infrastructure (educational institutes, R&D organisations in the public sector) in the innovative performance of Dutch industry (Ministry of Economic Affairs 1995, 1997). Special attention has been given to the linkage between knowledge infrastructure and industry. On the one hand, the dramatic decrease in Dutch R&D investment in the early 1990s and the negative effects of this on the competitiveness of the Dutch economy intensified this debate. On the other, the attention given to the alignment of university research with the knowledge demands of industry resulted from the relatively large public expenditure on university research, compared to the smaller sums contributed by industry.

In recent work, we have reported that a majority of Dutch firms tend to underutilise university research and public research laboratories, whereas R&D collaboration in the value chain occurs quite frequently (Meeus *et al.* 2000). In Table 8.1, data from four different surveys are presented. We found a strong variation in types of R&D collaboration. In general, the involvement of buyers and suppliers in R&D collaboration was found to be the strongest. An exception was found in the data on man–machine Interaction, where 61 per cent of innovating firms were found to practise R&D collaboration with universities and professional education and simultaneously there is a significantly higher percentage of R&D collaboration with R&D centres. Furthermore, our surveys of 1997 and 1998 revealed that in the networks of organisations involved in image processing technologies and man–machine interfacing technologies, the Dutch universities and TNO (Dutch Centre for Applied Research) were considered to be very important knowledge suppliers (Meeus *et al.* 1997, Oerlemans *et al.* 1999).

In sum, these findings suggest a rather loose coupling between knowledge infrastructure and the innovation processes of innovating firms. This ambivalent relation between industry and the knowledge infrastructure was also found by Rosenberg and Nelson (1996) and Mansfield (1991). However, other researchers

Table 8.1 Percentage of R&D collaborators with external actors in four Dutch surveys

R&D Collaboration	*MINT Survey (1992/1993) North-Brabant)*[a]	*CINT Survey (1996)*[b]	*Man-machine Interaction Survey (1998)*[c]	*Image processing Survey (1997)*[d]
Competitors	5	8	8	0
Education (universities, professional education)	12	17	61	21
R&D centres	18	23	26	21
Buyers	48	47	37	28
Suppliers	43	47	50	66

Notes
a Listwise N of R&D collaborators = 420.
b Listwise N of R&D collaborators = 224.
c Listwise N = 47.
d Listwise N = 35.

reported that this loose coupling was not invariable and may sometimes be transformed into very intense collaboration (Mitchell 1991). Galli and Teubal (1997) argue that this ambivalence toward the knowledge infrastructure is changing at present. Before the Second World War, NSIs (National Systems of Innovation) developed within a relatively well-defined sectoral or sub-system configuration schematically based on three R&D performing sectors (business sector, public sector, and universities), with relatively weak linkages between them, and a fourth basic infrastructural sub-system (bureau of standards, patent office, etc.). Every organisation within a building block fulfilled a specific role or function. For universities, this was higher education and basic research; for government labs, mission-oriented research; for business firms, applied research and technological development. Nowadays, it is necessary to distinguish between function and organisation, as the latter tends to play increasingly multiple roles. The major trends in all three sectors can be summarised by, on the one hand, a growing connectivity within and between the building blocks, and, on the other, a stronger alignment of knowledge generation and knowledge demand. For all actors involved, there seems to be a growing emphasis on linkages, on interaction, and on knowledge exchange and transfer (Galli and Teubal 1997). Although these observations are very appealing, they lack a sound theoretical explanation and an empirical basis. The aim of this chapter is to contribute to a more complete and theoretical understanding of the *probability* of interactive learning in innovator firms and the knowledge infrastructure in the context of innovation. Our research question is: why do firms develop linkages, and interact with actors in the knowledge infrastructure?

Our theoretical effort adds to the growing body of literature on technological collaboration, knowledge transfer, and boundary spanning of organisation, and performs several functions. First, we combine linkages, interaction, and learning into 'interactive learning' (Lundvall 1993) and advance an empirical measure for this concept. Second, we explore empirically the *complementarity* of activity and resource-based explanations of cooperation between innovator firms and actors in the knowledge infrastructure. In this chapter, we develop a theoretical account for interactive learning, synthesising the resource-based organisation theories in economics and sociology (Barney 1991; Håkansson 1987; Pfeffer and Salançik 1978) with elements of the knowledge-based theories on networks and learning (Cohen and Levinthal 1990; Edquist 1997; Grant 1996; Hage and Alter 1997; Jin and Stough 1998; Kogut and Zander 1992; Teece and Pisano 1998). Third, whereas much empirical literature focuses on dyadic relations of innovator firms with one external actor, we analyse the innovator firms' interactions with both a technical university (Eindhoven University of Technology, TU/e) and a public research organisation (Dutch Centre for Applied Research, TNO). This allows a comparison that has never been made before.

The structure of this chapter is as follows. First, we describe the components of our theoretical framework. Second, we describe the research design, including the sample and the analytical procedures. Third, we describe our results. Finally, we discuss these results and derive some theoretical and policy inferences.

Research model

Interactive learning

Theoretically, Lundvall's notion of interactive learning specifies the resource dependence argument in the context of innovation (see Figure 8.1). The basic premise of resource dependence theory is that organisations are open systems. From this, it follows that organisations (1) are not self-sufficient; (2) cannot

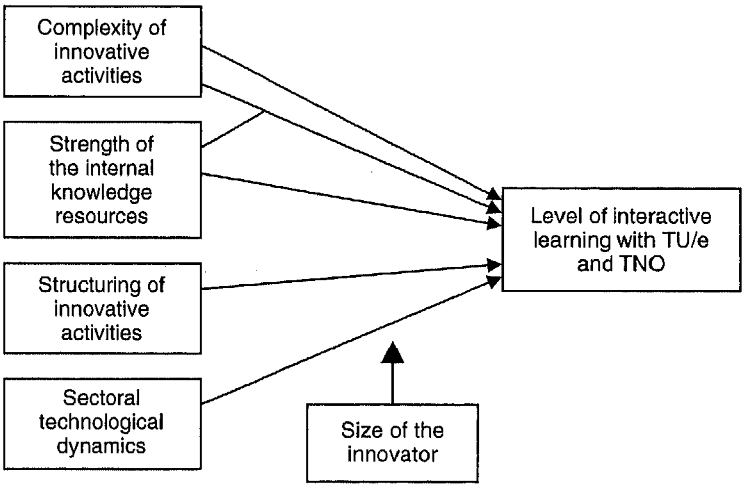

Figure 8.1 A research model of the relationship between interactive learning of innovating firms with divergent actors, the complexity of innovative activities, the strength of the internal knowledge resources, the structuring of innovative activities, effects of sectoral technological dynamics, controlling for size

generate all the necessary resources internally; and (3) must mobilise resources from other organisations in their environments if they want to survive. Acquiring the necessary resources involves interaction with other organisations that control these critical resources (Pfeffer and Salançik 1978: 25–28).

However, given the nature of innovation, the control assumption applied in the context of interactive learning 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 that enables firms to profit from the innovation, and explains innovator firms' inclination to formalise innovative ties. On the other hand, the complicated nature of technical knowledge (Von Hippel 1987; Lam 1997; Senker and Faulkner 1996; Szulanski 1996), its range, and significance are so difficult to assess that any contractual arrangement pursuing a specification of knowledge transactions would become an unworkable straitjacket. In the context of innovation, the control assumption is also put in perspective by the uncertain outcomes of knowledge exchange and knowledge sharing. Several authors have pointed to the loss of autonomy and increased dependence between collaborating firms (Alter and Hage 1993; Galaskiewicz 1985: 282; Hage and Alter 1997; Saxenian 1994: 148–149). The reluctance to initiate external knowledge acquisition (Huber 1991: 98), and the enhanced imitation risks diminishing innovation rents (Kogut and Zander 1992) also illustrate the limited control possibilities.

If the control of critical resources in innovation – in this case, technical knowledge – is so troublesome, the question arises as to why innovator firms engage in interactive learning. Galli and Teubal's main assumption is that the changing roles of actors in NSIs and the very nature of innovation generate a mutual interest for the producers of innovations and the knowledge infrastructure to interact and to learn.

Lundvall (1985) transformed the notion of user–producer interaction, introduced in the 1970s by Von Hippel (1976), Teubal (1976), and others, into the concept of interactive learning. The level of interactive learning between the innovator firms and external actors indicates the extent to which innovator firms have access to and acquire knowledge from external actors in order to innovate their products and/or processes. Operationally, the level of interactive learning is defined as the frequency with which innovator firms acquire knowledge inputs from external actors and transfer knowledge to external actors in order to effectively innovate products and/or processes. By engaging in interactive learning, firms expect to enhance their innovative and overall economic performance and to create value due to the pooling of complementary knowledge.

Resources

The central tenet of the resource-based approach is that firms select actions that best capitalise 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 environments 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 recognised, and hence neither product nor process innovations could be achieved. The heterogeneity of the resources – specialised skills, facilities and money – needed in innovation urges firms to actively monitor their resource bases as well as their financial position and to decide how to solve their resource deficits. The strength of internal knowledge resources determines their ability to cope with this heterogeneity. If resources are occupied or not available, a search for complementary resources starts. In that context, the intensification of existing relationships or the formation of new linkages with other firms or, institutional actors like universities are 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.

Freeman and Soete (1997: 133) contend that knowledge deficits explain the university–industry collaboration. In the chemical sector, the larger firms have tried to develop new specialised products themselves. However, as they did not have the necessary scientific research experience, they were often obliged to collaborate with universities. Monsanto, Hoechst, and ICI all made major agreements with selected university departments and hospitals in the fields of biotechnology.

Therefore, the interaction between innovating firms and a broad variety of firms and institutional actors is, on the one hand, the corollary of their needs for heterogeneous resources. On the other, it is an indication of external actors' capabilities to supplement their partners' resource deficits or shortages (Aiken and Hage 1968: 930; Combs and Ketchen Jr. 1999: 868; Håkansson 1987; Lundvall 1992). Summarising, interactive learning of innovator firms with actors in the knowledge infrastructure permits firms to share resources and thereby overcome resource-based constraints for innovative activities. This yields the following proposition:

Proposition 1 *The stronger the innovator firm's internal knowledge resources, the lower the probability of interactive learning with actors in the knowledge infrastructure.*

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. First, Cohen and Levinthal (1990) and Gulati (1995) argue that the ability to evaluate and utilise outside knowledge – firms' absorptive capacity – 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:

Proposition 2 *The stronger the innovator firm's internal knowledge resources, the higher the probability of interactive learning with actors in the knowledge infrastructure.*

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

Proposition 3 *Innovator firms with knowledge resources of moderate strength have a higher probability of interactive learning with actors in the knowledge infrastructure than innovator firms with weak or strong knowledge resources.*

Complexity of innovative activities

The major flaw of the resource-based view of the firm is the fact that resources and activities are conflated (Barney 1991: 101; Wernerfelt 1984: 172), which limits their analytical value. Lundvall's (1988) original account for interactive learning turns out to be more activity-based. In his view, the rate and radicalness of innovations occasion interactive learning. Therefore, it is theoretically useful to extend the resource-based view on interactive learning.

Kogut and Zander (1992: 388) define the complexity of a task as the number of operations required to solve a task. Jones *et al.* (1997: 921) stress another dimension of task complexity by referring to the number of specialised inputs needed to complete a product or service. In accordance with this, we define the complexity of innovative activities in terms of the innovator firm's learning and problem-solving efforts induced by the implemented innovative activities. We discern two complexity dimensions that both significantly enlarge this number of learning and problem-solving operations: first, the heterogeneity and intensity of perceived innovation pressures that compel innovator firms to adapt, and, second, the actual innovation rate. Innovation pressures include, e.g. perceived customer needs, competitor behaviour (Lundvall 1993), proliferation of new technical knowledge, new technical findings (Hage and Alter 1997), legal requirements, emergence of new markets, standardisation (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 specialised skills and knowledge (Dewar and Hage 1978; Jones *et al.* 1997), or makes existing competencies obsolete (Leonard-Barton and Doyle 1996). The higher the likelihood of incompatible innovation pressures, the higher the required capacity for problem solving, thus 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 can grow and this demands more interaction with external actors, primarily buyers and suppliers, but also with the knowledge infrastructure (Freeman and Soete 1997; Mitchell 1991).

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 1990; Rosenbloom and Christensen 1998). High innovation rates erase existing communication codes between users and producers (Lundvall 1992: 58), and raise the likelihood of the innovator firm's needing additional specialised skills of third parties, such as knowledge producers.

In sum, both the heterogeneity of innovation pressures and the rate of innovation demand more coordination and cooperation, the building of external linkages, and the control of many discrete activities, which in tandem generate a higher complexity of innovative activities (Evan 1993: 230; Hage and Alter 1997). The general proposition derived from the complexity argument is as follows:

Proposition 4 *Innovator firms performing more complex innovative activities have a higher probability of interactive learning with actors in the knowledge infrastructure.*

As was the case with the resource-based propositions, the relation between complexity and interactive learning could be either monotonic or non-monotonic. On the one hand, the argument is that innovative activities with low complexity probably do not require interactive learning, because neither innovation pressures nor innovation rates are high, hence there is no need for complementary knowledge. On the other, innovator firms are more inclined to perform extremely complex innovative activities within organisational boundaries. First, because the innovator firm's reputation might be damaged if external actors find out that the innovator firm cannot solve its own innovation problems (Huber 1991). Second, because the likelihood of finding partners that are able to solve problems associated with highly complex innovative activities decreases after a certain threshold point. Firms initiating innovations with moderate levels of complexity are more likely to detect problems they cannot solve themselves than firms initiating innovations of low complexity, and, simultaneously, the risk of a damaged reputation is lower than when extremely high complexity levels are involved. This increases the chance that a moderate complexity of innovative activities induce a comparatively high probability of interactive learning. This yields the following proposition:

Proposition 5 *Innovator firms performing innovation projects with moderate levels of complexity have a higher probability of interactive learning with actors in the knowledge infrastructure than firms performing innovative activities with low or high levels of complexity.*

The interaction between complexity of innovative activities and the strength of the knowledge resources

An additional reason to combine Lundvall's activity-based and the resource-based explanation of interactive learning is that we expect that their effects are complementary. Actually, a synthesis of the resource-based and the activity-based explanation for interactive learning yields a more comprehensive theoretical account of interactive learning. The complexity of the innovator firms' innovative activities 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 routine distribution activities with lower complexity, hence they reveal resource deficits or shortages and affect the probability of interactive learning. This yields the following proposition:

Proposition 6 *The effect of the strength of the internal knowledge resources on the probability of interactive learning with actors in the knowledge infrastructure is moderated by the complexity of the innovative activities.*

A non-monotonic version is also explored for this proposition. We expect that moderate levels of complexity and moderate quality of the resource base are associated with the highest probability of interactive learning. The argument runs parallel with the arguments pertaining to Proposition 3 and Proposition 5.

Proposition 7 *Innovator firms combining moderate levels of complexity of innovative activities with a moderate strength of their knowledge resources are more inclined to interactive learning with actors in the knowledge infrastructure than innovator 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 organisations contrasts strongly with the newer versions of the resource-based theories, such as the knowledge-based theory of Cohen and Levinthal (1990), Grant (1996), Kogut and Zander (1992) and Teece and Pisano (1998). These authors stress the significance of organisational 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 the 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 interrelated. 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; Dougherty 1992: 179; Teece and Pisano 1998: 198–200). 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-looking (production, engineering) and outward-looking (R&D, sales/marketing) departments enable a comparison of the internal and external opportunities for cooperation in innovation projects.

Proposition 8 *A higher level of integration of internal innovative activities increases the probability of interactive learning with actors in the knowledge infrastructure.*

In the systems of innovation literature, a new aspect of the organisational structuring of innovative activities is advanced: the embeddedness of innovating firms in so-called bridging institutions (Edquist 1997; Midgley *et al.* 1992). This may be the central government, but also agents such as technology centres responsible for local knowledge transfer, regional development authorities, trade or industrial associations, chambers of commerce, etc. 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). Because European and Dutch technology policies are geared toward clustering and networking (Cooke *et al.* 2000), in many EC countries technology subsidies are assigned only if the submitted innovation projects induce (international) collaboration. Many bridging institutions operate in this technology subsidy niche and are rewarded for their 'network' activities, which is conducive to their legitimacy. This yields the final proposition:

Proposition 9 *Stronger links with bridging institutions induce a higher probability of interactive learning with actors in the knowledge infrastructure.*

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 we control for is firm size, which is often considered a proxy for resource availability. Empirical research shows that firm size has dual effects. On the one hand, resource availability tends to grow as 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. Cash flow, for instance, a measure of internal financial capabilities, is empirically associated with higher levels of R&D intensity (Cohen and Levin 1989: 1072). Simultaneously, slack resources buffer firms from competition and promote insularity, affording economies of scale that capitalise 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 utilisation (Miller and Friesen 1982; Tushman and Romanelli 1985).

The second contingency is the enormous difference between sectoral technological dynamics. Pavitt's (1984) research revealed that the technological change between the high-tech and low-tech sectors differs significantly due to higher R&D spending in the former.

Research design

In this research, we combined case study analysis with survey research. We analysed twenty-three innovation projects in eighteen local firms. This helped us to develop a questionnaire allowing for a full treatment of theoretical issues related to innovative behaviour in innovation networks, issues which were left out of the Community Innovation Survey (CIS). This survey was performed in fifteen 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. Gathering data from a representative sample of firms allows us to generalise our findings.

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 in this region was roughly 210,000, i.e. the manufacturing sector share of employment in the region was 28.8 per cent (the Netherlands, 19.5 per cent). The region of North Brabant has features that differ widely from agricultural regions (Zeeland, Groningen, and Drenthe), and Dutch service-oriented regions like South and North Holland. Brabant's industrialisation started in c. 1850 and was based on traditional industries like dairy, textiles and wool. The North Brabant region has two universities and three innovation centres. A strong group of key players in internationalised industries and its location near important distribution centres like Rotterdam and Antwerp make this region highly attractive for foreign direct investment. In the Dutch context this region is considered a high-tech region, housing multinational enterprises such as Philips, DAF trucks, Royal Dutch Shell, Akzo Chemical, DSM, former Fokker (aircraft) and Fuji. Brabant also accommodates a number of important medium-sized niche international players, like ASM Lithography, OCÉ and Rank Xerox (copiers), ODME (optical disc equipment), Ericsson, EMI (CDs), General Plastics, etc.

The population of firms in the region consists of a mix of small, medium-sized and large enterprises. About 84 per cent of the responding firms have one 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 per cent boundaries. The mean deviation between the percentages in the sample and in the response is 6.4 per cent points. The sample of industrial firms is classified according to Pavitt's taxonomy (Oerlemans 1996) (see Table 8.2).

Table 8.2 Population and sample divided into Pavitt sectors

Pavitt sector	*Population (%) (N)*	*Total sample (%) (N)*	*Sample of innovating respondents (%) (N)*
Supplier-dominated	33.5 (1028)	25.7 (149)	22.9 (92)
Scale intensive	41.1 (1261)	36.1 (209)	34.1 (137)
Specialised suppliers	13.6 (478)	21.4 (124)	22.1 (89)
Science-based	11.8 (363)	16.8 (97)	20.9 (84)
Total	100 (3130)	100 (579)	100 (402)

Measurement

Interactive learning is measured as a multidimensional construct, with a learning dimension and an interaction dimension (for the items, see Table 8.3).

The learning dimension of interactive learning was measured in terms of the contents of the transferred knowledge that supplement the innovating firms' knowledge base (Dodgson 1993) and augments the range of their potential behaviour (Huber 1991; Jin and Stough 1998). Our indicators measured the extent to which TNO or TU/e actively contributed to the innovating firms' innovations, either by active participation in or by their contribution of ideas to the innovation process of the innovating 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 in which the behaviours of one actor are consciously reorganised, and influenced by 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.

Table 8.3 Measurement of the dependent variable 'Interactive Learning'

Variable	*Indicators*
Interactive Learning with Technische Universiteit Eindhoven (Eindhoven University of Technology)	Two items were included in this variable: (1) firms were asked if they acquired information and/or knowledge from Eindhoven University of Technology (TU/e); (2) firms were asked how often Eindhoven University of Technology (TU/e) contributed to their innovation processes by bringing up ideas, or participate actively. Item 1 was coded: (1) No, or (2) Yes. For item 2 answers were coded: (1) never; (2) sometimes; (3) regularly; (4) often; (5) always. A sum score was computed. If the resulting sum score equalled 2, this value was coded 0 indicating no interactive learning between the innovating firm and Eindhoven University of Technology (TU/e). A resulting sum score higher than 2 was coded 1 indicating interactive learning between Eindhoven University of Technology (TU/e) and the innovating firm.
Interactive Learning with TNO (Dutch Centre for Applied Research)	Two items were included in this variable: (1) firms were asked if they acquired information and/or knowledge from the Dutch Centre for Applied Research (TNO); (2) firms were asked how often the Dutch Centre for Applied Research (TNO) contributed to their innovation processes by bringing up ideas, or participate actively. Item 1 was coded: (1) No, or (2) Yes. For item 2 answers were coded: (1) never; (2) sometimes; (3) regularly; (4) often; (5) always. A sum score was computed. If the resulting sum score equalled 2, this value was coded 0 indicating no interactive learning between the innovating firm and the Dutch Centre for Applied Research (TNO). A resulting sum score higher than 2 was coded 1 indicating interactive learning between the Dutch Centre for Applied Research (TNO) and the innovating firm.

Resources

Scholars have different opinions with regard to the resources involved in innovation. Håkansson (1989) 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 restricted the measurement of the strength of the knowledge resources to three different knowledge-based indicators (see Table 8.4). First, R&D intensity (Baldwin and Scott 1987; Cohen and Levinthal 1990); second, the percentage of higher educated workforce (Jin and Stough 1998; Kleinknecht and Reijnen 1992); third, the number of problems firms had experienced during their innovation projects (Meeus, *et al.* 1996). A large number of innovation problems indicates large resource deficits. In order to align the meaning of this indicator with the other indicators, the raw scores were recoded. High scores on this indicator represent 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 8.4). The first dimension is the heterogeneity and intensity of perceived innovation pressures, which define the diversity of environmental pressures (Duncan 1972) pushing firms to innovate. The items pertain to customer demands, innovative behaviour of competitors, new market needs, and technical findings, as well as 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 (Pisano 1990; Schumpeter 1975: 83; Tushman and Anderson 1986). 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 1988–93. The rate of innovation measures the extent to 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.

Structuring of activities

The structuring of innovative activities is measured using two separate variables: the level of integration of internal innovative activities and the

Table 8.4 Measurement of the independent variables and one control variable

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-year period. Each item was coded: (1) 0–20%; (2) 20–40%; (3) 40–60%; (4) 60–80%; (5) 80–100%. An average score was computed, which was standardised.
	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 standardisation. Items were coded: (1) never; (2) sometimes; (3) regularly; (4) often; (5) always. An average score was computed, which was standardised.
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 standardised.

Variable	*Indicators*	*Calculation of scores*
	Percentage of higher educated employees	The number of higher educated employees as a percentage of the total workforce of the firm. The variable was standardised.
	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, it was coded 1, else it was coded 0. A sum score was computed and the resulting variable was recoded and standardised. Low scores indicate high levels of resource deficits, and high scores indicate low levels of resource deficits.
Structuring of innovative activities The separate indicators 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 standardised.
	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 standardised.
Pavitt sector	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 control variable	Size dummy	Firms were coded 0 if they had less than 100 employees. Firms were coded 1 if they had 100 employees or more.

level of support of bridging institutions. We measured the integration of internal innovative activities keeping in mind the extent to which internal departments contribute to the firm's innovation process. The external dimension – the level of support from bridging institutions – was measured by the frequency with which chambers of commerce, industrial associations, and innovation centres contributed to the innovating firms' innovation process (for the items, see Table 8.4).

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 8.4). We used a dummy variable for the measurement of technological dynamics. We made a distinction between traditional industries (supplier-dominated and scale-intensive industries) and modern industries (specialised suppliers and science-based industries). Empirical research confirmed the differences in participation and R&D spending between Pavitt sectors in the Netherlands. R&D spending in Dutch industries has the following ranking: (4) supplier-dominated; (3) scale-intensive; (2) specialised 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 in different Pavitt sectors. The impact of sectoral differences requires a control for its effects. Therefore, we distinguish 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.

Analyses

In this chapter, we restrict our analyses to exploratory analyses. After all, no empirical research has tested the same models. For this reason, one must be cautious in generalising the empirical findings. In testing our propositions, we used stepwise logistic regression. Owing to the skewed distribution of the level of interactive learning, and the ordinal dependent and independent variables, ordinary least square regression was not allowed. Six separate models were estimated, exploring the probability of interactive learning with (1) TU/e (Eindhoven University of Technology); (2) TNO (Dutch Centre for Applied Research); (3) TU/e for small and medium-sized innovator firms with less than 100 employees; (4) TU/e for firms with 100 employees or more; (5) TNO for small and medium-sized firms with less than 100 employees; and (6) TNO for firms with 100 employees or more.

The interpretation of our research findings differs for the monotonic and non-monotonic propositions. The variables interactive learning, 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. A significant Exp(b) larger than 1.0 signifies that higher scores on the independent variables are associated with a higher probability of interactive learning. A significant Exp(b) smaller than 1.0 means that higher levels of complexity are associated with a lower probability of interactive learning.

To control for non-monotonic effects, we included squared terms for the strength of the knowledge resources, the complexity of innovative activities, and their cross-product term. For the squared variables, the interpretation is as follows. A significant Exp(b) larger than 1.0 means that the relation between that independent variable and the probability of interactive learning is U-shaped. So, low and high scores on the independent variable are associated with a higher probability of interactive learning, and the moderate scores on that independent variable are associated with a lower probability of interactive learning. A significant Exp(b) smaller than or equal to 1.0 signifies an inverted U-shaped relation between independent variables and the probability of interactive learning. In this case, moderate scores on the independent variable are associated with the highest probability of interactive learning, and low and high scores of the independent variable are associated with low probabilities of interactive learning.

Results

First, we will review the outcomes of our descriptive analyses. Then, the results of Propositions 1–8 will be reviewed.

Table 8.5 reveals that there are only weak correlations between interactive learning and the independent variables. The structuring of innovative activities turns out to be associated positively with interactive learning between innovator firms and both TU/e and TNO. The complexity of innovative activities and the strength of the internal knowledge resources are only correlated with the interactive learning of innovator firms with TU/e. As expected, sectoral technological dynamics impacted on the probability of interactive learning.

Table 8.6 displays the results relevant to our propositions. Proposition 1 and 2 predicted either a positive or a negative effect of the strength of the internal knowledge resources on the probability of interactive learning with external actors. Our findings in Table 8.6 (model 3 Exp(b) = 1.44, *p.* = 0.05; model 6 Exp (b) = 1.40, *p.* = 0.10) support Proposition 2 and confirm the absorptive capacity argument. The resource deficit argument rendered in Proposition 1 is rejected by these findings.

Proposition 3 predicted an inverted-U shaped relation between the strength of internal knowledge resources and the probability of interactive learning with external actors. This proposition is supported only for interactive learning of small and medium-sized innovator firms with the TU/e (model 2: Exp(b) 0.85, *p.* = 0.05). This finding refines the absorptive capacity argument in several

Table 8.5 Descriptive statistics

Variables	*Mean scores*	*SD*	*Correlation (Spearman's Rho) of independent variables with dependent variables* *Interactive learning with EUT*	 *Interactive learning with TNO*
Interactive learning with Eindhoven University of Technology	0.285	0.452		
Interactive learning with Dutch Centre for Applied Research (TNO)	0.380	0.486		
Complexity of innovative activities	0.004	1.576	0.15^{c}	0.06
Complexity of innovative activities [squared]	2.480	3.454	−0.02	−0.07
Strength of internal knowledge resources	0.347	2.175	0.09^{a}	0.03
Strength of internal knowledge resources [squared]	4.859	14.202	0.03	0.02
Cross-product term of strength of internal knowledge resources and complexity	0.366	3.501	−0.01	0.01
Cross-product term of strength of internal knowledge resources and complexity [squared]	12.358	52.745	0.01	−0.04
Level of integration of internal innovative activities	0.003	0.999	0.14^{b}	0.10^{a}
Level of support by bridging institutions	0.003	1.001	0.14^{c}	0.19^{d}
Pavitt sector	0.432	0.496	0.09^{a}	-0.13^{b}

Notes
a $p = 0.10$.
b $p = 0.05$.
c $p = 0.01$.
d $p = 0.001$.
Listwise N = 266.

Table 8.6 Stepwise Logistic Regression Analyses with interactive learning with TU/e and TNO 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

Independent variables	*Indicators*	*IL with TU/e*			*IL with TNO*		
		Model 1 *All firms* *Exp(b)*	*Model 2* *Less than 100* *Exp(b)*	*Model 3* *100 or more* *Exp(b)*	*Model 4* *All firms* *Exp(b)*	*Model 5* *Less than 100* *Exp(b)*	*Model 6* *100 or more* *Exp(b)*
Strength of the internal knowledge resources	P1/2 SIKR	1.12	0.94	1.44^{b}	1.10	0.96	1.40^{a}
	P3 SIKR (Sq.)	0.94	0.85^{b}	1.03	0.97	0.95	1.16
Complexity of innovative activities	P4 COMP	1.25^{a}	1.15	1.58^{a}	0.99	0.92	1.68
	P5 COMP (Sq.)	0.87^{a}	0.75^{b}	1.17	0.90^{a}	0.89	1.02
Interaction effects	P6 COMP*SIKR	0.97	1.04	1.03	1.01	1.04	1.36
	P7 [COMP*SIKR] Sq.	1.03^{b}	1.09^{c}	0.95	1.03^{b}	1.02^{b}	0.97
Structuring of innovative activities	P8 LIIA	1.13	0.98	1.14	1.07	0.99	0.87
	P9 LSBI	1.27^{a}	1.39^{b}	1.45	1.56^{c}	1.72^{d}	1.79
Pavitt sectors	PAVITT (dummy)	1.46	1.67	1.32	0.57^{b}	0.56^{a}	0.39
Constant	Constant	−1.09^{d}	−0.99^{d}	−0.57^{b}	−0.27	−0.82^{d}	0.36
-2LL		279.79	181.10	75.337	329.247	228.064	81.732
Goodness of fit		266.87	194.651	61.747	267.456	205.758	62.106
Significance		0.5605	0.5094	0.1377	0.2742	0.3047	0.1625
Percentage correct		75.9%	61.9%	62.1%	65.4%	73.4%	61.9%
Model Chi Square		13.754	20.394	8.394	20.868	20.117	3.674
Significance		0.0081	0.0004	0.0150	0.0003	0.0002	0.0553
Nagelkerke R Square		7.5%	15.2%	17.0%	10.3%	13.4%	7.6%
N		266	203	63	266	203	63

Notes

a $p = 0.10$.
b $p = 0.05$.
c $p = 0.01$.
d $p = 0.001$.

COMP = Complexity of innovative activities; COMP (Sq.) = Complexity of innovative activities squared; SIKR = Strength of the internal knowledge resources; SIKR (sq.) = Strength of internal knowledge resources squared; COMP*SIKR = Interaction term of complexity of innovative activities and strength of the internal knowledge resources; [COMP*SIKR] Sq. = Interaction term of complexity of innovative activities and strength of the internal knowledge resources squared; LIIA = Level of integration and innovative activities; LSBI = Level of support by bridging institutions; PAVITT = Pavitt sectors.

senses. First, because stronger knowledge resources occasion higher probabilities of interactive learning only up to a threshold, beyond which the presumed absorptive capacity effect is inverted. Second, the effect only holds for small and medium-sized innovator firms' interactive learning with TU/e.

Proposition 4 predicted that a higher complexity of innovative activities would occasion a higher probability of interactive learning with external actors. As Table 8.6 reveals (model 1 (Exp(b) = 1.25, *p.* = 0.10; model 3 (Exp(b) = 1.58, *p.* = 0.10), this proposition is supported for the probability of interactive learning with the TU/e. A sample split, controlling for size effects, shows that this complexity effect is significant for innovator firms with more than 100 employees. Proposition 4 was not supported for interactive learning with TNO.

Proposition 5 predicted an inverted U-shaped relation between complexity of innovative activities and the probability of interactive learning. This was confirmed in model 1 (Exp(b) = 0.87, *p.* = 0.10), model 2 (Exp(b) = 0.75, *p.* = 0.05) and model 4 (Exp(b) = 0.90, *p.* = 0.10). This means that innovator firms performing innovative activities with moderate levels of complexity have the highest probability of interactive learning, and innovator firms performing innovative activities with low and high levels of complexity have relatively lower probabilities of interactive learning. However, these findings turned out to be quite sensitive for size effects. In the case of interactive learning with the TU/e, a sample split revealed that Proposition 5 was only valid for innovator firms with more than 100 employees. For the models estimating Proposition 5 for TNO the predicted effects disappeared when the sample was split into two size classes.

Proposition 6 was not supported at all. Proposition 7 predicted an *inverted* U-shaped relation between the cross-product term of 'complexity of innovative activities and strength of knowledge resources' and the probability of interactive learning. This proposition was rejected by our findings, which showed that for both TU/e and TNO there was a U-shaped relation between the interaction effect and the probability of interactive learning. A sample split again showed that this interaction effect occurred especially among small and medium-sized innovator firms.

The results with respect to the effects of the structuring of innovative activities – P8 and P9 – again informed us about the rather specific patterns of interactive learning. Proposition 8 was not supported at all by our findings. The level of support of bridging institutions was found to affect the probability of interactive learning with TU/e and TNO positively (model 1 Exp(b) = 1.27, *p.* = 0.10; model 2 Exp(b) = 1.39, *p.* = 0.05; model 4 Exp(b) = 1.56, *p.* = 0.01; model 5 Exp(b) = 1.72, *p.* = 0.001). Again, the control for sample size revealed that the effect of embeddedness in bridging institutions was particularly strong among small and medium-sized firms. The effect of sectoral technological dynamics was contrary to our expectations in the sense that the traditional sectors especially (supplier-dominated and scale-intensive) turned out to induce higher probabilities of interactive learning. As was the case with many other tested effects, the technological dynamics appeared to be contingent on the type of actor and size, and were only valid for small and medium-sized innovator firms' interactive learning with TNO.

Conclusion

This study sheds new light on the way in which innovative behaviour affects the link between individual firms and the knowledge infrastructure. Economic theorists have focused on the institutional effects of interactive learning without theorising on its antecedents, whereas network theorists, learning theorists, and resource-base theorists have concentrated either on the governance, structures, outcome effects, or resources shoved around in networks and ignored the specific learning processes going on in networks (Oliver and Ebers 1998). Our theoretical model brings interactive learning into the realm of organisation theory and unites several perspectives by exploring levels of interactive learning with a theoretical model that combines resource dependence, resource-based, and activity-based arguments.

This study provides evidence suggesting that a singular theoretical perspective would yield a very partial explanation of interactive learning between innovator firms and the knowledge infrastructure. Neither a singular resource-based explanation (Cohen and Levinthal 1990), nor a singular activity-based explanation (Lundvall 1992) would explain the probability of interactive learning sufficiently. The significance of the interaction effect between the complexity of innovative activities and strength of the knowledge base of innovator firms convincingly supports our approach of combining theoretical perspectives. Our model of interactive learning suggests that the interactive learning of innovator firms with actors in the knowledge infrastructure can and should be studied by considering the internal knowledge base, the complexity of innovative activities and the external embeddedness of innovator firms in bridging institutions.

The relations we proposed between the complexity of innovative activities, the strength of the internal knowledge resources, the structuring of innovative activities, and the level of interactive learning turned out to be very sensitive for the contingencies we have specified. The significant effects were found either after a sample split (Table 8.6: P1/2, model 3 and 4; P3 model 2), or disappeared after a sample split (Table 8.6: P5, model 4), or remained significant after a sample split for one of the size categories (Table 8.6: P4, model 1 and 3; P5, model 1, and 3; P7, model 1, 2, 4, and 5; P9, model 1, 2, 4, and 5). There were also differences between the science-oriented TU/e and TNO, which performs applied science. The empirical findings suggest that our theoretical model yields more significant results for the interactive learning with TU/e. For the small and medium-sized innovator firms, a proximity effect might explain this phenomenon, as TNO's head office is located in another province. However, such an explanation does not hold for larger firms.

Our approach of testing monotonic effects in combination with non-monotonic effects, interaction effects, and a control for size and type of actor proved to be very fruitful theoretically. It allowed us to specify the main arguments advanced. The significance of non-monotonic effects allowed for a refinement of the absorptive capacity argument (Cohen and Levinthal 1990) and the resource deficits arguments of Aiken and Hage (1968) and Evan (1993). The significance of the non-monotonic effects of the complexity of innovative activities enhances a refinement of the complexity argument (Lundvall 1988; Pfeffer and Salançik 1978), and illustrates that the absorptive capacity effect is conditional on the complexity of innovative activities. Our findings contrast strongly with the general notion of interactive learning in the systems of innovation literature (Edquist 1997; Lundvall 1992, 1993). The results suggest that there is more than one avenue for initiating interactive learning between the enormous variety of actors involved in the innovation process. Practically speaking, it may be possible to facilitate interactive learning by investing in a highly skilled workforce and pooling social and technical disciplines by means of intelligent organisational designs and project management. However, this would probably yield different effects on the level of interactive learning with, e.g. the customers, than on the level of interactive learning with the (public) knowledge infrastructure, and it would work out differently in distinct industrial sectors. For future research, this implies that scholars of interactive learning should include and specify a broad variety of external actors and industrial sectors in their analyses.

Caution is needed in assessing the contribution of our study, as there is no comparable research available that has empirically tested explanations of interactive learning. 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 features that, combined with a consensus-driven Dutch regulatory style, might induce very distinct patterns of interaction between industry and knowledge infrastructure. 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 recommend research focusing on the comparison of strategies for the acquisition of distinct resources and their relative contributions to innovative performance. This would allow us to support the efficiency of network strategies as well as the efficacy of regional innovation systems more solidly.

References

Aiken, M. and Hage, J. (1968) 'Organizational Interdependence and Intra-organizational Structure', *American Sociological Review* 33: 912–929.

Alter, C. and Hage, J. (1993) *Organizations Working Together*, Newbury Park, CA: Sage Publications.

Anderson, P. and Tushman, M. L. (1990) 'Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change', *Administrative Science Quarterly* 35: 604–633.

Baldwin, W. L. and Scott, J. T. (1987) *Market Structure and Technological Change*, London: Harwood Academic Publishers.

Barney, J. (1991) 'Firm Resources and Sustained Competitive Advantage', *Journal of Management Studies* 17: 99–120.

Chung, S., Singh, H. and Lee, K. (2000) 'Complementarity, Status Similarity and Social Capital as Drivers of Alliance Formation', *Strategic Management Journal* 21: 1–22.

Cohen, W. M. and Levin, R. C. (1989) 'Empirical Studies of Innovation and Market Structure', in R. Schmalensee and R. D. Willig (eds) *Handbook of Industrial Organisation*, Amsterdam: Elsevier Science Publishers, pp. 1060–1170.

Cohen, W. M. and Levinthal, D. A. (1990) 'Absorptive Capacity: A New Perspective on Learning and Innovation', *Administrative Science Quarterly* 35: 128–152.

Cohendet, P., Héraud, J. A. A. and Zuscovitch, E. (1993) 'Technological Learning, Economic Networks and Innovation Appropriability', in D. Foray and C. Freeman (eds) *Technology and the Wealth of Nations: The Dynamics of Constructed Advantage*, London: Pinter Publishers, pp. 66–76.

Combs, J. G. and Ketchen Jr., D. J. (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, P., Boekholt, P. and Tödtling, F. (eds) (2000) *The Governance of Innovation in Europe: Regional Perspectives on Global Competitiveness*, London: Pinter.

Dewar, R. and Hage, J. (1978) 'Size, Technology, Complexity and Structural Differentiation: Toward a Theoretical Synthesis', *Administrative Science Quarterly* 23: 111–136.

Dodgson, M. (1993) 'Organizational Learning: A Review of Some Literatures', *Organization Studies* 14: 375–394.

Dougherty, D. (1992) 'Interpretive Barriers to Succesful Product Innovation in Large Firms', *Organization Science* 3: 179–202.

Duncan, R. B. (1972) 'Characteristics of Organizational Environments and Perceived Environmental Uncertainty', *Administrative Science Quarterly* 17: 313–327.

Edquist, C. (ed.) (1997) *Systems of Innovation: Technologies, Institutions and Organizations*, London: Pinter.

Evan, W. (1993) *Organization Theory: Research and Design*, New York: Maxwell MacMillan Publishing Company.

Freeman, C. and Soete, L. (1997) *The Economics of Innovation*, London: Pinter.

Galaskiewicz, J. (1985) 'Interorganizational Relations', *Annual Review of Sociology* 11: 281–304.

Galli, R. and Teubal, M. (1997) 'Paradigmatic Shifts in National Innovation Systems', in C. Edquist (ed.) *Systems of Innovation: Technologies, Institutions and Organizations*, London: Pinter, pp. 343–370.

Gambardella, A. (1992) 'Competitive Advantages from In-house Scientific Research: The U.S. Pharmaceutical Industry in the 1980's', *Research Policy* 21: 391–407.

Grandori, A. (1997) 'An Organizational Assessment of Interfirm Coordination Modes', *Organization Studies* 18: 897–925.

Grant, R. (1996) 'Prospering in Dynamically-competitive Environments: Organizational Capability as Knowledge Integration', *Organization Science* 7: 375–387.

Gulati, R. (1995) 'Social Structure and Alliance Formation: A Longitudinal Analysis', *Administrative Science Quarterly* 40: 619–652.

Hage, J. and Alter, C. (1997) 'A Typology of Interorganizational Relationships and Networks', in J. R. Hollingsworth and R. Boyer (eds) *Contemporary Capitalism: The Embeddedness of Institutions*, Cambridge: Cambridge University Press, pp. 94–126.

Håkansson, H. (1987) *Industrial Technological Development: A Network Approach*, London: Croom Helm.

Håkansson, H. (1989) *Corporate Technological Behavior: Co-operation and Networks*, London: Routledge.

Henderson, R. M. and Clark, K. B. (1990) 'Architectural Innovation: The Reconfiguration of Existing Products and the Failure of Established Firms', *Administrative Science Quarterly* 35: 9–30.

Huber, G. P. (1991) 'Organizational Learning: The Contributing Process and the Literatures', *Organizational Science* 2: 88–115.

Jin, D. J. and Stough, R. R. (1998) 'Learning and Learning Capability in the Fordist and Post-Fordist Age: An Integrative Framework', *Environment and Planning* A 30: 1255–1278.

Jones, C., Hesterly, W. S. and Borgatti, S. P. (1997) 'A General Theory of Network Governance: Exchange Conditions and Social Mechanisms', *Academy of Management Review* 22: 911–945.

Kleinknecht, A. and Reijen, J. O. N. (1992) 'Why Do Firms Cooperate on R&D? An Empirical Study', *Research Policy* 21: 347–360.

Kogut, B. and Zander, U. (1992) 'Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology', *Organization Science* 3: 383–397.

Lam, A. (1997) 'Embedded Firms, Embedded Knowledge: Problems of Collaboration and Knowledge Transfer in Global Cooperative Ventures', *Organization Studies* 18: 973–996.

Lawrence, P. R. and Lorsch, J. W. (1967) *Organization and Environment: Managing Differentiation and Integration*, Harvard Graduate School of Business Administration, Cambridge, MA: Harvard University Press.

Leonard-Barton, D. and Doyle, J. L. (1996) 'Commercializing Technology: Imaginative Understanding of User Needs', in R. S. Rosenbloom and W. J. Spencer (eds) *Engines of Innovation: U.S. Industrial Research at the End of the Era*, Cambridge, MA: Harvard Business School Press, Boston, pp. 177–208.

Lundvall, B.-Å. (1985) *Product Innovation and User-Producer Interaction*, Aalborg: Aalborg University Press.

Lundvall, B.-Å. (1988) 'Innovation as an Interactive Process', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds) *Technical Change and Economic Theory*, London: Pinter, pp. 349–369.

Lundvall, B.-Å. (1992) 'User-producer Relationships, National Systems of Innovations and Internationalisation', in D. Foray and C. Freeman (eds) *Technology and the Wealth of Nations: The Dynamics of Constructed Advantage*, London: Pinter, pp. 277–300.

Lundvall, B.-Å. (1993) 'User-producer Relationships, National Systems of Innovation and Internationalization', in B.-Å. Lundvall (ed.) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London: Pinter, pp. 45–67.

Mansfield, E. (1991) 'Academic Research and Industrial Innovation', *Research Policy* 20: 1–12.

Meeus, M. T. H. and Oerlemans, L. A. G. (1993) 'Economic Network Research: A Methodological State of the Art', in P. Beije, J. Groenwegen and O. Nuys (eds) *Networking in Dutch Industries*, Leuven and Apeldoorn: Garant, pp. 37–68.

Meeus, M. T. H. and Oerlemans, L. A. G. (1995) 'The Competitiveness of Firms in the Region of North-Brabant', in P. Beije and O. Nuys (eds) *The Dutch Diamond: The Usefulness of Porter in Analyzing Small Countries*, Leuven and Apeldoorn: Garant/Siswo, pp. 223–256.

Meeus, M. T. H., Oerlemans, L. A. G. and Boekema, F. W. M. (1996) 'Knowledge Indicators and Innovative Performance' (in Dutch), in O. Atzema and J. van Dijk (eds) *Technology and the Regional Labour Market*, Assen: Van Gorcum, pp. 144–161.

Meeus, M. T. H., Oerlemans, L. A. G. and Dijck, J. van (2000) 'Interactive Learning within a Regional System of Innovation: A Case Study in a Dutch Region', in F. Boekema, K. Morgan, S. Bakkers and R. Rutten (eds) *Knowledge, Innovation and Economic Growth: The Theory and Practice of Learning Regions*, Cheltenham: Edward Elgar.

Meeus, M. T. H., Oerlemans, L. A. G. and Faber, E. (1997) *IOP Image Processing: Matching Knowledge Demand and Supply by Means of Identification of Knowledge Producers and Users and Network Analysis* (in Dutch), external report commissioned by SENTER for Technology, Energy and Environment, The Hague.

Meeus, M. T. H., Oerlemans, L. A. G. and Hage, J. (1999) *Sectoral Patterns of Interactive Learning: An Empirical Exploration of a Case in a Dutch Region*, ECIS Working Paper Series 99/5, Eindhoven: ECIS.

Midgley, D. F., Morrison, P. D. and Roberts, J. H. (1992) 'The Effects of Networks Structure in Industrial Diffusion Processes', *Research Policy* 21: 533–552.

Miller, D. and Chen, M. J. (1994) 'Sources and Consequences of Competitive Inertia: A Study of the U.S. Airline Industry', *Administrative Science Quarterly* 39: 1–23.

Miller, D. and Friesen, P. H. (1982) 'Innovation in Conservative and Entrepreneurial Firms: Two Models of Strategic Momentum', *Strategic Management Journal* 3: 1–25.

Ministry of Economic Affairs (1995) *Dynamic Knowledge: On Knowledge and Skills in the Dutch Economy* (in Dutch), The Hague: Ministry of Economic Affairs.

Ministry of Economic Affairs (1997) *The Competitiveness Test 1997* (in Dutch), The Hague: Ministry of Economic Affairs.

Mitchell, W. (1991) 'Using Academic Technology: Transfer Methods and Licensing Incidence in the Commercialization of American Diagnostic Imaging Equipment Research, 1945–1988', *Research Policy*, 20: 203–216.

Mowery, D. C., Oxley, J. E. and Silverman, B. S. (1996) 'Strategic Alliances and Interfirm Knowledge Transfer', *Strategic Management Journal* 17: 77–91.

Nelson, R. (1982) 'The Role of Knowledge in R&D Efficiency', *Quarterly Journal of Economics* 97: 453–470.

Nelson, R. (ed.) (1993) *National Innovation Systems: A Comparative Analysis*, New York: Oxford University Press.

Oerlemans, L. (1996) *The Embedded Firm: Innovation in Industrial Networks* (in Dutch), Tilburg: Tilburg University Press.

Oerlemans, L. A. G., Meeus, M. T. H. and Boekema, F. W. M. (1998) 'Do Networks Matter for Innovation', *Journal of Social and Economic Geography* 3: 298–309.

Oerlemans, L. A. G., Meeus, M. T. H. and Kraus, A. (1999) *IOP Human Systems Interaction: Matching Knowledge Demands and Supply by Means of Identification of Knowledge Producers and Users and Network Analysis* (in Dutch), external report commissioned by SENTER for Technology, Energy and Environment, The Hague.

Oliver, A. L. and Ebers, M. (1998) 'Networking Network Studies: An Analysis of Conceptual Configurations in the Study of Inter-organizational Relationships', *Organization Studies* 19: 549–583.

Pavitt, K. (1984) 'Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory', *Research Policy* 13: 343–373.

Pfeffer, J. and Salançik, G. R. (1978) *The External Control of Organizations: A Resource Dependence Perspective*, New York: Basic Books.

Pisano, G. P. (1990) 'The R&D Boundaries of the Firm: An Empirical Analysis', *Administrative Science Quarterly* 35: 153–176.

Rosenberg, N. and Nelson, R. R. (1996) 'The Role of Universities in the Advance of Industrial Technology', in R. S. Rosenbloom and W. J. Spencer (eds) *Engines of Innovation: U.S. Industrial Research at the End of an Era*, Cambridge, MA: Harvard University Press, pp. 87–110.

Rosenbloom, R. S. and Christensen, C. M. (1998) 'Technological Discontinuities, Organizational Capabilities, and Strategic Commitments', in G. Dosi, D. J. Teece and J. Chytry (eds) *Technology, Organization, and Competitiveness: Perspectives on Industrial and Corporate Change*, Oxford: Oxford University Press, pp. 215–247.

Saxenian, A. (1994) *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Cambridge, MA: Harvard University Press.

Schumpeter, J. (1975) *Capitalism, Socialism and Democracy* (third edn), New York: Harper and Row (originally published in 1942 by Harper and Row).

Senker, J. and Faulkner, W. (1996) 'Networks, Tacit Knowledge and Innovation', in R. Coombs, A. Richards, P. P. Saviotti and V. Walsh (eds) *Technological Collaboration: The Dynamics of Cooperation in Industrial Innovation*, Cheltenham: Edward Elgar Publishing Ltd., pp. 76–97.

Smith, K. (1995) 'Interactions in Knowledge Systems: Foundations, Policy Implications and Empirical Methods', *STI Review* 16: 69–102.

Szulanski, G. (1996) 'Exploring Internal Stickiness: Impediments to the Transfer of Best Practice within the Firm', *Strategic Management Journal* 17: 27–43.

Teece, D. and Pisano, G. P. (1998) 'The Dynamic Capabilities of Firms', in G. Dosi, D. J. Teece and J. Chytry (eds) *Technology, Organization, and Competitiveness: Perspectives on Industrial and Corporate Change*, Oxford: Oxford University Press, pp. 193–212.

Teubal, M. (1976) 'On User Needs and Need Determination: Aspects of the Theory of Technological Innovation', *Research Policy* 5: 266–289.

Turner, J. (1988) *A Theory of Social Interaction*, Stanford, CA: Stanford University Press.

Tushman, M. L. and Anderson, P. (1986) 'Technological Discontinuities and Organizational Environments', *Administrative Science Quarterly* 31: 439–465.

Tushman, M. L. and Romanelli, E. (1985) 'Organizational Evolution', in L. L. Cummings and B. S. Staw (eds) *Research in Organizational Behavior: An Annual Series of Analytical Essays and Critical Reviews* 7, Greenwich, CT: JAI Press Inc, pp. 171–222.

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

Von Hippel, E. (1987) 'Cooperation between Rivals: Informal Know-how Trading', *Research Policy* 16: 291–302.

Vossen, R. W. and Nooteboom, B. (1996) 'Firm Size and Participation in R&D in A. H. Kleinknecht (ed.) *Determinants of Innovation: The Message from New Indicators*, London: Macmillan Press Ltd, pp. 155–168.

Wernerfelt, B. (1984) 'A Resource-based View of the Firm', *Strategic Management Journal* 5: 171–180.

Windrum, P. (1999) 'Simulation Models of Technological Innovation', *American Behavioral Scientist* 42: 1531–1550.