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Aija Leiponen

ESSAYS IN THE ECONOMICS OF KNOWLEDGE

Innovation, Collaboration, and Organizational Complementarities

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ABSTRACT: This study consists of an introduction and four essays on the organization of innovation activities in firms. The first essay (Chapter 2) examines theoretically the organization choice of an innovating firm. The firm may carry out an innovation project internally or outsource R&D. The chapter focuses on the effects of institutional environment on the costs of organization and the effects of technological environment on the incentives to invest in learning. Because there are complementarities among the essential knowledge assets, and transaction costs related to knowledge exchange, there is interaction between investment and organizational decisions. It follows that external organization of innovation projects is observed more often in highly uncertain technological environments characterized by radical innovation. More generally, organizational choices have long-term implications for firms' performance.

The second essay models the question of whether knowledge exchange between an R&D expert and an innovating firm is more efficient within an organization than across organizations. Knowledge exchange and cooperation, which underlie innovation, require investments of time and effort. It is argued that the same levels of effort may be achieved with relational contracts (the expert owns the essential asset) and employment contracts (the firm owns the asset). Both of these are long-term implicit contracts that necessitate patience and "not too high" variation of returns. However, the sustainability of these arrangements may differ. Specifically, relational contracts are more sustainable if involuntary knowledge spillovers are high, because their fallback option is then very inefficient. In contrast, employment contracts are relatively more sustainable when the learning investments of the collaborating parties strongly reinforce each other.

The third essay investigates empirically how skills of employees in Finnish manufacturing firms are associated with collaborative innovation arrangements. Particularly, firms that collaborate with universities are found to have very high levels of research competence. This is interpreted as evidence of the need for "absorptive capacity" in collaborative innovation. Outsourcing of innovation activities may not be an efficient alternative for firms without internal competencies. The chapter also generates indicators for firms' technological environments which are found to have significant effects on the likelihood of engaging in R&D, pursuing collaborative innovation and making product innovations.

The fourth essay continues the empirical analysis of firm level innovation behavior and performance. Complementarities among firms' internal competencies, collaborative ventures and innovation output are explicitly assessed. An innovating firm's profitability is found to be higher if it possesses complementary technical and "dynamic" competencies. Similarly, profitability effects of collaborative innovation are stronger in firms with high competence levels. The absorptive capacity hypothesis thus obtains further support; firms' internal competencies and external innovation activities are complementary.

KEY WORDS: Innovation, organization, competencies, complementarities
JEL codes: D21, D23, J24, L14, L22, O31, O32

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TIIVISTELMÄ: Tutkimus muodostuu johdannosta ja neljästä esseestä, jotka käsittelevät yritysten innovaatiotoiminnan organisointia. Ensimmäinen essee tarkastelee teoreettisesti innovoivan yrityksen organisointipäätöstä: suoritetaanko innovaatioprojekti yrityksen sisällä vai ostetaanko ulkopuolista tutkimus- ja kehityspalvelua. Yrityksen institutionaalinen toimintaympäristö vaikuttaa organisaatiokustannuksiin. Teknologinen toimintaympäristö puolestaan vaikuttaa kannustimiin sijoittaa T&K-toimintaan ja oppimiseen. Koska projektiin liittyvät tietovarannot täydentävät toisiaan ja osaamisen siirtämiseen liittyy transaktiokustannuksia, investointi- ja organisointipäätökset vaikuttavat toisiinsa. T&K:n ulkoistaminen soveltuu silloin paremmin epävarmoihin teknologisiin ympäristöihin, joissa tehdään radikaaleja innovaatioita. Organisaatioratkaisuilla on pitkän aikavälin vaikutuksia yritysten menestymiseen.

Toinen essee mallintaa kysymystä, onko tiedonvaihto T&K-asiantuntijan ja innovoivan yrityksen välillä tehokkaampaa organisaation sisällä kuin niiden välillä. Tiedonvaihto ja yhteistyö ovat innovoinnin perusta ja vaativat ajan ja vaivan panostusta. Mallin mukaan samanlaiset kannustimet voidaan saavuttaa pitkän tähtäyksen liikesuhteessa (asiantuntija omistaa projektille olennaisen voimavaran) ja työsuhteessa (yritys omistaa voimavaran). Molemmat ovat implisiittisiä sopimuksia, jotka edellyttävät osapuolien kärsivällisyyttä ja suhteellisen ennustettavia tuottoja. Sopimusten kestävyydet voivat kuitenkin poiketa toisistaan. Liikesuhde on kestävämpi kuin työsuhde, jos tahattomat tietovuodot ovat huomattavia, koska silloin sopimuksen purkamisvaihtoehto on hyvin tehoton. Toisaalta työsuhde on kestävämpi, jos osapuolten panostukset vahvistavat toisiaan.

Kolmannessa esseessä tutkitaan empiirisesti, kuinka henkilöstön osaaminen vaikuttaa innovaatioyhteistyöhön suomalaisissa teollisuusyrityksissä. Havaitaan, että tutkimusosaaminen on tärkeää innovaatioyhteistyössä yliopistojen kanssa. Tämä voidaan tulkita siten, että innovaatioyhteistyö edellyttää yrityksiltä "omaksumiskykyä". Innovaatiotoiminnan ulkoistaminen ei ole järkevää, jos yrityksellä ei ole sisäistä osaamista, jonka avulla tulkita ja hyödyntää ulkoista innovaatiotoimintaa. Luvussa myös kehitetään indikaattoreita kuvaamaan yritysten teknologista ympäristöä, joka vaikuttaa yritysten T&K-toiminnan, innovaatioyhteistyön ja tuoteinnovaatioiden todennäköisyyteen.

Neljäs essee jatkaa yritysten innovaatiotoiminnan ja menestymisen empiiristä analyysiä. Siinä testataan hypoteeseja, joiden mukaan yritysten oma osaaminen, innovaatioyhteistyö ja innovaatiot täydentävät toisiaan. Tulosten mukaan innovoivien yritysten kannattavuus on korkeampi, jos niillä on täydentävää teknistä ja "dynaamista" osaamista. Lisäksi innovaatioyhteistyön positiiviset vaikutukset yritysten kannattavuuteen ovat voimakkaampia, jos yrityksellä on runsaasti omaa osaamista. "Omaksumiskyky-hypoteesi" saa siten lisää empiiristä vahvistusta: Yrityksen oma osaaminen ja ulkoinen innovaatiotoiminta täydentävät toisiaan.

ASIASANAT: Innovaatio, organisaatio, osaaminen, komplementaarisuus
JEL: D21, D23, J24, L14, L22, O31, O32

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Most of this research was carried out while I was working at the Research Institute of the Finnish Economy (ETLA). ETLA has provided a tremendously flexible working environment, allowing me to spend extended periods of time abroad either studying full time or working on theoretical aspects of my research projects. Moreover, ETLA has supported my participation in a number of research projects, which have broadened my perspective on economic development. For making this possible, I am grateful to Managing Director Pentti Vartia. Discussions with and encouragement from ETLA colleagues, particularly Research Director Rita Asplund and Dr. Petri Rouvinen, were always very helpful. I want to express special thanks to Managing Director Pekka Ylä-Anttila who has greatly influenced my thinking about firms and their evolution, and always encouraged me to explore new ideas – and new research locations.

The first foreign location for carrying out my dissertation research was Austria where in 1995-96 I worked in the International Institute of Applied Systems Analysis (IIASA). There, I participated in the research group focused on technological and economic dynamics lead by Professor Giovanni Dosi. This international research group forced me to question just about everything I had learned about economics up to that point. Discussions with Professor Dosi and Dr. Yuri Kaniovski, other researchers in the group and participants at various workshops at IIASA were truly stimulating.

My postgraduate research initially focused on macroeconomic growth and particularly the contributions of human capital. I am grateful to Professor Matti Pohjola for suggesting this topic to me when I started working on my Master's thesis. Later on, while working in ETLA my interest shifted gradually, and I became fascinated by how innovation takes place in firms and how people and their competencies contribute to this process. However, it was not until I studied for two years in the doctoral program of the Haas School of Business in the University of California at Berkeley that I started learning more about organizational aspects of innovation. I am grateful to Professor David Mowery for both giving me access to this environment and being an inspiring teacher and scholar. Studying with Professor Oliver Williamson was also particularly stimulating at the time when I began to work on the theoretical framework of this thesis. My studies in the United States were enabled by a Yrjö Jahnsson Fulbright scholarship. The financial support from Yrjö Jahnsson Foundation is gratefully acknowledged. I also want to thank the Finnish Cultural Foundation (Suomen Kulttuurirahasto), which provided additional financial support.

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Helsinki, September 2000

Aija Leiponen

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1 INTRODUCTION

1.1 Knowledge and economic development

Firms are the basic units of production in industrial economies, even though their boundaries may have become increasingly blurred in recent years. Traditionally economists have conceptualized firms in terms of production functions, abstracting from the roles of structure, administration, and organizational interactions within the firm. In contrast, observation suggests that firms can be characterized as clusters of complementary activities such as R&D, administration, marketing, manufacturing and distribution. How these activities are structured differs both between industries and within industries. This begs the question whether these differences have implications for firms' long-term performance.

Technical change and innovation underlie improvements in productivity, the primary source of economic development. But in addition to the efficiency and capacity of machines and equipment used to produce goods and services, productivity levels hinge on people's competencies both to produce and consume, and their ways to collectively engage in these activities. Thus we can identify a fundamental complementarity between "software" and "hardware."

In studies of economic growth, improvements in technological capabilities are often equal to the investments in research and development (R&D). However, R&D investments alone are not sufficient to explain technological development. For instance, there are large differences in the productivity performance of nations. Sweden and the United Kingdom invest relatively large shares of GDP in R&D related activities, while their growth performance has been mediocre. Furthermore, at the level of firms, R&D investment does not always translate into economic performance. For example, in telecommunication industry, Ericsson's R&D investment was around 15% of sales in the late 1990s, while Nokia's R&D remained at less than 9%. Even the most R&D intensive telecommunications group of Nokia invested only 13% in 1998. In spite of these differences in levels of investment, and the fact that the firms operate in essentially the same environment, Nokia has economically outperformed Ericsson in recent years, especially in mobile phones. Ericsson may possess deeper scientific knowledge due to its long experience and heavy investment in large-scale research, but many analysts suggest that Nokia's success is based on its mass production capacity and its ability to understand endusers. These complementary capabilities appear to be critical for benefiting from R&D investments.

An important recent dynamic in industrial economies has been the information technology revolution. Finland has been one of the forerunners in adopting information technologies both to automate manufacturing and administration, and to facilitate personal communication. The concept of *information society* has often been invoked. However, information, and communication technologies that enhance access to information are useful only to the extent that people can transform the increasing amounts of information into practical knowledge, that is to say to interpret and apply it in practice, and preferably develop it further. Knowledge, that is individuals' and organizations' capabilities, may be the fundamental factor that determines long-term economic performance.

Therefore, other commentators have argued, we should be talking about the new *knowledge-based economy*, in which success hinges on competencies. It is often forgotten that knowledge and capabilities have long been recognized as critical factors underlying economic performance. Adam Smith emphasized learning by doing enabled by a division of labor in his description of the pin factory (1776). Alfred Marshall (1890/1920: 115) argued that the most important factors of production are organization and knowledge. We know that new technologies alone rarely increase productivity. Competent users are required and it is also essential to combine technological knowledge with market knowledge in order to innovate successfully. Hence it has always been important to *combine* the various elements of "software" and "hardware."

Integration of knowledge assets, that is, communication and cooperation among actors in systems of innovation depends to a great extent on organizational arrangements. According to the transaction cost literature (Teece, 1986), the mode of organization of knowledge can be critical for realizing its potential. Knowledge assets that are not available to and connected with complementary assets fail to manifest their full potential. For instance, high technology without the skills to use it, or knowledge about clients' needs without the capacity to fulfill them, is not economically productive. Despite their apparent economic importance, these issues have not been much studied in economics, partly because of difficulties in measuring knowledge and specifying organizational forms. As a result, how to generate and organize productive capabilities is not very well understood.

This dissertation focuses on how firms invest in and organize capabilities, and how the choices of investment and organization affect their economic performance. The conceptual starting point is the exceptional nature of knowledge. First, knowledge is partly tacit (silent), so it does not always transfer easily or completely between people or within and across organizations. Skills, like playing the violin, cannot be completely explained in words. The skill can sometimes be taught, but this takes many years and requires considerable talent from the student.

Second, productive knowledge is possessed by individuals but used in an organizational context, for example a firm. In organizations an important component of an individual actor's knowledge is about who knows what and how to execute tasks in particular environmental settings. Culture, norms, and organizational structures and procedures, or routines in the language of Nelson and Winter (1982), are examples of institutions that have implications for how knowledge is used and interpreted. *Organizational knowledge* thus consists of the skills and capabilities possessed by individuals within an organization. However, the whole of these knowledge assets is more valuable than the sum of the parts because of the complementarities among them.

Third, perhaps the most well known characteristic of knowledge is related to its codifiable component. When knowledge can be codified and thus disseminated at very low costs, its production gives rise to increasing returns as it can be used in several places simultaneously, or over and over again in time. A downside of this for the developer of knowledge is that when the cost of reproduction and transfer is low, it can be difficult to appropriate the knowledge. Only in a minority of cases can intellectual property rights be defined and enforced so tightly as to prevent spillovers of codified knowledge. Patents can be circumvented, and even applying for a patent reveals some information about the technology.

The somewhat elusive character of knowledge leads to several contractual problems. A famous paradox is that the buyer cannot know the value of knowledge until it has been revealed, after which it does not make sense to pay for it. It can also be difficult to agree on what is being traded, if, as in the case of contract R&D, the knowledge does not yet exist at the time of contracting. For these reasons, the pricing of knowledge is extremely difficult. Reputation effects facilitate this only in the longer term.

The characteristics of knowledge have implications for how firms and individuals invest in and organize their capabilities. The difficulty of transferring tacit knowledge does not completely exclude the possibility of exchanging knowledge between organizations, but it certainly has an effect on how to organize the transfer. The long duration of the transfer process and the uncertainties related to it, particularly leakage of knowledge assets, give rise to transaction hazards. There is a large literature, following Williamson's (1985) seminal work, on the organizational responses to transaction hazards arising from the opportunism of individuals. The focus of the theoretical work in this dissertation is on the incentives created by different modes of organization. The organization of innovation activities importantly structures the incentives to engage in cooperation and share knowledge, either supporting or hampering the realization of potential increasing returns to knowledge.

The empirical essays in this dissertation focus on the competence requirements of profitable innovation and especially the reception aspects of knowledge exchange. As mentioned previously, much collaboration depends on the "talent", or competencies of the receiving partner. Without capabilities to interpret, synthesize and make use of new knowledge, an organization or an individual cannot benefit from knowledge exchange. Cohen and Levinthal (1989) identified R&D as an activity that builds "absorptive capacity;" in other words, the aforementioned capabilities to interpret and use knowledge. In this thesis I argue that there are other relevant means of building absorptive capacity. One important source of capacity is higher education. Educational attainment is a signal of both talent and acquired skills, of which the most important ones are dynamic such as the capabilities to learn and search, or interactive such as the communication, negotiation, and socialization skills. Education turns out to be an important covariate both in the process of innovation and in benefiting economically from innovation. Another one is learning by doing – potentially a source of increasing returns. For example, simply engaging in collaborative innovation makes a firm more efficient at collaborating. Indeed, Geroski, Machin and van Reenen (1993) suggest that there are benefits to the *process* of innovation in terms of learning, in addition to the *products* of innovation, that is, new or improved products and technologies.

1.2 Complementarities in innovation?

Many economic analyses of innovation postulate a knowledge or innovation production function. By investing in some type of R&D, the firm will realize returns on this investment through implementing the innovation in manufacturing and selling the differentiated product. This linear model of innovation has been criticized in the empirical innovation literature since the late 1960s. Science Policy Research Unit in England carried out seminal studies characterizing and comparing successful and unsuccessful innovations (Rothwell et al., 1974). The main findings included that the success of an innovation depends on how well the innovator understands users' needs and makes use of outside technology and scientific advice.

Rothwell (1992) discusses the evolution of innovation models since the linear model. He argues that current understanding of innovation emphasizes parallel efforts in different functions (research, design, process development, marketing etc.). Strong linkages to leading edge customers and primary suppliers, and horizontal linkages to complementors and competitors through collaborative research and marketing are also important. However, Senker (1995) criticizes this model for inadequate emphasis on the public sources of knowledge, that is universities and other research institutions. She suggests that this "arises from the failure to recognize the significance of tacit knowledge associated with scientific advance" (p. 445). If public research knowledge contains a tacit component, then it cannot be accessed by reading the literature or by other remote media. Access requires personal interaction.

The modern conception of innovation thus emphasizes the need to combine the development activities within the firm (research, development, design, testing, redesign, manufacturing etc.) so that each "stage" proceeds in parallel as opposed to sequentially, and that high levels of interaction are sustained among development activities. Moreover, the new thinking stresses the importance of accessing knowledge from external sources, such as users, suppliers, competitors, and public research. However, as all of the relevant knowledge has a tacit component, communication between actors in different functions needs to be deep and frequent. These "prerequisites of success," if you will, highlight the importance of the organization of knowledge exchange among cooperators, and more generally, the systemic character of innovation. In summary, successful innovation draws on knowledge from a variety of complementary yet heterogeneous sources, and due to the partly tacit character of knowledge, integration mechanisms are critical. And, due to the particularities of knowledge as an asset or substance, coordinating structures are difficult to create and sustain.

1.3 Outline of the thesis

The purpose of this dissertation is to explore the economic implications of creation and utilization of knowledge. The first essay develops a model of the firm as a bundle of capabilities. The work by empirical scholars of innovation and organization of R&D suggests that the benefits from R&D activities and technological change depend on the firm's capacity to combine several capabilities, particularly the marketing, manufacturing and innovation capabilities (Teece, 1986, Mowery and Rosenberg, 1989). On the other hand, technological transactions are particularly hazardous due to the partly tacit nature of technological knowledge. Transaction costs arising from transferring technology-related assets across organizational boundaries thus have implications for the organization of innovation activities. The firm needs to balance the costs of organization with the benefits from knowledge accumulation. The essay is an attempt to understand the dynamic implications of organizational choices of firms, and the interactions between the institutional and technological environments in which the firms operate. Institutional environment affects the costs of transaction among firms, while technological environment, or regime, specifies the patterns of technological change, and consequently the incentives to invest in learning and innovation. Under strong knowledge-related complementarities the choices of organization and investment interact. Here I compare the effects of cumulative innovation and radical innovation on firms' organizational choices.

Transaction cost reasoning related to technological or knowledge exchange is based on the assumption that the kind of collaboration that underlies knowledge transactions is more easily carried out within organizations. More frequent interaction among actors and fewer strategic problems of leakage of knowledge assets, it is argued, make it easier and less risky to exchange knowledge. The second essay assesses this critical assumption more explicitly in an incomplete contracting framework. I treat cooperation and knowledge exchange as investments of time and effort by the participants and study the incentives associated with different organizational arrangements. The contracting environment is described by the intensity of knowledge spillovers, that is, appropriability conditions within the technological regime. A key issue is also how firms' options outside the relationship studied affect their behavior. This essay thus examines the contracting issues related to integrating knowledge from external sources.

The third essay examines the determinants of innovation collaboration through analysis of Finnish data on manufacturing industries. Cross-sectional analysis of the 1997 innovation survey data is focused on innovation investments that are observed together. R&D, innovation collaboration and product innovation are specified as a jointly determined system of activities, and the effects of firms' internal skills and competencies on these innovation activities are econometrically examined. The results do not establish complementarity between activities, but some robust evidence is generated on the clustering of specific innovation activities and firm characteristics.

Another theme of the third essay is technological regime. It has often been observed in empirical studies of industrial organization that innovation behavior differs quite drastically across industries (Pavitt, 1984, see also Cohen, 1995, for a survey). The theoretical essays (Chapters 2 and 3) examined the effects of two dimensions of the technological environment, cumulativeness and appropriability of knowledge, and concluded that the organization of innovation depends to a great deal on these characteristics. The third essay develops additional measures of the technological regime based on the external sources of knowledge for innovation, and produces new results on how industries differ in terms of their innovation behavior. I show that the characteristics of the technological regime affect the locus of innovation (cf. von Hippel, 1988, 1994) and as a consequence, the pattern of investment by the various actors. Technological regime thus has implications for which particular internal competencies and external sources of knowledge are relevant for firms.

The last essay explicitly tests for complementarities between different knowledge and innovation investments by looking at their interaction effects on firms' profitability over time. Specifically, I explore the role of firms' internal competencies in benefiting from internal and collaborative innovation activities in a longitudinal setting. In case complementarities between competencies and innovation investments are strong, collaborating or innovating without competencies has suboptimal returns. This essay sheds light particularly on the competence requirements of accessing external sources of knowledge.

1.4 The data

The data used in the two empirical essays (chapters 4 and 5) consist of the business surveys 1990-96, employment register 1990-96, and two cross-sectional innovation surveys from 1989-91 and 1994-96 compiled by Statistics Finland. These data comprise a cross-section of 1029 manufacturing firms for chapter 4 and a longitudinal panel of 159 firms over 7 years for chapter 5. Information collected in the qualitative innovation surveys include the extent of research and development activities, engagement in collaborative arrangements with different partners, sources of knowledge for innovation, factors hampering innovation, and of course, the success in making product or process innovations or product improvements.

Representativeness of the surveys is relatively good – response rates exceeded 70% and all manufacturing industries are reasonably represented – but naturally one can question the accuracy and meaning of self-reported firm data on innovativeness. It can be argued that firms tend to exaggerate this because of the value judgement that innovation is "good" and good managers are innovative managers. Some of this bias has been reduced as firms are asked to reveal the share in sales revenue generated by new products launched within the past two years. The definition of product innovation used in the two empirical essays is based on this information. For process innovation there is no such measure, so the indicator is the firm's answer to the question of whether or not the firm introduced a process innovation. There is no rationale to suspect bias in the answers to the questions on knowledge sources or collaboration partners. Of course, problems may arise in comparison and aggregation of individuals' subjective assessments.

More positively, these kinds of innovation survey data enable comparison of a broad cross-section of companies and industries. Previously used measures of innovation output like patents are not informative even in most manufacturing industries, not to mention services, because the propensity to patent innovations varies drastically across sectors (see e.g. Griliches, 1990 for a discussion). Another approach is to collect information on major innovations and then trace them back to the firms. Science Policy

Research Unit pioneered this historical method, and more recently the VTT Group for Technology Studies in Finland has followed their lead (Palmberg et al., 2000). Although the VTT data are likely to yield interesting results in the future, it must be recognized that both the cost of collecting data and making international comparisons make survey data appealing. Moreover, organizational data are only accessible through case studies or surveys. Thus there are advantages and disadvantages to the survey approach.

2 CORE COMPLEMENTARITIES OF THE CORPORATION: KNOWLEDGE AND THE ORGANIZATION OF AN INNOVATING FIRM[1]

Abstract

This chapter examines the dynamic implications of organizational choices. External arrangements such as strategic R&D alliances have proliferated over the past decades. However, the benefits and costs of alternative ways to organize the pursuit of innovation are still not very well understood. The chapter develops a simple model to study how to organize innovation activities in different technological and institutional environments. The starting point is that cooperation and cross-functional communication are more easily sustained in internal organization, i.e., hierarchy. The efficiency of internal organization is then increasing in the strength of complementarities among the innovation-related activities. In contrast, independent governance of complementary activities is more efficient when accumulation of knowledge is slower or depreciation of knowledge is faster (high rate of radical technical change). Consequently, organization, investment, and innovation decisions are intertwined. Organizational complementarities also imply that the institutional environment impacts incentives to invest in learning and innovation and technological environment affects organizational choices.

Key words: Innovation, organization, firm capabilities, complementarities

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[1] The chapter was written while I was visiting the Haas School of Business at the University of California, Berkeley. It has benefited from the discussions with the faculty and Ph.D. students of the Business and Public Policy group, particularly Oliver Williamson, David Mowery, and Vit Henisz. Ilya Segal and Bengt Holmström have provided useful comments on earlier versions, as well as the EARIE conference participants (Turin 1999), especially Armin Schmutzler, and the seminar participants at CEPREMAP, Paris, particularly Eve Caroli and Robert Boyer. Of course, the remaining errors and obscurities are mine alone.

2.1 Introduction

Pharmaceutical firms tend to carry out their research and development (R&D) internally, but often outsource biotechnological R&D. For example, SmithKline Beecham has an alliance with Human Genome Sciences (HGS) on genomics, and Novartis is a majority owner of the biotech firm Chiron. In metallurgy, a specialized Finnish copper casting technology firm, Castform, develops most other components of casting internally, but contracts for ceramic technologies. The telecommunications equipment company Nokia has developed internally the handsets for mobile "communicators" (combined mobile phone and handheld computer) but has collaborated with Ericsson, Motorola and Psion to create an operating system for such devices. It is proposed here that these anecdotal observations all highlight strategies associated with breaks in technological regimes, or more precisely, in the mode of accumulation of knowledge within firms. Technological collaboration and outsourcing of R&D are ways to learn and internalize knowledge that may become complementary later on. Firms in industries with converging technologies or other types of discontinuities in technological conditions are more likely to engage in external arrangements of innovation. These arguments are supported by a number of analyses which link interfirm collaboration with uncertainties surrounding the generation of new technologies (see Freeman, 1991).

The Hollywood movie industry is a famous case of network organization (Powell, 1990; Faulkner and Anderson, 1987). The typical pattern of modern movie making is to create the production organization almost from scratch for each film. After the project is finished, the organization dissolves, even though the same individuals may collaborate in another production later on. This same pattern has been observed in the construction industry (Eccles, 1981). I argue that at least part of the reason for observing these organization patterns is that in these sectors the different components of the production process are not complementary in the innovation process. Script writing, sound, camera technology, and make-up represent separate learning domains. While there is surely an element of cumulative learning within these components of film making, innovation in each does not depend on interaction across them. In contrast, to develop a new drug requires accumulation within and fertilization across basic and applied research in several fields.

The purpose of this chapter is to develop an explicit framework to begin to investigate the dynamic aspects of organization. The focus is on the interactions among innovation, technological change, and organization. The main research question concerns the dynamic benefits and costs of internal and external organization of an activity. I argue that organizational form has an impact on how fully complementarities among firms' capabilities are realized. For instance, if a firm contracts for R&D, it may find it difficult to internalize all the knowledge created during the development process, limiting the capacity to apply what was learned in the firm's other operations. By outsourcing R&D the firm can appropriate the "artifact-embodied" technology, but not the "human-embodied" learning. On the other hand, acquiring and organizing activities internally is costly and risky, so in certain situations it is optimal to outsource activities, even those complementary to other projects of the firm.

The tradeoffs related to the organization of productive activities and their implications for the firm's dynamic performance are investigated to understand the settings in which internalization or externalization is likely to be selected. The firm is viewed as a bundle of activities that are supported by capabilities. Capabilities complement one another in the development, manufacture, and marketing of products, but as the previous examples demonstrated, they can be juxtaposed within complex governance structures. My interest here is in better understanding how the optimal organization of activities changes when the technological or institutional environment shifts. Relevant literature is reviewed in the following section. Section 2.3 introduces the concepts used in the analysis. Section 2.4 develops a simple model of an innovating firm, the results of which are discussed in section 2.5. Section 2.6 concludes.

2.2 Related literature

Economic theories do not shed much light on how organization is related to innovation processes. Evolutionary economics emphasizes innovation as the fundamental dynamic process, and the firm is seen as a "repository of productive knowledge" (e.g., Winter, 1988). However, the framework does not explain how organization affects the accumulation of knowledge. Transaction cost and agency theories of the firm consider organizational issues explicitly, but they are essentially silent about firm dynamics, including innovation. The few exceptions include Holmström (1989) and Aghion and

Tirole (1994). Their work represents a useful start, but only scratch the surface of how organization is intertwined with innovation. If innovation is the key to competitiveness and must be closely coordinated with other activities in the organization to exploit "synergies," when should knowledge be "made" in-house, and under what circumstances is it more efficient to "buy"?

The idea of organizational interdependencies is not new (see e.g. Chandler, 1962; Richardson, 1972), but so far its implications have not been analyzed explicitly. Mowery (1983), Mowery and Rosenberg (1989) and Teece (1986) carried out seminal empirical studies on organization and innovation, contributing significantly to framing and conceptualizing the problem. Arora and Gambardella (1990) examined empirically organizational complementarities related to innovation and technological change. Both Teece and Arora and Gambardella are concerned with the idea that bringing an innovation profitably to market requires a set of capabilities that complement one another. Prahalad and Hamel (1990) in their case studies of core competencies found that integrating and cross-fertilizing knowledge-bases across strategic business units was a more successful strategy than letting business units operate independently. Theoretical research on the interplay between firm boundaries and technological change is less well developed, however, partly because methods for formally analyzing organizational interdependencies were weak until Milgrom and Roberts (1990) applied the work of Topkis (1978, 1998) for economics of organization.

Hart and Moore (1990) examined interactions between assets in a firm and concluded that (strictly) complementary assets should be organized within a unified governance structure. Here the idea is slightly subtler: knowledge concerning one type of activity may enhance the returns to knowledge creation in another. Therefore knowledge production in two or more domains can be *complementary in innovation.* Like Hart and Moore, I focus on the incentives to invest in learning created by different ownership structures. Here, organization affects knowledge flows among activities and thus the innovation process.

Holmström and Milgrom (1994) suggested that low-powered incentives, therefore internal organization, are generally necessary to sustain informal cooperation and knowledge sharing. There is a tradeoff between the intensity of incentives and exchange of knowledge. Knowledge sharing can be viewed as a transaction in knowledge.

Williamson (1985) has argued that highly hazardous transactions tend to be organized internally, and knowledge-related transactions are plagued with hazards (Teece 1982). Therefore, if close cooperation between knowledge sources is necessary for innovation, then internalization of those sources has certain benefits.

The economic literature on complementarities has addressed issues of internal organization design. The starting point of the Milgrom and Roberts (1990) model was the observation that specific features of modern flexible manufacturing systems, especially information technologies, are observed together within firms. Ichniowski, Shaw, and Prennushi (1997) examined human resource management practices and noted that certain practices have a stronger impact on productivity in the presence of other practices. That is, there is a systemic element to human resource management and its effect on productivity.

Strong complementarities among discrete actions may make the improvement of performance impossible in the absence of concerted intervention. For instance, the adoption of information technologies may have such pervasive systemic effects that several simultaneous changes in the organization of activities are necessary to make the adoption productive (Brynjolfsson and Hitt, 1995). Then a decentralized system that optimizes the factors independently will not effectively improve performance and is not likely to lead to the globally optimal outcome. Instead, relevant factors and their interactions need to be considered simultaneously.

The model here builds on the work by Athey and Schmutzler (1995), who presented the first (quasi) dynamic approach to complementarities that considered innovation explicitly. They studied how the decisions of flexibility and investment in research capabilities influenced the future innovation opportunities and the costs of adjustment. Because product and process innovations are complementary, the long-run decisions concerning flexibility and research become complementary as well. However, they did not analyze complementarities between different activities nor the issue of governance. These are the contributions of the present chapter.

2.3 Underlying concepts: Capabilities, innovation, and technological regimes

A firm's stock of knowledge is a collection of capabilities. A capability is defined as a collective ability to carry out an activity. It consists of simple skills like technical, social and communication skills, considerable parts of which are tacit. Knowledge needs to be utilized in an organizational context, so that the skills or competencies possessed by individuals are connected with those of others engaged in a common activity. Activity refers to some identifiable function, for instance the marketing of a particular product. Typically activities in firms share boundaries with departments or services.

In line with recent empirical literature, innovation is conceptualized here as a process of interaction between different subunits of the firm, and between the firm and external sources of innovation inputs (e.g., Iansiti and Clark, 1994). The integration[2] of necessary knowledge sources is emphasized (see Kline and Rosenberg, 1986; Rothwell, 1994). Innovations can originate not only in R&D, but also in manufacturing or marketing. Even in the case where R&D department is the source of the innovative idea, a close collaboration with other functions is usually indispensable to ensure that the innovation is technically appropriate and desired in the marketplace.

Interaction, i.e., communication and cooperation among the relevant functional units, is thus requisite for *profitable* innovation. Interaction necessitates the integration of knowledge sourced internally and externally, the latter being essential to keep up with changes in technology and markets. Integration is achieved by creating communication channels and codes (cf. Arrow, 1974), and coordination routines, such as cross-functional teams or key employee rotation.

A firm does not operate in isolation. The model developed here examines how a given technological and institutional environment shapes firms' investments in learning and their organizational choices. The environment is represented by exogenous parameters that shift the investment incentives and organizational costs. However, I abstract from strategic interactions among firms.

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[2] Integration refers throughout the chapter to integration of knowledge, not vertical integration, unless indicated otherwise.

Institutional environment impacts the costs of organization through the costs of transacting. For instance, labor market institutions including laws, unemployment benefits and trade unions affect the employment contracting costs. Similarly, contract law and property rights may or may not support transactions between organizations. Organizational choice reflects the firm's institutional environment (Williamson, 1985).

The Schumpeterian tradition to study economic dynamics has identified two technological environments, or regimes. Innovation within an "entrepreneurial regime" occurs in large numbers of small firms operating in an environment with frequent entry and exit and high levels of technological turbulence (Schumpeter, 1934). In contrast, in a "routinized regime" (Schumpeter, 1942) there are economies of scale in innovation and R&D. Therefore innovation occurs in a handful of large firms featuring significant internal R&D capacity. Winter (1984) examined the connection between these regimes and the evolution of industry structure. Following this tradition, Malerba and Orsenigo (1993) have suggested that the cumulativeness of knowledge – the extent to which new knowledge builds on previous knowledge – is an important characteristic of a firm's technological environment. They argue that high cumulativeness is associated with internalization of activities, because of increasing returns to innovation. However, they fail to specify the mechanism linking cumulativeness to organizational choice.

Cumulativeness of knowledge can be described by the familiar economic concept of depreciation: higher cumulativeness implies slower depreciation, as knowledge useful today may be obsolete tomorrow. Capabilities and knowledge depreciate in response to technological change but also in relation to perceived probability of technological rupture. Under conditions of high cumulativeness, learning is associated with increasing returns, and first-mover advantages may exist. When cumulativeness is low and depreciation is high, it becomes important for a firm to diversify its knowledge base, potentially through external sourcing of information. Related concepts used in empirical research include competence-enhancing vs. competence-destroying technological change (Anderson and Tushman, 1990) and incremental vs. radical innovation.

The Schumpeterian literature has focused on the effects of technological regimes on industry and innovation dynamics through analyzing market structures and product life cycles. For instance, Winter (1984) examined sectoral entry and competition dynamics. However, his approach does not account for the fact that incumbents can react to new entrants either by making internal adjustments *or by seeking an alliance* in the hope of learning from the entrant. It is argued here that shifts in the technological environment can have important effects on organizational structures, including inter-firm relationships, not only industry structure as measured by size distribution and concentration. Mergers, acquisitions and alliances are reactions to both market conditions (narrowly defined) and technological conditions.

2.4 A model of complementary capabilities, organization, and innovation

This section develops a simple two-period model of an innovating firm based on the Athey and Schmutzler (1995) framework. The firm is monopolistic and seeks to maximize profits, which are a function of the price-cost margin and quantity produced. The objective is to identify the effect of external conditions on organizational choice. This approach highlights the tradeoffs between internal (i.e., in-house) and collaborative or contractual strategies.

To simplify maximally, I study the organization of a single activity essential in bringing a product to market. While the model applies to any essential activity, one can think of product development or manufacturing as suitable examples. It is supported by capabilities that the firm can upgrade indirectly through investments in learning such as employing qualified workers and investing in training, R&D, intellectual property, and consulting services.

The firm maximizes expected profits by investing in learning and choosing an appropriate organizational structure. Learning investments translate into capability accumulation. This affects profitability indirectly as the increased stock of capabilities shifts the probability distribution of returns to adopting an innovation. Innovation is described as a draw from a probability distribution of returns. The more capabilities or productive knowledge assets the firm possesses, the more favorable odds it faces. Innovation opportunities[3] are available to all firms, but the decision to seize one depends on the expected returns on the project, which are affected by capabilities. The

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[3] In effect, the model applies to all kinds of innovations, the implications of which can be described with the profit expression, i.e., price- (or demand-) inducing, cost-saving, or market-expanding innovations.

technological regime comes into play by affecting both accumulation and depreciation of capabilities and the incentives to invest in learning.

The firm can decide to outsource or internalize the activity. Organizing internally facilitates close interaction between capabilities mobilized in this activity and those associated with the firm's other internally organized activities. However, internal organization comes at a cost. Though not modeled explicitly, agency, bureaucratic inefficiency, and weaker incentives give rise to organizational costs. Additionally, the relative costs of internal organization compared to external are shaped by the institutional (contracting) environment.

2.4.1 Profits in the second period

The model is solved by backward induction. In the first period the firm chooses how much to invest in learning and how to organize the activity. In the second period the firm decides whether or not to adopt the innovation into production ($I \in \mathcal{I} = \{0,1\}$) and how much of the product to produce ($Q \in \Theta = \mathbf{R}^+$) based on the revealed innovation returns (R). I and Q are chosen to maximize profits, which are a function of price (P), unit cost (C), and quantity (Q).

(1) $$\max_{I,Q} \Pi_2 = \left[P(Q,R,I) - C(Q,R,I)\right]Q$$

Prices and costs depend on quantity (the monopolistic firm faces a downward sloping demand curve), returns to adopting an innovation, and the dummy variable for the decision to adopt: $I = 1$ in case of adoption and $I = 0$ otherwise. Innovation opportunities are available for all firms. The decision to seize one depends on the innovation returns, which are realized after the first period.

Innovations can apply to products or processes. Here I assume that either type of innovation improves the price-cost margin without distinguishing between product and process innovation. We can write:

(2) $$\max_{I,Q} \Pi_2 = \left[PCM(Q,R,I)\right]Q$$

where PCM denotes the price-cost margin. This is equivalent to Topkis's (1998) model 3.3.7, if for product innovations, $P = P(Q,R,I)$ and $C = C(Q)$, in other words, product innovations enhance demand:

(2a) $$\max_{I,Q} \Pi_2 = \left[P(Q,R,I) - C(Q)\right]Q$$

And for process innovations, $P = P(Q)$ and $C = C(Q,R,I)$, in other words, process innovations reduce costs:

(2b) $$\max_{I,Q} \Pi_2 = \left[P(Q) - C(Q,R,I)\right]Q$$

Define the effects of adopting an innovation, and assume that they are always positive with respect to the *PCM* (unprofitable innovations are not adopted):

(A1) $$\Delta PCM_I \equiv PCM(Q,R,1) - PCM(Q,R,0) \geq 0$$

The higher the returns to innovation, the larger the increase in *PCM,* i.e., *R* and *I* interact non-negatively:[4]

(A2) $$\frac{\partial \Delta PCM_I}{\partial R} \geq 0$$

The third assumption (A3) is that the effect of implementing a profitable innovation on the marginal returns to quantity is positive.[5] Producing a larger quantity thus does not decrease the positive effects of the adoption of innovations. This is equivalent to a positive interaction of *I* and *Q* in terms of profits, and implies "market power" due to innovation; it is worthwhile to expand production volume, because better quality or lower price increases the demand for the firm's product. Innovation is thus associated with some positive scale returns. For instance, in case of a process innovation, the new idea can be profitably exploited over a larger production volume. This reflects the increasing returns arising from the unembodied nature of knowledge: once innovation has been made, it can be spread internally for low cost making it profitable to exploit the innovation over a larger quantity. For more discussion on this, see Cohen and Klepper (1996).

(A3) $$\frac{\partial \Delta PCM_I}{\partial Q} Q + \Delta PCM_I \geq 0$$

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[4] Thus *PCM* is supermodular with respect to *R* and *I.* See the appendix for the definition of supermodularity.

[5] This is equivalent to positive cross-partial derivatives in the case of continuous variables, i.e. $\frac{\partial^2 \Pi_2}{\partial I \partial Q} \geq 0$ if *I* were a continuous variable.

Higher innovation returns (R) also reinforce the scale effects of innovation (A4). It is then more profitable for the firm to increase volume the higher the realized innovation returns.

(A4) $$\frac{\partial^2 \Pi_2}{\partial Q \partial R} = \frac{\partial PCM(Q,I,R)}{\partial R} + Q \frac{\partial PCM(Q,I,R)}{\partial Q \partial R} \geq 0$$

It follows that larger returns on innovations increase the likelihood of implementing an innovation and the production quantity (see Lemma 1). Thus innovation and output expansion are expected to be correlated in pooled firm data, other things being equal.

Lemma 1 *Optimal second-period choices of implementing innovations (I) and quantity produced (Q) are monotone non-decreasing in returns to innovation (R).*

Proof By assumptions 1 and 2, Π_2 is supermodular in (I, R), by A3 in (Q, I), and by A4 in (Q, R). Therefore, Π_2 is supermodular in (I, Q, R). Apply Theorem 1 by Topkis (1978; reproduced in Appendix 2). Lemma 1 follows. *Q.E.D.*

Necessary conditions for increasing optimal solutions are guaranteed by the supermodularity of *PCM* in (Q,R,I) (see Topkis, 1998, Theorem 3.3.4), when I and Θ are sublattices.[6]

2.4.2 First-period decision to invest in learning

The first period problem is to invest in learning (k) and organize the activity (H) to maximize the expected profit of the following period. $H = 1$ if the activity is internalized, otherwise $H = 0$.[7]

(3) $$\max_{k,H} \Pi_1 = E(\Pi_2) - L(k) - O(H,\eta)$$

$$= \int_R \Pi_2(R) dG(R; K, H) - L(k) - O(H,\eta)$$

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[6] For definitions of a lattice and a sublattice, see Topkis, 1998: 11-17.

[7] Alternatively, H could be continuous between 0 and 1, or there could be several discrete organization forms, which vary with respect to their "degree of integration:" full integration (common ownership) – joint venture – long term contract – short term contract – spot transaction. However, these formulations would not affect the results obtained here.

L denotes the cost of learning investments, which might include training, consultation, and research. Cost of organization is $O(H, \eta)$, parameterized by η that represents the institutional environment. The cumulative probability distribution function G generates the returns to innovation R. The form of the distribution is affected by the capability stock K and organization of activities H.

Define higher η as implying higher costs of internal organization relative to external transactions:

(A5) $$\frac{\partial}{\partial \eta}\left[O(1,\eta) - O(0,\eta)\right] \geq 0$$

This cost parameter reflects agency (weaker incentives) and administrative costs, in addition to the setup costs of internalizing an activity. The relative cost of internal governance also depends on the contracting environment. An institutional environment may encourage external governance via solid reputation mechanisms, contract enforcement, property rights, and tradition of collaboration. Of course, the institutional environment also affects internal contracts. For example, labor relations and unionization have implications for the costs of internalization. Thus, η weighs administrative and agency costs and employment contract hazards against market transaction costs. Alternatively, we can think of η as the cost of implementing incentive schemes against the cost of external safeguards.

2.4.3 Accumulation of capabilities

The firm cannot choose the capability levels directly. Capabilities have to be developed internally — the firm can outsource only the outputs produced by capabilities, not capabilities themselves. Higher *rates* of learning (accumulation) can be achieved by investing in R&D and training, hiring skilled employees, and so forth.

The Schumpeterian creative destruction of knowledge is represented by the depreciation of capabilities, or the inverse of cumulativeness of knowledge. The technological regime is captured in the model by the parameter δ, which determines the fraction of initial capabilities in the first period that become useless in the second period. Capability $K = K(k, \delta)$, is a non-decreasing function of learning investment (k) and a non-increasing function of depreciation of knowledge δ (i.e., non-decreasing function of cumulativeness of knowledge (-δ)). In addition, we assume that the cross-partial derivatives of k and δ are non-positive (A6). Then investments in learning are more efficient when cumulativeness of knowledge is high – fewer unrelated and irrelevant technological avenues need to be explored.[8]

(A6) $$\frac{\partial^2 K(k,\delta)}{\partial k \partial \delta} \leq 0$$

In technological regimes with high depreciation, the firm has to invest in learning just to maintain a certain capability level. In the long run, firms generally need to keep net learning non-negative, but in turbulent environments it might be worthwhile to do a bare minimum, since a large portion of an investment is quickly devalued.

2.4.4 Dynamic complementarity

Innovation opportunities are represented by the cumulative distribution function *G(R;K,H)*. Higher capabilities shift the distribution to the right, in the sense of first-order stochastic dominance.

(A7) $$\frac{\partial G(R;K,H)}{\partial K(k,\delta)} \leq 0$$

The effect of the choice of organization on the distribution of innovation returns is defined as follows:

Definition 1 $$\Delta G_H \equiv G(R;K,1) - G(R;K,0)$$

The key assumption of the model is that a given increase in capability K shifts the probability distribution more under internal governance, because knowledge can be more easily disseminated and utilized (A8). This assumption is supported by consideration of knowledge-based transaction costs. These costs stem from internal

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[8] For instance, a very simple functional form for knowledge accumulation could be $K_t = (1-\delta)\left(K_{t-1} + k_{t-1}\right)$

Then knowledge stock at the beginning of period t would depend on previous period stock and investment, less the depreciation. Then the cross-partial derivative of the current stock is negative: $\frac{\partial^2 K_t}{\partial k_{t-1} \partial \delta} = -1 < 0$.

agents' difficulties in exchanging tacit knowledge with external actors and their weaker incentives to communicate with them.

(A8) $$\frac{\partial \Delta G_H}{\partial K(k,\delta)} \le 0$$

Thus, the organization of activities shapes the "dynamic complementarities" because interactions (e.g. communication, knowledge sharing, cooperation) among activities are more frequent and intense under unified governance relative to outsourcing. If one of the complementary activities is outsourced, interaction is reduced decreasing the expected returns on innovation.

The assumptions A1—A8 presented above have the following implications.

Proposition 1 *The optimal choices of learning investment k^* and internal organization H^* are monotone non-increasing in depreciation δ.*

Proof See Proposition 2.

High cumulativeness of knowledge (low δ) increases the returns to investment due to more efficient knowledge accumulation. Accumulation of capabilities increases the probability of profitable innovation. Consequently, adoption of innovations is more likely and quantity produced is larger in the second period. Moreover, the returns to internalizing the activity are higher, because internal organization intensifies the interaction between activities, resulting in a higher probability of innovation. Therefore, depreciation δ, *i.e.*, higher cumulativeness makes internal organization ($H = 1$) more likely.

Proposition 2 *Optimal choices of learning investments k^* and internal governance H^* are monotone non-increasing in the institutional cost of internal organization η.*

Proof of Propositions 1 and 2. By Lemma 1, Π_2 is supermodular in (I, Q, R). By Theorem 2 by Topkis (see Appendix 2), supermodularity is preserved in maximization, hence $\Pi_2^*(R) = \arg\max_{I,Q} \Pi_2(I,Q,R)$ is non-decreasing in (R). Assumption A7 and Lemma 2 (Athey and Schmutzler, 1995; see the Appendix) establish that Π_1 is nondecreasing in K. A6 ensures the supermodularity of K with respect to $(k, -\delta)$. Hence Π_1 is supermodular in $(k, -\delta)$. A5 establishes its supermodularity with respect to $(-\eta, H)$. A8 makes Π_1 supermodular in (K, H). The rest of the variables do not interact. Π_1 is supermodular in $(k, H, -\delta, -\eta)$. Apply Theorem 1 (Appendix 2). Optimal choices of k and H are monotone nonincreasing in δ and η. *Q.E.D.*

Higher relative costs of internal organization obviously decrease the incentives to internalize. More interestingly, since the choices of H and k are interdependent we see that higher η also decreases the incentives to invest in learning. This result reflects the assumption (A8) stated earlier: Internal organization facilitates more intensive interaction among relevant capabilities across activities, and interaction among capabilities has a positive effect on innovation returns. Therefore, higher η, *ceteris paribus*, decreases k^*. It follows that the adoption of innovation is less likely in the second period and output is lower:

Corollary 1 *Optimal second-period choices of implementing innovations (I*) and quantity produced (Q*) are monotone non-decreasing in learning investments (k) and internal organization (H).*

Proof Lemma 1 shows that Π_2 is supermodular in (I, Q, R), and consequently (I^*, Q^*) are non-decreasing in R. By proposition 1, Π_1 is supermodular in $(k, H, -\delta, -\eta)$. By A6, A7, and A8, higher k and H are associated with a higher stochastic outcome R (i.e., R is non-decreasing in k and H). Thus, it follows that optimal (I^*, Q^*) are non-decreasing in (k, H), ceteris paribus. *Q.E.D.*

Corollary 2 *Optimal second-period choices of implementing innovations (I*) and quantity produced (Q*) are monotone non-increasing in depreciation (δ) and cost of internal organization (η).*

Proof By proposition 1, Π_1 is supermodular in $(k, H, -\delta, -\eta)$. Corollary 1 shows that I^* and Q^* are non-decreasing in (k, H). Consequently, I^* and Q^* are non-increasing in (δ, η). *Q.E.D.*

Learning investments and organization are linked to the second-period choices through the stochastic innovation returns. The higher the investments in learning in period one, the more likely the firm will find it profitable in period two to adopt innovations and produce more. Internal organization of the activity also increases the chances of profitable innovation because complementarities are more efficiently harnessed. Further, changes in the institutional and technological environment have indirect effects on innovation and quantity produced. Lower cumulativeness of knowledge and costlier internal organization can imply fewer innovations and slower growth. There is a caveat however. Technological environments with high turbulence may feature abundant technological opportunities as well. Opportunities, which are not incorporated into the model here, encourage investments in learning, while the results here only reflect the cumulativeness of knowledge.

2.4.5 Two activities

Next consider the case of two complementary activities in the firm. One further result is obtained: learning investments tend to correlate across activities. Assume that there are two activities, 1 and 2, with associated capabilities K_1 and K_2 and depreciation rates δ_1 and δ_2. To render the complementarity explicit, capabilities are assumed to have positive effects on the probability distribution of innovation returns and be mutually reinforcing:

(A9) $$\frac{\partial^2 G(R; K_1, K_2, H)}{\partial K_1(k_1, \delta_1)\partial K_2(k_2, \delta_2)} \leq 0$$

Moreover, this interaction is stronger under internal governance relative to the case where one of the activities is outsourced:

(A10) $$\frac{\partial^2 \Delta G_{Hi}}{\partial K_1 \partial K_2} \leq 0 \text{ for i} = 1, 2$$

where ΔG_{Hi} refers to the effect of the organization choice of activity i on the distribution G.

Solving the model in the two-activity scenario shows that if the technological parameter δ_1 decreases, then optimally k_1* increases, resulting in higher K_1 (see Proposition 3 below). Due to the dynamic complementarity defined in (A9) and (A10), the firm optimally increases also k_2, because the higher K_1 is, the higher are the returns to increasing K_2. Furthermore, because of (A10), lower δ_1 makes internal organization of both activities more profitable.

Proposition 3 *Optimal learning investments k_1* and k_2* and optimal organization choices H_1* and H_2* are monotone non-increasing in (δ_1, δ_2).*

Proof Write assumptions A5-A8 and definition 1 in terms of k_i, H_i, K_i, δ_i. Again, by Proposition 1, Π_1 is then supermodular in (k_i, H_i, K_i). A9 establishes that Π_1 is supermodular in (K_1, K_2), from which it follows that it is non-decreasing in (k_1, k_2, $-\delta_1$, $-\delta_2$) by A6. A10 imposes the supermodularity of Π_1 with respect to (K_1, K_2, H_i), for i =1, 2. Thus Π_1 is supermodular in (k_1, k_2, H_1, H_2, $-\delta_1$, $-\delta_2$). Therefore, by Theorem 1, the optimal choices (k_1^*, k_2^*, H_1^*, H_2^*) are monotone non-increasing in (δ_1, δ_2). *Q.E.D.*

2.5 Discussion and relation to empirical literature

Learning investment k^* is lower in a technological regime of higher depreciation of knowledge δ. Internalization of activities H^* is less likely for higher institutional costs of internal organization represented by η. Because of the interactions – at least weak supermodularity – among capabilities and internal organization, the effects of knowledge depreciation and institutional organization costs disseminate in the system. Consequently, technological regime affects organizational choice, and institutional environment affects learning investments. More specifically, when relative costs of internal organization are high, more activities are outsourced reducing the incentives to invest in learning. This is because the benefits from complementarities in innovation are diminished, making learning investments less productive. As a result, the probability of adopting an innovation is lower in the second period, and so is quantity produced. Symmetrically, higher depreciation of knowledge slows down capability accumulation. As lower capabilities create fewer benefits from internalization, incentives to organize internally are reduced.

These results imply that an institutional environment that favors external transactions may impede profitable innovation due to "excessive" outsourcing. Savings from external organization for a specific activity may be illusory, and internalization of the activity may be warranted based on consideration of internal complementarities. Moreover, in technological regimes featuring high cumulativeness, or low probability of radical innovation, this possibility is magnified. The "make-or-buy" decision must be evaluated in a broader and more dynamic context. In other words, there is a tradeoff between static and dynamic costs and benefits. The interpretation here is that outsourcing, whether it is temporary hourly workers, consulting engineers, or contract manufacturing, can have detrimental effects on innovation in the long run. However, this does not mean that external collaboration in activities that are not complementary within the firm leads to a reduction of the rate of innovation. On the contrary, there is empirical evidence to believe that a firm can both be highly innovative and selectively engage in externalization of non-complementary (in the dynamic sense) activities. But as Mowery and Teece (1993) have pointed out, firms need to ensure that external operations are well integrated with the corporate strategy and that the firm possesses sufficient internal capabilities to adopt and utilize externally created knowledge.

The dynamic effects of organizational choice demonstrated here are in line with the empirical work of Mowery and Rosenberg (1989), who examined the role of public policy in creating institutions that affect firms' organizational choices. Comparing the organization of large industrial corporations in the U.K. and the U.S. in the first half of the 20th century, they suggested that the stringent antitrust legislation in the U.S. (Sherman Act) led to the internalization of R&D activities that firms had previously outsourced. Instead, British competition regulation was very lax, and firms continued to collude in both markets and R&D. Mowery and Rosenberg argued that this change in the institutional setup is a major reason for the organizational innovation of corporate R&D laboratory in American industry. Internal R&D enabled close collaboration with the firm's other functions, and contributed to a more rapid technological development in the U.S. than in the U.K.

The results also speak to the current proliferation of the networking strategy. Network forms of organization are advocated because they induce faster learning (e.g. Powell et al. 1996[9]). However, learning does not always translate into *profitable* innovations. As Dodgson (1994: 288) observes, the literature on inter-firm collaboration emphasizes its

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[9] Powell et al. (1996) note, however, that networks of learning are important *in industries where technological change is rapid and innovation is competence-destroying*. This amounts to a high rate of depreciation in the context of the model. Often, though, the network literature advocates external collaboration as the "best" organization form quite unconditionally.

positive aspects and discounts the negative ones, while the empirical evidence suggests that it is often difficult for the partners to gain mutually satisfactory outcomes. If the benefits of collaboration are so overwhelming, why are there firms in the first place? In other words, what are firms good at? I submit here that firms are advantaged in making use of the dynamic complementarities among knowledge assets and activities. Even if learning can be rapid in networks, profitable and *cumulative* innovation may be more efficiently carried out in internal organization, because learning in one activity needs to be internalized and integrated with the firm's other capabilities.

An interesting area of empirically examining the model's implications is firms' diversification behavior. The resource-based view of the firm (e.g. Chatterjee and Wernerfelt, 1991; Montgomery and Hariharan, 1991; Silverman, 1999) explains diversification with "excess resources," which cannot be easily rented or sold due to prohibitively high transaction costs. The idea is that the excess resource can be utilized in different activities *within* the firm but not across firm boundaries. For diversification to make sense in the long run, the activities must perform better together than apart in a continuous fashion. Therefore, between the merging businesses there must be continued knowledge flows that would not be so likely to take place across firm boundaries. The businesses are then complementary in learning and innovation, as has been explicated in the model here. Diversification will not continue to generate rents in the long run unless the diverse activities continue to create resources that can be shared and cross-fertilized across business unit boundaries.

An empirical test of the idea of diversification based on dynamic complementarities would be to examine the effects of related diversification on firms' innovativeness. If the existing and new activities are complementary in innovation, then diversification should accelerate innovation. Capron and Mitchell (1998) obtained results from a dataset of horizontal acquisitions that lend support to this proposition: "Bilateral redeployment of resources," that is, when both the target and acquiring firms' resources are shared and modified during the integration process, is associated with improved R&D capabilities. Complementarity of capabilities is a necessary condition for bilateral resource redeployment. Intensified interaction due to the integration of the dynamically complementary capabilities of the acquiring and target firms can then enhance innovation capacity.

The model's propositions could be assessed more directly in empirical research. The following hypotheses concerning how capabilities, learning, organization, and innovation are related can be derived. First, capabilities in different activities may reinforce one another. It follows then that activities' investments in learning tend to move together — investments in R&D and manufacturing learning (training) pay off more if accompanied with investments in marketing competencies. The existing Finnish innovation survey data indeed suggest the clustering of investments in innovation activities and competencies (see Chapters 4 and 5; also Leiponen, 2000c).

Second, the technological regime shapes the incentives to invest in learning and organization, and as a result, innovation. Empirical measures for the different dimensions of technological regimes (e.g. Levin et al., 1987; Malerba and Orsenigo, 1993) could be used to analyze comparatively learning investment, organization of R&D, and innovation in different regimes. One empirical hypothesis along these lines is that a shift in the technological regime, for example due to a scientific breakthrough that opens new opportunities or changes the process of innovation, should be followed by changes in the learning investments by firms. Further, if complementarities are strong, these changes should induce effects on the organization of complementary activities. A recent example of this is the emerging pattern of technological change in drug design. Pharmaceutical R&D is becoming cheaper and quicker thanks to the new techniques such as combinatorial chemistry and high-throughput screening.[10] These enable "rational drug design" (Cockburn, Henderson and Stern, 1999), which significantly reduces drug development times and increases the success rates for compounds. Consequently, entry barriers have become lower and cumulativeness has reduced, at least temporarily, which have been followed by the emergence of "pharmaceutical service companies" dedicated to providing genomic information or combinatorial-chemistry libraries or to running pre-clinical and clinical trials.[11]

Finally, supermodularity of the profit function with respect to innovation, output and learning investments means that they are likely to move coherently in response to a change in an exogenous parameter (in the comparative static sense – controlling for other exogenous factors). Then "good" characteristics tend to cluster in the same firms.

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[10] The Economist, May 24, 1997

[11] The Economist , Feb 21, 1998

For instance, firms which initially have "high" capabilities may find it more profitable to invest, innovate and grow. Conversely, firms with low initial capabilities perceive low returns on innovation, which do not induce investment in learning and larger output. Firms can become trapped in a vicious – or a virtuous – cycle. For some empirical evidence, see Chapter 5.

A limitation of the model is that it describes only one round of innovation or product development in the firm. A farsighted firm would take into account the cumulative implications of their learning investments for the *following* round of innovation. It would anticipate that by investing heavily in learning now, the firm would face a more beneficial distribution of returns in the next cycle. This is not considered in the two-period model here; agents are assumed to be somewhat myopic. The model also ignores almost completely the implications of demand and strategic interactions between firms. Athey and Schmutzler (1999) have started to investigate oligopoly competition in comparative statics models. This would be an interesting extension.

2.6 Conclusion

This chapter proposes a new framework for analyzing innovation, capabilities and organizational choices in firms. Organizational and investment choices of an innovating firm are modeled to shed light on the long-run implications and tradeoffs of organization. Previous theoretical literature has considered how organizational arrangements affect the incentives to invest. This study examines the long-term effects and interactions of organization and learning investments explicitly, in particular on innovation and growth of the firm. These aspects have been ignored in the extant literature, even though they are important for understanding the microfoundations of economic performance and growth.

A firm's operating environment has implications for the organization of activities. This has not been investigated in the current theory of the firm. Empirical research on innovation has examined the determinants of organizational choices and investment in learning separately. The first coherent theoretical framework developed here demonstrates that to understand the determinants and effects of organization, the impact on knowledge accumulation needs to be considered explicitly and vice versa.

The model proposed here has ramifications for the theory of the firm. First, learning investments and governance decisions interact, which parallels the incomplete contracting framework by Hart and Moore (1990) but differs from the transaction cost approach due to Williamson (1985, 1991), where organization and production are assumed to be independent.

Second, the choice of organization may influence the firm's long-run performance, or in other words, there are dynamic costs and benefits related to different organizational forms. External modes of organization have benefits in terms of efficient learning in changing environments, but they entail a dynamic cost due to less efficient utilization of knowledge complementarities. This aspect has been ignored in earlier studies.

Third, interactions between the firm and its environment indicate that it is important to be precise about the assumptions concerning the environment. Policy conclusions that consider only one aspect of the environment may be misleading. For example, antitrust policies may have different effects on innovation in regimes of high and low cumulativeness of knowledge. Low cumulativeness of knowledge or equivalently a high rate of radical technological change was suggested to be the main driver of external governance of complementary activities. Then firms in a low cumulativeness regime would optimally carry out more innovation in external collaborative arrangements. Competition policies intending to prevent this could be socially counterproductive. Another example is that firms are likely to react to government subsidies to collaborative R&D differently in regimes of tight and loose intellectual property rights (institutional environment). If intellectual property rights are weak, firms are not so willing to engage in open collaborative research with their competitors within a research consortium, for instance, and this policy tool is less effective.

Lastly, it may be unwise policy in the long run to render internal organization costly for instance through labor market regulation. However, supporting long-term collaboration among organizations by policy measures is useful in conditions of high uncertainty. Firms in an uncertain environment are reluctant to internalize risky activities. Some of the benefits of internal organization can be created within long-term collaborative arrangements. In contrast, spot transactions discourage socially beneficial learning investments and knowledge sharing.

Appendix 2

Definition of supermodularity

A function f: $\mathbf{R}^n \rightarrow \mathbf{R}$ is supermodular if for all x, x' $\in \mathbf{R}^n$, f(x) + f(x') $\leq$ f(min(x,x')) + f(max(x,x')), where min(x,x') and max(x,x') refer to component-wise minimum and maximum. The function f is submodular if -f is supermodular.

Theorem 1 *Increasing Optimal Solutions (Topkis, 1978, see Topkis, 1998: Theorem 2.8.1)*

Let f: $\mathbf{R}^n \times \mathbf{R}^m \rightarrow \mathbf{R}$ such that f(**x**, **t**) is supermodular in (**x**, **t**). Then if S is a sublattice of $\mathbf{R}^n$, $\text{argmax}_{\{x \in S)}$ f(**x**, **t**) is monotone nondecreasing in **t** (in the strong set order).

Theorem 2 *Preservation of Supermodularity (Topkis, 1978, see Topkis, 1998: Theorem 2.7.6)*

Suppose that f: $\mathbf{R}^{1+n} \rightarrow \mathbf{R}$ is supermodular and continuous in its first argument. Then for all a, b $\in \mathbf{R}$, the function g: $\mathbf{R}^n \rightarrow \mathbf{R}$ defined by g(x) = $\max_{y \in [a, b]}$ f(y,x) is supermodular.

Lemma 2 *(Athey and Schmutzler, 1995. Originally in Athey, 1995. Modified to represent the notation and variables used in the model here.)*

The following two conditions are equivalent:

(i) $\int_R \Pi(X,R)dG(R;Y)$ (where X is a vector of variables)

is supermodular in (X, Y) for all payoff functions Π: $\mathbf{R}^n \times \mathbf{R} \rightarrow \mathbf{R}$ that are supermodular.

(ii) $\frac{\partial G(R;Y)}{\partial Y} \leq 0$

This lemma implies that if the random variable R increases the returns to X_i in the payoff function Π, then shifting probability weight toward higher realizations of R raises the returns to X_i in terms of increasing expected profits. That is, if Y shifts the distribution of R according to first order stochastic dominance, then Y and X_i will be complements (Athey and Schmutzler, 1995: 568).

3 INNOVATION, COLLABORATION, AND CHOICE OF ORGANIZATIONAL FORM[12]

Abstract

This chapter examines the choice of organizational arrangement in the case of technological collaboration. The main question addressed is what determines whether a firm hires an outside expert as a regular employee, engages in a long-term relationship with the expert, or transacts through the markets. Theories of property rights and implicit contracting are applied to characterize technological cooperation and examine the incentives and commitment created by different organization forms. The results indicate that long-term implicit contracts are always socially efficient, but they may not be sustainable due, for example, to high volatility (risk) of payoffs. Comparison of two types of implicit contracts, "firm" and "relational contract," shows that contrary to received wisdom, firm is a more robust arrangement in the presence of low involuntary spillovers of knowledge. This is because suboptimal market contracting offers a "too reasonable" alternative to relational contracting. Further, firm arrangement is more sustainable in supporting innovation that is based on long-term mutually reinforcing cooperation. In contrast, relational contracts are the most efficient alternative if spillovers are high and there is no need to sustain the relationship in the long run (e.g., if knowledge exchange takes only a limited time).

Key words: Implicit contracts, R&D cooperation

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[12] This chapter has benefited from the discussion in the Finnish Economic Society meeting (Kansantaloustieteen päivät) in Tampere, January 2000, particularly comments by Pentti Forsman.

3.1 Introduction

How does the choice of organizational form affect innovation activities? Economic historians have long emphasized the effect of institutions and organizational arrangements on economic performance of nations and firms (North, 1990; Mokyr, 1992; Mowery and Rosenberg, 1989). Unfortunately, organizations and institutions do not lend themselves easily to dynamic analysis. Instead, one can study the incentives they create and the associated behavior. Incentives to learn and innovate are recognized as critical prerequisites for sustained economic development. I argue in this chapter that the incentives to communicate and cooperate are at the heart of the question of how organizational arrangements affect innovation.

Empirical studies of technological change emphasize that innovation depends often on the integration of key sources of knowledge. Rothwell *et al.* (1974) found that information exchange both within the firm – among functions and departments – and between the firm and its customers and suppliers is important for successful introduction of new products and technologies in the markets. Thus there appear to be complementarities among the diverse sources of knowledge. Internal and external sources interact in the innovation process exerting joint effects on firms' economic performance. Indeed, empirical evidence in Chapter 5 suggests that firms that have sufficient internal competencies and access external knowledge sources through collaborative R&D benefit more from their innovation activities.

The question remains how to integrate the sources of knowledge in practice. When do firms organize learning and innovation internally and which projects do they outsource? This is likely to depend on both the characteristics of underlying knowledge and the characteristics of the possible organizational arrangements. This chapter focuses on the latter. How do alternative organizational arrangements differ in terms of their effects on the innovation process?

A stream of theoretical literature has examined the choice of organizational form for R&D activities (d'Aspremont and Jacquemin, 1988; Kamien, Muller and Zang, 1992; and others building on their seminal contributions). This approach focuses on formation of horizontal research joint ventures (RJVs) in a duopolistic industry. The main conclusions are that R&D cooperation is usually welfare improving because it supports

R&D investment, and that individual firms' choices of whether or not to cooperate depend largely on the magnitude of knowledge spillovers in the industry. The larger the spillovers, the more beneficial the cooperative R&D.

This theoretical framework asserts that collaboration is costless and beneficial, but firms may choose not to collaborate because of the competitive situation – a firm's own R&D investments encourage the partner to produce more due to the knowledge spillovers, which are further intensified in the joint venture. The partners are thus competitors in the markets. However, according to recent innovation survey evidence from Belgium, Finland, and Germany (Cassiman and Veugelers, 2000; Chapter 4 in this thesis; and Kaiser, 2000, respectively), firms are much more likely to collaborate vertically with customers or suppliers than horizontally with rivals. This is possibly due to the aforementioned competition effect that makes it difficult to align the conflicting interests of rival firms. Unfortunately, the RJV framework does not lend itself very well to the study of vertical relationships, although recently Kesteloot and Veugelers (1997) have begun to analyze R&D collaboration between asymmetric horizontal partners.

Innovation partnerships are often motivated by complementary technological capabilities, in addition to sharing of risks and costs (Hagedoorn, 1993). If we believe in the RJV framework, then vertically related, non-rival firms with complementary technologies should always collaborate. Of course, this is not observed in reality. Another, more empirically motivated field of research argues that collaboration is associated with costs of organization and transaction (Pisano, Shan and Teece, 1988; Oxley, 1997). Whereas the theoretical RJV literature posits frictionless cooperation, the transaction cost theory submits that firms choose the organization of R&D by minimizing the sum of production and transaction (organization) costs (Williamson, 1985).

In the present chapter I model the costs of cooperation explicitly as an investment that affects the revenues from innovation projects. I examine a firm's problem of organizing an innovation project where an (outside) expert is an essential source of knowledge. The firm can indirectly trade in the expert's R&D capability through market-like one-time transactions. Then the R&D project output, a new product or a process technology, is the good being exchanged. Alternatively, the firm can establish a relationship based on an implicit contract of repeated transactions. In this case the expert's R&D effort is compensated through an incentive (profit sharing) contract.

The focus on cooperation stems from the observation that close collaboration is essential in exchanging tacit knowledge which underlies much innovation (see e.g. Zucker, Darby and Armstrong, 1994; Senker, 1995). The distinct, partly tacit competencies of various actors need to be integrated to create novel solutions to identified problems (i.a. Iansiti and Clark, 1994). Holmström and Milgrom (1994) have argued that internal organization supports cooperation better than collaborative arrangements across organizational boundaries, because of the incentive issues arising from multiple tasks. For instance, high-powered profit incentives for a team decrease the willingness of its members to cooperate with parties outside the team, unless specific incentive schemes are implemented to encourage cooperation across teams. Therefore it may be better to internalize the actors with which a team needs to cooperate, even at the cost of lower-powered incentives.

The approach here is more explicit: technological cooperation entails an investment of time and effort in a joint R&D project. Cooperation investment has certain special characteristics. First, it is not measurable or verifiable and thus not contractible. However, the collaborating parties can observe the effort made by the other party, and thus will know it even if no formal contract can be signed. Second, communication during cooperation leads to involuntary spillovers of strategic knowledge. As a result, each party unwillingly improves the outside option of the partner. Which organizational arrangement provides the most optimal incentives to invest in cooperation, and when is this arrangement likely to arise?

This question can be analyzed in the implicit contracting framework developed by Baker, Gibbons and Murphy (1997) building on the property rights literature pioneered by Grossman and Hart (1986) and Hart and Moore (1990). The basic property rights model (e.g. Hart, 1995) examines trade in products that are incompletely defined and measured *ex ante*. There the focus is on the allocation of property rights, in other words, on the effects of vertical integration and its direction. Baker *et al.* identify two more organizational instruments in addition to the classical dichotomy between "markets" and "firms". Within "relational contracts," the outside expert retains ownership of the knowledge asset, but compensation is based on an incentive contract. "Spot employment" is an employment relationship based on short-term contracts. Moreover, Baker *et al.* incorporate repeated interaction as an essential element of organizational choice. The repeated game approach makes it possible to take some intertemporal aspects of cooperation into account. An extended time horizon is required to make implicit contracts sustainable.

The present chapter echoes the view by Hansmann (1996, p. 299) that the property rights approach is misguided in its emphasis on the ownership of *physical* assets. For a large number of firms, particularly in the service sector, physical assets are clearly less critical for competitiveness than the competencies and knowledge possessed by employees and teams. Therefore the chapter addresses the organization of firms operating in sectors such as knowledge-intensive business services (*e.g.* legal services, various types of consulting), where the firm cannot directly own the essential assets, namely employees' competencies. In such an environment, the question arises, what defines a firm when there are no essential physical assets to be owned? One can view the firm as a collection of jointly used and owned assets, including both physical and immaterial assets. Then the form of organization depends partly on whether property rights can be established to the immaterial assets or the outputs they produce.

Allocation of property rights to innovation outputs was discussed by Aghion and Tirole (1994) in their model of an R&D project. They examine the incentives and allocation of ownership to an innovation project in a standard property rights framework (Grossman and Hart, 1986). The model in this chapter is richer in organizational forms due to the repeated contracting framework. Indeed, as Baker *et al.* argued, repeated implicit contracting captures some essential features of the firm. These include the creation of "trust" and long-term perspective to contracting in general and R&D in particular. Moreover, the framework here incorporates some basic characteristics of technological knowledge, namely the possibility of involuntary knowledge spillovers and mutually reinforcing efforts.

A central assumption here is that revenues are measurable in the innovation project, for example in the form of sales of the new product or production efficiency gains. Thus the analysis does not apply to the kind of informal, unstructured cooperation where there is no specific project being carried out.

The chapter is organized as follows: The next section introduces the modeling framework and specifies the alternative contractual forms available for firms. Third section examines the sustainability of implicit contracts. Section 3.4 discusses some alternative assumptions, and section 3.5 discusses the implications of the framework. Section 3.6 concludes.

3.2 The model

There are two parties, D and E, who first contract on collaboration, then invest in communication, and in the last stage, share profits. D is a downstream firm that wants to use some (technological) knowledge possessed by E, who is an Expert in some specific field. E's human asset cannot be traded with directly, but by close collaboration the relevant knowledge can be communicated and embodied in D's new technology or product.

Denote the payoffs with R_D and R_O. The revenue from trade realized by D is $R_D = R_D(c_D, c_E)$, a function of the cooperation investments c_D and c_E by D and E respectively. $R_O = R_O(c_D, c_E)$ is the value of the best alternative outside option for E. Thus the same efforts increase the inside and outside options, but apart from this, the revenues are unrelated. Decisions about trade and investments are based on expected payoffs $E(R_D)$ and $E(R_O)$, associated with (unspecified) independent probability distributions.

There may be other providers of solutions to D's problem in the market, and E also has other interested buyers. He can take the R&D results to another downstream firm, but then the value of the R&D work is reduced because of the firm-specific element in the innovation process. Thus the market is competitive, but not perfectly. Trade between D and E is socially efficient (see assumption *eff* below) in the relevant range of investment levels.

(*eff*) $$R_D(c_D, c_E) > R_O(c_D, c_E) \geq c_D + c_E \quad \text{for given } c_D, c_E$$

The revenue schedules are fixed by assuming that no investments is expected to yield no revenue, and that the gradient of the expected revenue function R_D is positive at the origin. I also assume that the expected inside revenue function is strictly concave in (c_D, c_E).

(zero) $E(R_D(0,0)) = 0, E(R_O(0,0)) = 0,$

$$\text{and } \frac{\partial E(R_D(0,0))}{\partial c_i} > 0 \text{ for } i = D, E.$$

The aspect of mutual dependence in cooperation is reflected in the effects of investments on E's outside option. The assumption (*spill*) below specifies that D's investment improves E's outside option, and E's investment improves D's position by reducing E's own outside option:

(spill) $$\frac{\partial E(R_O(c_D, c_E))}{\partial c_D} > 0 \quad \text{and}$$

$$\frac{\partial E(R_O(c_D, c_E))}{\partial c_E} < 0 \quad \text{in the relevant range.}$$

Investments thus increase the dependence, represented by the outside option. The outside option is defined as E's option, and it is assumed that "power cancels power" to reduce the number of variables: when D's position is improved, E's outside option is reduced, and when E's position improves, his own outside option improves. Hence, here both parties invest and have an effect on E's outside option, which is a departure from the Baker *et al.* model. Alternative assumptions concerning the effects on outside options will be discussed in section 3.4.

In the first-best world, investments are chosen to maximize the expected total surplus:

(FB) $$\max_{c_D, c_E} E(R_D) - c_D - c_E$$

In this case, the derivatives of the expected inside revenue with respect to c_D and c_E are set equal to one:

(FOC^{FB}) $$\frac{\partial E(R_D)}{\partial c_D} = \frac{\partial E(R_D)}{\partial c_E} = 1$$

Assuming separable effects of c_D and c_E on R_D for now, the sufficient conditions for optimality are guaranteed by the concavity assumption.

Following Baker *et al.*, there are four possible organizational arrangements: Market (M), relational contract (R), firm (F), and spot employment (SE). In market transaction the price for the good depends on the bargaining powers of the parties. Compensation in a relational contract is also driven by the bargaining powers, but there are two incentive instruments instead of just the price. The expert owns the knowledge asset in these arrangements. The incentive contract under firm is similar to that under relational contract, but now the downstream firm holds the contractual rights to the new technology or product. This essentially transfers the right to the human asset (temporarily) to the downstream firm.[13] Finally, spot employment implies that the expert works for the firm as a salaried employee with a short-term contract without completely benefiting from his or her expertise. The definitions of firm and spot employment are rather extreme, but perhaps justified since the focus is on the fundamental differences among the organizational (or contractual) forms.

3.2.1 Market

In the market exchange, D and E maximize

(M)
$$\text{D: } \max_{c_D} \Pi_D^M = (1-p)E(R_D) - pE(R_O) - c_D$$

$$\text{E: } \max_{c_E} \Pi_E^M = p\big(E(R_D) + E(R_O)\big) - c_E$$

p denotes the sharing rule reflecting the bargaining powers of D and E. Usually it is assumed to be ½, following the Shapley (Nash) bargaining solution. I will follow this convention in what follows.

Now the first order conditions (see FOC^M below) imply a departure from social optimum. The sharing rule and the outside option divert cooperation decisions away from the first-best levels:

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[13] Baker et al. discuss the possibility of a "no compete clause" between an employee and a firm that would transfer the property rights to the knowledge asset to the firm. However, it is debatable whether such contracts are legal. Courts might not recognize the prohibition of competition implied, because of the freedom of profession. In practice we do sometimes observe key employees agreeing to quarantine periods and other arrangements that significantly – and credibly – reduce their outside options. Firm arrangement here could thus be defined as an incentive contract with this kind of a credible commitment by the employee. Relatedly, Aghion and Tirole (1994) discuss the use of "trailer clauses" specifying that innovations made by the expert for some time period after the employment contract has terminated are owned by the employer.

(FOC^M)

$$\frac{\partial E(R_D)}{\partial c_D} - \frac{\partial E(R_O)}{\partial c_D} = 2$$

$$\frac{\partial E(R_D)}{\partial c_E} + \frac{\partial E(R_O)}{\partial c_E} = 2$$

Second-order conditions now require that the curvature of R_D is stronger than that of R_O:

(SOC^M)

$$\frac{\partial^2 E(R_D)}{\partial c_D^{M^2}} < \frac{\partial^2 E(R_O)}{\partial c_D^{M^2}}$$

$$\frac{\partial^2 E(R_D)}{\partial c_E^{M^2}} < \left| \frac{\partial^2 E(R_O)}{\partial c_E^{M^2}} \right|$$

Under the assumption (*spill*) concerning involuntary knowledge spillovers, cooperation effort by D improves E's market position with respect to other potential partners, because D's strategies and technologies spill over to E during the relationship. Similarly E's effort improves D's position. As a consequence, (FOC^M) implies that the stronger the unintended effects of c_D and c_E on R_O are (the steeper the gradients), the smaller the investments by D and E. This can be established more formally by parameterizing the spillover. Let $R_O = R_O(c_D, c_E, t)$, where t is a parameter representing the intensity of the involuntary knowledge flow. Assume that R_O is supermodular in (c_D, t) and $(-c_E, t)$[14]. This specifies t as reinforcing the positive impact of c_D on R_O, and mitigating the negative impact of c_E on R_O. c_D and c_E are assumed not to interact. Then the interaction effects on profits are the following:

$$\frac{\partial^2 \Pi_D^M}{\partial c_D^M \partial t} = -\frac{1}{2} \frac{\partial^2 E(R_O)}{\partial c_D \partial t} < 0$$

$$\frac{\partial^2 \Pi_E^M}{\partial c_E^M \partial t} = \frac{1}{2} \frac{\partial^2 E(R_O)}{\partial c_E \partial t} < 0$$

Profit functions Π_i are thus supermodular in $(c_i, -t)$, where i = D,E. It follows that the optimal choices of c_i are decreasing in t (see Theorem 1 by Topkis in Chapter 2, p. 33). The more intensive the spillovers, the lower the investments.

[14] In the case of the twice differentiable functions here, supermodularity of R_O is equivalent to positive cross-partial derivatives of R_O with respect to c_D and t, and negative with respect to c_E and t (see Topkis, 1998).

3.2.2 Spot employment

Spot employment contract is the following:

(SE)
$$\max_{c_D} \Pi_D^{SE} = E(R_D) - c_D - s$$

$$\max_{c_E} \Pi_E^{SE} = s - c_E$$

Because (SE) is a short-term contract, D's promises of performance-related compensation are not credible, and therefore E is compensated only with flat salary s. As a result, E has no incentives to invest in cooperation, and D gets all the revenue. Consequently, D has optimal investment incentives.

(FOC^{SE})
$$\frac{\partial E(R_D)}{\partial c_D^{SE}} = 1$$
$$c_E^{SE} = 0$$

Concavity of $E(R_D)$ suffices as the second order condition in this case.

3.2.3 Implicit contracts

Implicit contract encompasses both firm and relational contract arrangements. It entails separate compensation for the inside and outside trade and a flat *ex ante* salary. D and E maximize, respectively:

(I)
$$\max_{c_D} \Pi_D^I = (1-b)E(R_D) - \beta E(R_O) - c_D - s$$

$$\max_{c_E} \Pi_E^I = s + bE(R_D) + \beta E(R_O) - c_E$$

b is E's share of inside revenue, and β is the compensation for outside competition. s denotes the fixed salary payment. This incentive contract is another (slight) departure from the model by Baker *et al.* Here the contract is assumed to be of the profit sharing kind instead of fixed payments associated with discrete outcomes.

Again, first order conditions demonstrate the impact of the spillover externality whereby spillovers are likely to induce a departure from the social optimum:

(FOC[I]) $$(1-b)\frac{\partial E(R_D)}{\partial c_D} - \beta\frac{\partial E(R_O)}{\partial c_D} = 1$$

$$b\frac{\partial E(R_D)}{\partial c_E} + \beta\frac{\partial E(R_O)}{\partial c_E} = 1$$

Second-order conditions are modified now by the contract parameters:

(SOC[I]) $$(1-b)\frac{\partial^2 E(R_D)}{\partial {c_D^I}^2} < \beta\frac{\partial^2 E(R_O)}{\partial {c_D^I}^2}$$

$$b\frac{\partial^2 E(R_D)}{\partial {c_E^I}^2} < -\beta\frac{\partial^2 E(R_O)}{\partial {c_E^I}^2}$$

With an implicit contract it is in fact possible to reach the first-best investment levels by choosing the compensation parameters in a specific way, provided that β is allowed to be negative.

Lemma 1 *With an implicit contract it is possible to attain first-best investment levels.*

Proof b and β can be solved from (FOC[FB]) and (FOC[I]) yielding

$$b^{FB} = -\frac{\dfrac{\partial E(R_O)}{\partial c_D^{FB}}}{\dfrac{\partial E(R_O)}{\partial c_E^{FB}} - \dfrac{\partial E(R_O)}{\partial c_D^{FB}}}$$

$$\beta^{FB} = \frac{1}{\dfrac{\partial E(R_O)}{\partial c_E^{FB}} - \dfrac{\partial E(R_O)}{\partial c_D^{FB}}}$$

The socially optimal b^{FB} and β^{FB} depend on the elasticity of R_O with respect to c_D and c_E. Under assumptions (*spill*), b^{FB} is positive and β^{FB} negative. This contract elicits first-best levels of investment. *Q.E.D.*

In the implicit contract with optimal parameters b^{FB} and β^{FB}, E is rewarded for increasing the inside revenue and punished for improvements in the outside option. D, in contrast, invests because he is rewarded for both higher R_D and higher R_O. Whether first-best investment levels are actually attained depends among other things on the bargaining powers and sequence.

Even if the price p in the market case could be freely determined, first-best investments would still not be attained. Carrying out the above computation for the socially optimal p in the market case reveals that attaining the optimal investments would require that the partial derivative of R_O with respect to c_D equals -1. This is never the case, since the partial is positive by assumption. The efficiency of (I) follows from these observations:

Proposition 1 *(a) The (I) contract can always replicate the (M) contract, and (b) improve on it (in the sense of shifting toward first-best actions).*

Proof When the effects of investment on the outside option are as assumed in (spill), (a) fix $b = \beta = p$. (b) Let b and β differ from one another, and decrease β. The cross-partials of profits with respect to communication efforts and β indicate that the optimal choices of c_D^I and c_E^I are decreasing in β:

$$\frac{\partial^2 \Pi_D^I}{\partial c_D^I \partial \beta} = -\frac{\partial E(R_O)}{\partial c_D^I} < 0$$

$$\frac{\partial^2 \Pi_E^I}{\partial c_E^I \partial \beta} = \frac{\partial E(R_O)}{\partial c_E^I} < 0$$

Thus lower β will induce higher c_D and c_E. Adopting two separate incentive instruments and allowing β to decrease will constitute a move towards social optimum. *Q.E.D.*

3.3 Sustainability of implicit contracts

3.3.1 Relational contracts

The (I) contract is sustainable if the expected payoffs from collaboration exceed the rewards from reneging in the current period. This comparison takes place after investments are made and stochastic revenues have been realized. Reneging implies receiving the fallback payoff from there on. In the relational contract case, the fallback arrangement is market (M) exchange, which is the short-term contract with E's ownership of the critical knowledge asset. For D and E respectively, the individual rationality constraints are:

$$(\mathrm{IR}_D{}^R) \quad -bR_D - \beta R_O + \frac{1}{r}E(\Pi_D^R) \geq \frac{1}{r}E(\Pi_D^M)$$
$$\Leftrightarrow E(\Pi_D^R) - E(\Pi_D^M) \geq r\left(bR_D + \beta R_O\right)$$

$$(\mathrm{IR}_E{}^R) \quad bR_D + \beta R_O + \frac{1}{r}E(\Pi_E^R) \geq \frac{1}{r}E(\Pi_E^M)$$
$$\Leftrightarrow r\left(bR_D + \beta R_O\right) \geq E(\Pi_E^M) - E(\Pi_E^R)$$

Here r is the discount interest rate. Immediately we can see from (IR^R) that the *expected* surplus can be divided in such a way that satisfies both parties if the total expected surplus from (R) arrangement exceeds that expected from (M) arrangement. However, to ensure the actual sustainability of the contract, the above constraint must apply for the extreme realizations of R_D and R_O, as well. Therefore, assume that it is possible to identify some "maximum" and "minimum" values of R_D and R_O, defined as the 1- and 99-percentiles, for instance, in the case of continuous distributions of outcomes: $R_D{}^{max}$ and $R_D{}^{min}$, and $R_O{}^{max}$ and $R_O{}^{min}$. Then (IR^R) must be valid for

$$(1) \quad \begin{cases} E(\Pi_D^R) - E(\Pi_D^M) \geq r\left(bR_D^{\max} + \beta R_O^{\max}\right) \\ r\left(bR_D^{\min} + \beta R_O^{\min}\right) \geq E(\Pi_E^M) - E(\Pi_E^R) \end{cases} \quad \text{for } \beta > 0$$

$$(2) \quad \begin{cases} E(\Pi_D^R) - E(\Pi_D^M) \geq r\left(bR_D^{\max} + \beta R_O^{\min}\right) \\ r\left(bR_D^{\min} + \beta R_O^{\max}\right) \geq E(\Pi_E^M) - E(\Pi_E^R) \end{cases} \quad \text{for } \beta < 0$$

Combining (1) and (2) and denoting $\Delta R_D = R_D^{\max} - R_D^{\min}$ and $\Delta R_O = R_O^{\max} - R_O^{\min}$, we get

$$(\mathrm{S}^R) \quad E(\Pi_D^R) + E(\Pi_E^R) - E(\Pi_D^M) - E(\Pi_E^M) \geq r\left(b\Delta R_D + |\beta|\Delta R_O\right)$$
$$\Leftrightarrow E(TS^R) - E(TS^M) \geq r\left(b\Delta R_D + |\beta|\Delta R_O\right)$$

The sustainability of the (R) contract thus depends on the gains from trade within the relationship, but also on the discount rate and the variability of the values that the inside and outside payoffs may take. Variability of payoffs is related to the variances of the probability distributions associated with R_D and R_O.

Proposition 2 *The higher the interest rate, the smaller the expected gains from the relationship, or the higher the variance of the payoff distributions, the more likely the implicit relational contract is to break.*

Proof Follows directly from (S^R). Q.E.D.

Proposition 1 demonstrated that it is optimal to have two incentive instruments as investment levels of both D and E are decreasing in β. Thus (M) is never socially optimal for the kind of transaction examined here, according to this model. However, (M) can be individually optimal, if interest rate r is very high or stochastic outcomes of R_D or R_O have a high variance.

3.3.2 Firm contracts

In the firm arrangement, the incentive contract is the same as in the (R) case, but the sustainability constraints are different. Now the fallback option is spot employment (SE) contract. D can claim the contractual rights to the project output or E has signed a "no compete clause" or in some other way committed to not utilizing his special asset to trade with D's rivals in case of breach. In essence, E has then temporarily transferred the rights to control the asset to D.

(F) contract will be honored if it is individually rational for D and E:

(IR_D^F)

$$-bR_D - \beta R_O + \frac{1}{r}E(\Pi_D^F) \geq \frac{1}{r}E(\Pi_D^{SE})$$
$$\Leftrightarrow E(\Pi_D^F) - E(\Pi_D^{SE}) \geq r(bR_D + \beta R_O)$$

(IR_E^F)

$$bR_D + \beta R_O + \frac{1}{r}E(\Pi_E^F) \geq \frac{1}{r}E(\Pi_E^{SE})$$
$$\Leftrightarrow r(bR_D + \beta R_O) \geq -E(\Pi_E^F)$$

The expected *ex post* profits under spot employment are zero for E. Knowing this, E has no incentives to invest. Combining the constraints as in the (R) case, we obtain

(S^F)

$$E(TS^F) - E(TS^{SE}) \geq r(b\Delta R_D + |\beta|\Delta R_O)$$

Next we can compare the sustainability of (F) and (R) arrangements.

Proposition 3 *When investments have separable effects on R_D,*[15] *firm is a more robust arrangement than relational contract for small spillovers, while large spillovers make relational contract a relatively more easily sustainable organization form.*

Proof Due to the same incentive schemes in (R) and (F), expected total surpluses are equal in these two arrangements. (S^F) thus differs from (S^R) only by the fallback options. When $E(TS^M) > E(TS^{SE})$, there is less "slack" in the (R) contract than in the (F) contract, making (F) more robust to extreme realizations of stochastic revenues. This obtains when spillovers are not too large, as shown below.

Recall that $E(TS^M) = E(R_D^M) - c_D^M - c_E^M$ and $E(TS^{SE}) = E(R_D^{SE}) - c_D^{SE} = E(R_D^{SE}) - c_D^{FB}$ because E will not invest under (SE), and then D is the residual claimant and gets optimal investment incentives.

To simplify, assume that R_D is separable in c_D and c_E: $R_D = R_{DD}(c_D) + R_{DE}(c_E)$. Moreover, $E(R_{DD}(0)) = 0$ and $E(R_{DE}(0)) = 0$ with positive gradients at the origin (see assumption (*zero*)). Then, $\exists \overline{c}_D < c_D^{FB}$ and $\exists \overline{c}_E < c_E^{FB}$ such that for $c_D < \overline{c}_D$ and $c_E < \overline{c}_E$, $E(TS^M) < E(TS^{SE})$ and for $c_D > \overline{c}_D$ and $c_E > \overline{c}_E$, $E(TS^M) > E(TS^{SE})$. To see this, recall that $E(R_{DE}(c_E^{FB})) - c_E^{FB} > 0$. Therefore if both D and E invest optimally under the (M) contract: $c_D^M = c_D^{FB}$ and $c_E^M = c_E^{FB}$, then $E(R_{DD}(c_D^{FB})) + E(R_{DE}(c_E^{FB})) - c_D^{FB} - c_E^{FB} = E(TS^M) > E(TS^{SE}) = E(R_{DD}(c_D^{FB})) - c_D^{FB}$. On the other hand, $E(R_{DD}(0)) = 0$ and $E(R_{DE}(0)) = 0$ by assumption, therefore if neither D nor E invests: $c_D^M = 0$ and $c_E^M = 0$, then $0 = E(TS^M) < E(TS^{SE})$. Thus for small investments, i.e., $c_D < \overline{c}_D$ and $c_E < \overline{c}_E$, $E(TS^M) < E(TS^{SE})$ and for large investments, the opposite applies.

Let the parameter t, as defined previously, represent the exogenous appropriability environment. Profit functions of D and E are supermodular in (c_D, $-t$) and (c_E, $-t$), respectively. Then optimal choices of c_D and c_E are decreasing in t. It follows that for sufficiently

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[15] The non-separable case is analyzed in Proposition 4.

large spillovers, $c_D < \overline{c}_D$ and $c_E < \overline{c}_E$, and consequently $E(TS^M) < E(TS^{SE})$. This creates more "slack" in (S^R) compared to (S^F): $E(TS^R)$-$E(TS^M) > E(TS^F)$-$E(TS^{SE})$, when $E(TS^R) = E(TS^F)$ and thus (R) is more robust than (F) to extreme stochastic values for the payoffs. The opposite applies for sufficiently small spillovers. *Q.E.D.*

The result has two interpretations. On the one hand, small spillovers may arise from low usefulness of spillover knowledge outside the relationship, or in other words, highly firm- or relationship-specific knowledge. If knowledge is highly specific, firm is a relatively more sustainable arrangement than relational contract. On the other hand, spillovers may be related to the broader technological regime of appropriability of the returns to innovation, including the possibilities to use patents and other intellectual property rights (IPR) (see Levin *et al.*, 1987). If IPRs are efficient in protecting knowledge, then somewhat counter-intuitively, firm is a more robust organization form.

This outcome turns on the effects of investments on the fallback options in the case of breach. If spillovers are small, i.e., appropriability is high, (M) becomes a more feasible alternative reducing the sustainability of (R). For instance, when the variance of payoffs is high (say, a rapidly changing technological environment) and intellectual property rights are strong, it may be difficult to sustain relational contracts, because market transactions offer a reasonable alternative. Thus in high appropriability environments one is likely to observe relatively more market and firm arrangements and fewer relational contracts. On the contrary, market transactions are disadvantaged under low appropriability, and there will be more relational contracts relative to firms.

3.3.3 Positive interactions between the investments

This subsection studies the implications of mutually reinforcing cooperation and knowledge exchange. Reinforcing effects arise when the more partners know about each other, the more productively they can focus their efforts of collaboration to suit both parties' competencies and goals. Then the more one participant invests, the more it pays off for the other to reciprocate. Proposition 4 examines optimal investments and in particular the relative sustainability of (F) and (R) in the presence of mutually reinforcing cooperation.

Proposition 4 *Positive interactions between cooperation investments (supermodularity of the inside payoff R_D with respect to c_D and c_E) expand the sustainability area for the firm arrangement compared to that for relational contracts, making firm a relatively more robust organization form.*

Proof Assume that R_D is not separable and investments interact positively. Then R_D is supermodular in c_D and c_E, *i.e.*, $\partial^2 E(R_D)/\partial c_D \partial c_E \geq 0$. Define $c_D^M = c_E^M = \overline{c}$ as investment levels that make E(TS^{M}) = E(TS^{SE}) in the separable case:

(A) $$E\left(R_{DD}(\overline{c})\right) + E\left(R_{DE}(\overline{c})\right) - 2\overline{c} = E\left(R_{DD}(c_D^{FB})\right) - c_D^{FB}.$$

However, under supermodularity of R_D,

(B) $$R_D(\overline{c},\overline{c}) \geq R_D(\overline{c},0) + R_D(0,\overline{c}) = R_{DD}(\overline{c}) + R_{DE}(\overline{c}).$$

Now define $c_D^M = c_E^M = \overline{\overline{c}}$ such that $R_D(c_D^{FB},0) - c_D^{FB} = R_D(\overline{\overline{c}},\overline{\overline{c}}) - 2\overline{\overline{c}}$. Based on (A) and (B) above, $\overline{\overline{c}} < \overline{c}$. Hence, the breakpoint identified in Proposition 3, investments above which make E(TS^{SE}) < E(TS^{M}) and investments below which make E(TS^{SE}) > E(TS^{M}), is lower under supermodularity than under separability. It follows that larger spillovers are required to make E(TS^{SE}) > E(TS^{M}) in the positive interaction case than in the separable investment case. Hence, positive interaction makes (F) more sustainable relative to (R). *Q.E.D.*

This result suggests that firm is a relatively more robust organizational arrangement than relational contracts when positive interactions are strong in cooperation investments. This is because the positive interactions between investments affect market transactions but not in spot employment, and hence the sustainable range of outcomes is relatively larger under firm. In this scenario it is particularly productive for E to tie his hands by committing to the firm arrangement and reducing his fallback alternative to spot employment.

In addition to the sustainability of optimal long-term implicit contracts, there is yet another consideration when the downstream firm is choosing whether to offer the outside expert a relational contract or an employment contract. The firm and the expert will have to negotiate a price for exchanging the property rights to the asset, or in other words, for the expert accepting the "no compete clause" or other contractual commitment stipulated in the employment contract. Then the choice between relational contract and firm contract is based on comparing the potential benefits of the better sustainability of the firm contract against the price of the commitment clause.

3.4 Alternative assumptions on spillovers and outside options

If the inequalities in the assumption (*spill*) are reversed, i.e., cooperation efforts lead to internalization of partner's knowledge, not to leakage of own knowledge, then it is possible that parties overinvest. Under this new assumption (*spill'*), D's investment will reduce E's outside option, as he will adopt E's competencies and can for instance use them in cooperation with other suppliers. Similarly, E's investment increases his outside option, because he learns more from D the more time and effort he spends collaborating. Then the presence of an outside option in fact increases incentives to cooperate, and this can exceed the investment-reducing effect of the division of the surplus. The efficiency of implicit contracts (R) and (F) over spot (short-term) arrangements stems here from the possibility to separate b and β, and reduce b. In reality investments are likely to work both ways: firms try to minimize spillovers and maximize learning and knowledge adoption (Hamel, Doz and Prahalad, 1989).

We could also have modeled D's outside option separately from E's. Then the assumption concerning spillovers would be that D's investment improves either E's or its own outside option, and similarly for E. In the first case (as under the original (*spill*) assumption), firms gradually learn from one another and build up their opponent's outside option. Investments will be suboptimal because each party tries to prevent his own knowledge from leaking, thus cooperating less than efficiently. Under the active knowledge adoption assumption (*spill'*), internalizing spillovers requires effort. In this scenario, first-best investment levels may follow, because the drawback from dividing the marginal surplus may be offset by the incentive to try to learn from the partner.

In both cases, the outside options will build up gradually, faster under (*spill'*) than (*spill*), but eventually the setups lead to the unraveling of the relationship. If there is no generation of new knowledge in the relationship and (*eff*) is not assumed, sooner or later there will be no more useful things to learn from the partner, and the outside option becomes more lucrative. As a result, the partners will go their separate ways. This illuminates one of the possible reasons behind the temporary nature of many technological alliances. The dissolution of the alliance is not necessarily a failure, but a built in characteristic of the arrangement.

3.5 Discussion

This chapter asserts that some relevant aspects of innovation and technological cooperation can be analyzed through the formal incomplete contracting analysis. The results lend support for Holmström and Milgrom's argument about long-term implicit contracts being more conducive to cooperation than short-term (market) transactions. At the same time, the model yields some results that are somewhat at odds with the received economic wisdom concerning the effects of knowledge spillovers on optimal organizational form. In particular, high spillovers make relational contracts more sustainable than employment contracts.

The framework by Baker, Gibbons and Murphy (1997) does not posit "markets" and "hierarchies" as the extremes of a continuum of governance forms, with "hybrids" or relational contracts as an intermediate solution, as is customary in transaction cost economics. Rather, behavior associated with relational contracts differs from that associated with long-term employment relationships due to different fallback options. These stem from the ownership of the critical asset.

Property rights to knowledge assets are thus at the heart of the definitions of firm and relational contract in this setup. The firm contract is the same as relational contract in terms of incentives, but the downstream firm holds the property rights to the technology created, instead of the expert. As a result, even what is usually understood as employee relationship in a firm (long-term open-ended employment contracts) can in fact be a relational contract as defined here if the property rights to the employee's essential assets or output cannot be established.

A key issue is whether it is possible (or how costly it is) to define property rights to the asset or the output it produces – learning in addition to codified technologies. This is a real contracting problem particularly in knowledge- or skill-intensive business services. For instance, it is not unusual that allocating property rights to the software created during an information technology outsourcing relationship leads to disputes at the end of the relationship, when the client wants to change suppliers.[16] In contrast, in industrial design services it is customary to agree *ex ante* that the designs produced during the collaboration process belong to the client firm.[17] It is more difficult, however, to expropriate the tacit knowledge accumulated by the expert during the project. This problem is often solved in consulting and other business services by writing a contract where the consultants agree not to sell to the direct rivals of the client firm for a specified time period.

Indeed, sometimes these service relationships may be more reminiscent of firm contracts than relational contracts, even though the consultant is not employed by the client firm in formal terms. An interesting case in point is a Finnish engineering service firm in the field of shipbuilding, which voluntarily chooses not to apply for patents to appropriate the technologies developed during service relationships. An interpretation based on the model here is that specifying strong property rights to its technologies would impose a relational contract instead of a firm contract on the transaction. Then, if spillovers are not too high and thus market transactions are a feasible alternative, the implicit contract becomes very difficult to sustain. The engineering firm may be better off tying its hands and relying on more firm-like contracts, even though in the short-term it may not benefit fully from its intellectual property.

If ownership of the critical asset cannot be exchanged, property rights to project output cannot be established, or no-compete clauses are illegal, relational contracts and market transactions are the only available alternatives. This has implications particularly for fields such as management consulting and legal advice. In these "pure" consulting services no technical drawings or designs are produced as output, and physical assets are minimally involved. First, internal organization of these firms is often based on partnerships that clearly have features of relational contracting as the critical asset is the individual consultant's skills and experience which cannot be traded. Second, repeated interaction between independent, risk-taking consultants and their client firms also tends to rely on long-term relational contracting, unless more contractual commitments are specified, as discussed above.

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[16] Financial Times IT survey, Aug 4, 1999, p. 1.
[17] Based on interviews with four leading Finnish industrial design consultancies.

Incentives and property rights are thus specified as two separate governance dimensions in the framework. Transaction cost economics, in contrast, argues that a more "integrated" governance, which would be the firm arrangement here, has less intensive incentives and is better at protecting knowledge from spilling over than "hybrid" forms of governance represented here by relational contract (see e.g. Oxley, 1997). Additionally, transaction cost logic implies that internal organization involves more credible commitments and more intensive monitoring and administrative controls. In the model here, however, the two implicit contracts vary only by their fallback options, not incentives *i.e.* administrative or monitoring technologies. A joint venture or any other kind of a collaborative arrangement is assumed to be potentially monitored equally effectively as a firm's internal department.

In this modeling approach the differences between various implicit contractual forms arise from the differences in their fallback options. The most important drivers of long-term relationships may not always be written in the contract itself, but stem from the other alternatives available to the parties. A promising avenue within the economics of organization is to focus on the outside and fallback options as determinants of commitment in different types of governance structures, instead of studying incentive mechanisms within a given structure.

Fallback options in a way reflect the agents' commitments to a long-term relationship. Williamson (1983) studied these in the transaction cost framework and showed that firms indeed do manage commitments. In the present chapter small spillovers (high appropriability of knowledge) decrease the commitment to relational contract since organization through market becomes more feasible. When spillovers are large, market organization is very inefficient, which supports implicit contracting. All this is very much in line with the traditional transaction cost reasoning. In contrast, a move from a relational contract to a firm contract is not along the same "continuum" of governance forms. Firms and relational contracts have different outside options because ownership of the critical asset changes. Thus, large spillovers do not necessarily make long-term employment (firm) contract the most efficient. In fact, relational contracts are relatively more sustainable than long-term employment under very large spillovers. This is not accounted for in the transaction cost framework.

3.6 Conclusion

The main results from the model include the following:

1. Communication and cooperation are indeed more intensive in relationships governed by implicit contracts, defined here as relational contract or firm, than in market-like short-term transactions. The reason is related to Holmström's (1999) argument about access to complementary incentives in internal organization. One of the key benefits of implicit long-term contracts is the availability of more incentive instruments, with which it is possible to better take into account the interactions between the compensations for various (multiple) tasks. Here the relevant interactions are between the inside, outside, and fallback options, due to the multiple effects of cooperation investments.

2. High variances of the revenue distributions, in other words, high likelihood of extreme realizations of inside and outside revenues, reduce the probability that implicit contracts are honored. This would also result from a high probability of external shocks like changes in market conditions or technology. Even though implicit long-term contracts are always socially optimal, individual rationality may prevent them from being adopted and honored under these circumstances.

3. Large involuntary knowledge spillovers reduce the incentives to put effort into cooperation in innovative activities, when cooperation causes knowledge leakage. Small spillovers can be interpreted as high appropriability of technology and knowledge. Intellectual property rights (IPR) therefore support investment in productive cooperation, in line with extant empirical literature. However, the organizational form of cooperation may also be affected by the IPR regime. If IPRs are strong in an environment with high variance of stochastic outcomes, the inefficient market arrangement may be "too" feasible. In this case shifting to the firm arrangement by transferring the property rights to the critical assets or output of the project to the downstream firm may be more sustainable. IPR policies thus optimally take account of the institutional interactions.

4. Under positive interactions between the cooperation efforts, that is, mutually reinforcing efforts, sustainability of the firm contract becomes relatively more robust (less vulnerable to extreme realizations of payoffs) compared to the relational

contract. The benefits of internal organization, according to this framework, are in enabling long-term mutually reinforcing cooperation and communication among organizational actors. Where this is important for innovative activities, firm organization is likely to be more efficient. If the project goals are less long-term and hence the vulnerability of the contract is less of an issue, a relational contract offers an efficient alternative for innovative activities.

As is often the case, policy conclusions are not entirely straightforward. For instance, improving patent protection may make market transactions “too” feasible and shift contractual arrangements away from relational contracts. This reduces the incentives to cooperate productively, which is clearly suboptimal. Policy-makers would need to take into account the interactions between inside and outside payoffs by complementing the IPR protection policy with incentives to engage in long-term relationships for example by reducing their costs. This illustrates the interplay of technological and institutional environments through organizational choices.

4 WHY DO FIRMS *NOT* COLLABORATE? COMPETENCIES, R&D COLLABORATION, AND INNOVATION UNDER DIFFERENT TECHNOLOGICAL REGIMES[18]

Abstract

This empirical study focuses on the determinants of the organization of innovation. It is argued that differences in firms' collaboration behavior stem from their knowledge bases and technological environments (regimes). It is hypothesized that competencies complement collaborative innovation, and therefore, different types of collaboration are expected to necessitate different competencies. Technological regime, dimensions of which include appropriability, demand-pull, supplier-domination, science-push, and entrepreneurial vs. routinized innovation regime, also shape patterns of collaboration. Innovation is modeled as a system of equations, where R&D, collaborative arrangements, and product innovation are simultaneously determined.
Results of Finnish survey data indicate, first, that technical and research competencies are significant factors in firms' "systems of innovation." This reflects the need for absorptive capacity: to be able to internalize knowledge from external relationships the firm needs sufficient internal capabilities. For instance, research competencies are shown to be important for collaboration with universities. Second, collaboration with competitors is less common and differently determined than collaboration with other types of partners. This finding suggests that information concerning collaboration partners is necessary in the study of structure and function of innovation systems, and vertical alliances are at least as important objects of study as horizontal ones. Third, technological regimes have a significant impact on the organization of the firm. Understanding of how firms' innovation behavior is related to technological regimes can contribute to more effective technology policy.

Key words: R&D collaboration, innovation, competencies, technological regimes

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[18] I am grateful for the comments by the participants of the TSER workshop on Innovation and Economic Change in Delft, The Netherlands, especially Pierre Mohnen, Chris Walters, and José M. Labeaga, and comments by seminar participants at INRA, Toulouse and Amos Tuck School, Dartmouth College. Remaining errors are mine alone. This chapter is forthcoming in Kleinknecht and Mohnen (2001).

4.1 Introduction

Determinants and effects of innovation are topics of intense research interest, particularly since the fundamental relationship between economic and technological change has become widely acknowledged. As a result, contributions of research and development activities (R&D) to innovation and industrial evolution, especially in manufacturing industries, are well appreciated. However, in economic models and also in many empirical studies, R&D is often conceptualized as an innovation production function. Such treatment may be a useful first approximation of the innovation process within a linear model of innovation. However, in qualitative empirical studies over the past 20 years it has been observed that the organization of R&D is a critical determinant of both innovation (e.g. Mowery, 1983) and economic performance (e.g. Teece, 1986). Informal models of innovation emphasize feedbacks and complementarities among a firm's activities and knowledge bases (Kline and Rosenberg, 1986, Rothwell, 1994). Organizational choices, for instance whether to organize knowledge creation activities internally or outsource them, have a considerable impact on the strength of the interactions among the necessary sources of knowledge.

In this chapter product innovation is assumed to be supported by a system of activities: internal R&D, R&D collaboration with outside partners, and outsourcing of R&D. I argue that this system is complemented by competencies and skills of the firm. Competencies are hypothesized to be prerequisites for success in the three forms of R&D activities. Sufficient competence level may be necessary for both perceiving the benefits, locating, and making use of external knowledge.

It is well known that industries are characterized by different patterns of technological change (e.g. Pavitt, 1984). The effects of these sectoral differences in technological change on R&D investment (Cohen and Levinthal, 1989) and industrial structure (Winter, 1984) have been studied. Here I will assess how sectoral differences affect firms' organizational choices concerning R&D and, ultimately, innovation.

I use recent innovation survey data from Finland to analyze the determinants of external R&D arrangements of firms, i.e., collaboration with various partners and outsourcing. The main research question is, how is the organization of innovation activities affected by (1) competencies and (2) the technological environment?

4.2 Related literature

4.2.1 Firm capabilities

In recent years a literature on the capabilities of firms has emerged emphasizing the role of knowledge in firm performance and evolution. Original contributions include Penrose's work (1959) and the evolutionary approach to industrial dynamics (Nelson and Winter, 1982; Wernerfelt, 1984; Teece et al. 1997). In this perspective, a firm's knowledge resources are critical determinants of its competitiveness. At the same time, firm specificities arising from the organizational nature of productive knowledge make firms idiosyncratic, due to which they may perform very differently in markets over the long run. This literature holds great promise as to our understanding of firm behavior and industrial dynamics, but it has proven quite difficult to extend the analysis from case studies of individual firms to cross-sectional empirical studies and to produce theoretical models of firm organization.

Empirical innovation literature has emphasized the complex interactions among various internal and external sources of knowledge and capabilities (Rothwell et al. (1974), Rosenberg (1982), Freeman (1982), von Hippel (1988) among others). Cohen and Levinthal (1990), in line with the empirical work of many scholars in the 1980s, coined the term *absorptive capacity* referring to the firm's capability to assimilate information from the environment. The idea is that a firm carries out R&D not only to improve its own products and technologies, but also to keep up with the technological advance by other firms in the industry and to be able to use that knowledge internally. In other words, external and internal knowledge sources are complementary in the firm's innovation activities.

4.2.2 R&D collaboration

As technological change has become more rapid and complex, and dissemination and sourcing of information have become easier due to new technologies, many firms decide not to create all knowledge internally. Some of it can be acquired in the markets. However, there are no markets for certain kinds of knowledge. In particular, a significant part of firms' productive knowledge is tacit or collective and therefore not easily transferable, and other parts are firm specific or strategic and thus not for sale. Nevertheless, through intensive collaboration within an R&D alliance, even some of this "stickier" knowledge can be shared and jointly utilized. Collaborative R&D can be viewed as a transaction in organizational knowledge. Indeed, collaborative arrangements like R&D alliances, joint ventures, and research consortia are becoming increasingly common in modern economies. However, in order to make use of another firm's knowledge, a firm needs to possess sufficient internal competencies, in other words, absorptive capacity.

As collaborative arrangements between firms have proliferated over the past two decades, various explanations for their occurrence have been offered in the academic literature (see e.g. Contractor and Lorange, 1988). The benefits of collaboration are generally emphasized in these studies, partly due to a sampling bias: usually only collaborating firms are examined (e.g. Hagedoorn and Schakenraad, 1992; Powell, Koput and Smith-Doerr, 1996)[19]. The reasons for *not* collaborating are typically not assessed. The cross-sectional approach with random sampling in this chapter reduces this bias.

One of the few more critical views on collaborative arrangements comes from the transaction cost approach, which suggests that R&D collaboration can lead to unintended leakage of strategic information to the firm's competitors (Pisano, 1989; Oxley, 1997). Other studies argue that external organization of R&D may reduce the possibilities to innovate profitably as externally sourced knowledge may be more difficult to integrate tightly with the other activities of the firm. In such a situation, the potential complementarities related to innovation may remain only partially exploited (Mowery and Rosenberg, 1989; Chapter 2 in this thesis). External organization of R&D may be associated with a trade-off between lower costs of developing new capabilities, on the one hand, and the transactional hazards stemming from leakage of knowledge and missed opportunities for complementarity among knowledge resources, on the other. Moreover, firms lacking complementary internal competencies will find it less profitable to engage in collaborative innovation.

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[19] However, Contractor and Lorange (1988) in their introductory chapter discuss both benefits and costs of cooperative ventures.

According to Hagedoorn (1993), the main reasons behind strategic R&D alliances include i) technological complexity and complementarities, ii) reduction of the uncertainty and costs of R&D, iii) interest in capturing partners' knowledge, and iv) reduction of product development times. However, to my knowledge, the kinds of partners with which firms do and do not collaborate has not been empirically examined. The literature generally focuses on horizontal collaboration, perhaps as an outgrowth of economists' interest in the potential degradation of competition in the markets. Here I suggest it is likely that firms' motivations for forming alliances with customers or universities, for example, differ from those associated with partnering with competitors. The transaction cost point of view implies that the logic and cost structures supporting vertical alliances are different from those of horizontal organizational forms.

Beyond analyzing patterns of collaboration, this study seeks to examine the role of internal competence accumulation in collaborative innovation. Using Finnish survey data on innovation, we can compare the skill characteristics of firms entering collaborative arrangements with those of non-collaborating firms.

4.2.3 Technological regimes

A stream of research on technical change argues that it is possible to identify the underlying dimensions according to which industries differ from one another (*i.a.* Winter, 1984; Levin *et al.* 1987). One approach to classification suggests characterizing the technological and innovation environment according to the presence of innovation *opportunities* and the degree of *appropriability* of the returns to innovation (Levin et al. 1987; Klevorick et al. 1995). It is argued that high opportunities encourage investment in R&D, but appropriability can have two opposed effects due to the dual role of R&D: on the one hand, higher appropriability increases the returns to innovation, but on the other, lower appropriability increases the returns to imitation. Both can encourage R&D activities (Cohen and Levinthal, 1989).

Scholars in the Schumpeterian tradition (e.g., Audretsch, 1995, Malerba and Orsenigo, 1993) have characterized the technological environment through reference to the degree of technological turbulence (see also Tushman and Anderson, 1986). In an *entrepreneurial regime*, small and flexible firms will find it easier to innovate, while in a *routinized regime*, big firms with large scale R&D may be in a better position to innovate due to increasing returns to knowledge accumulation. Basically this is a question of whether or not there are returns to scale in innovation.

Pavitt (1984) suggested another approach to technological regimes. His taxonomy of the patterns of technological change identified four principle types of industries: (1) supplier dominated, (2) scale-intensive, (3) specialized suppliers, and (4) science-based. Pavitt *et al.* (1989) added another group: (5) information intensive, such as financial services and retailing. These authors argued that patterns of technological change, particularly innovation opprotunities, differ markedly between these groups and must be understood and taken into account in explaining the behavior and evolution of industries.

Finally, Schmookler (1966) among others has emphasized the importance of demand in creating incentives for innovation. Demand-induced innovation may be economically less risky compared to "science-" or "technology-push" innovation in the sense that a market already exists, provided firms can match innovations with technological opportunities.

The effects of the technological regime on innovation outcomes have been less frequently studied, with the exception of Levin, Cohen and Mowery (1985). Furthermore, the effects of the technological environment on the choice of organization of R&D have not been examined. This is the novelty of the chapter at hand.

4.3 Conceptual framework

This study examines the joint determination of R&D investment, R&D collaboration decisions, and product innovation. These activities are viewed as highly intertwined. When the firm decides to pursue innovation, it will also choose whether to carry out formal R&D, and how to organize such a project (internally, outsource, and/or collaborate).

The main hypotheses are, first, that competence investments complement collaboration in innovation, and thus the two are positively associated. Competencies are measured through reference to educational fields and levels of employees. Second, different types of skills complement collaboration with different types of partners. For instance, research cooperation with universities and other research organizations necessitates relatively high internal research skills due to the absorptive capacity requirement.

Collaboration with universities is thus expected to be associated with high research competencies. In contrast, collaboration with suppliers is expected to be associated with relatively low research competence requirements. Third, the technological regime affects the innovation behavior of firms as measured by their propensity to engage in R&D, collaborate in innovation, and innovate.

The proxies for technological regime include industry averages of the importance of various external sources of knowledge to the firm's innovation process. The Finnish innovation survey does not contain direct information about the appropriability of innovation returns. However, data on competitors as knowledge sources can serve as an indication of appropriability: when competitors are important sources of knowledge in an industry, it is likely that secrets are difficult to maintain, and thus appropriability is fairly low. On this basis, low appropriability is expected to discourage collaboration and outsourcing of R&D due to the transaction hazards.[20] Its effect on R&D investment is ambiguous, however, as R&D supports both internal innovation and absorption of spillover knowledge. The effect of low appropriability on innovation is hypothesized to be negative because of the disincentives to innovate created by spillovers.

Industry averages of importance of the other external knowledge sources – universities, customers, and suppliers – are also treated as indicators of particular technological environments. These indicators are thus measured at the industry level. The idea is that firms in an industry face the same technological conditions and patterns of change. This stems from the observations of Pavitt (1984) and others that industries differ considerably in terms of technological conditions and innovation behavior. It is therefore important to control for these differences in a study of innovation. Moreover, at the firm level, the observations of the use of knowledge sources may become endogenous: firms perceiving universities as important sources of knowledge tend strongly to seek to enter collaborative arrangements with them. Finally, from an estimation point of view, most non-innovating firms have not answered the survey questions on knowledge source.

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[20] For the lack of more detailed information on contractual arrangements, the implications of the model in Chapter 3 will not be tested.

Where universities are important knowledge sources, the regime is considered to be relatively science-intensive. According to Klevorick et al. (1995), science-intensive regimes are higher in innovation opportunities. Thus, firms in industries where universities are important knowledge sources are expected to be more likely to invest in R&D, collaborate with universities, and innovate.

The importance of customers as a knowledge source represents the demand for innovation and the need to be in touch with users, both of which bode well for profitable innovation. Therefore, firms operating in an environment in which customers frequently provide ideas and opportunities for innovation both invest more in innovative activities and succeed in innovation more often. They are also highly likely to collaborate with customers in R&D.

Finally, industries in which suppliers represent important sources of knowledge are treated as supplier dominated regimes (Pavitt, 1984). Supplier domination implies that a considerable part of technological development is delegated upstream for example to equipment suppliers. Consequently, innovations become embodied in production equipment, machinery, and service technicians. Firms in supplier dominated regimes are often oriented toward process improvement through incremental learning in their operations and do not necessarily introduce new products frequently. On this basis, outside of their close relations with suppliers, they are not expected to collaborate in innovation.

The "Schumpeterian" regime is hypothesized to affect the propensity of firms to externalize R&D. In a rapidly changing and unpredictable economic environment, expected returns to internally developed capabilities are lower, *ceteris paribus* (see Chapter 2). The reason is the higher risk that capabilities and associated competitive advantage will soon become obsolete due to some other firm's radical innovation. In such an unstable setting, firms can share innovation risks by collaborating instead of developing the complementary capabilities internally. Therefore it is expected that a more turbulent, or *entrepreneurial,* environment is associated with more frequent outsourcing of and collaboration in R&D.

Lastly, the level of competition in the industry characterizes the firms' economic operating environment. Because of particularities of the Finnish economy, namely its small size, I use measures of international competition: the firm's export share and import intensity of its industry.[21] International competition is expected to encourage innovative activities.

4.4 Econometric setup and the data

To assess the hypotheses stated in the previous section, a system of equations needs to be estimated because R&D investment, R&D collaboration and innovation are conceptualized as simultaneously determined:

$$(1)\begin{cases} RD\_inv_i = f(COMPETENCIES_{1,i}, FIRM_{1,i}, REGIME_{1,I}, COMPETITION_{1,I}) \\ COLLAB_i = g(COMPETENCIES_i, RD\_inv_i, FIRM_{2,i}, REGIME_{2,I}, COMPETITION_{2,I}) \\ INNO_i = h(COMPETENCIES_i, RD\_inv_i, FIRM_{3,i}, REGIME_{3,I}, COMPETITION_{3,I}) \end{cases}$$

Here $i = 1,\ldots,N$ refers to the individual firms and $I = 1,\ldots, 14$ to industries. *RD_inv* is the share of R&D investment in sales, *COMPETENCIES* is a vector of skill indicators, *FIRM* is a vector of firm-specific control variables, *REGIME* refers to a set of measures for the technological regime, and *COMPETITION* consists of the measures for the competitive environment. The other dependent variables are binary, and they refer to R&D collaboration with different partners (*COLLAB*) and product innovation (*INNO*).

However, since a system with two binary dependent variables and one continuous, but censored dependent variable cannot be subjected to a standard estimation procedure, it is modified into a system of three probit equations: RD_dum = 1 if RD_inv > 0, otherwise RD_dum = 0.

$$(2)\begin{cases} RD\_dum_i = f^*(COMPETENCIES_{1,i}, FIRM_{1,i}, REGIME_{1,I}, COMPETITION_{1,I}) \\ COLLAB_i = g(COMPETENCIES_i, RD\_inv_i, FIRM_{2,i}, REGIME_{2,I}, COMPETITION_{2,I}) \\ INNO_i = h(COMPETENCIES_i, RD\_inv_i, FIRM_{3,i}, REGIME_{3,I}, COMPETITION_{3,I}) \end{cases}$$

This approach allows us to account for the simultaneities and perform estimation with a standard procedure. Other approaches include the kind of two-stage methods suggested by Maddala (1983). However, this possibility is not pursued here due to the complexities involved in deriving the covariance matrix. A sequential approach, for instance nested logit, is not pursued either, because the decisions clearly are not fully

[21] The traditional variables of industry concentration and market share were originally included as well, but they did not capture statistically significantly the aspects of competition in Finnish manufacturing, perhaps due to the too high level of aggregation and the small open economy environment.

sequential. Logically one could think of a sequence of investing in R&D, then deciding whether to collaborate, and in the last stage, succeeding in innovation or not. However, there are innovating firms in the sample that do not collaborate or invest in R&D, as well as firms that engage in collaboration, but not in R&D. Thus simultaneous equations approach is the most suitable here.

The estimation method is thus trivariate probit maximum likelihood, where the decisions to engage in R&D, to collaborate in R&D with other organizations, and to innovate are simultaneously estimated. Collaboration data is binary but has several "dimensions": did the firm collaborate with rivals, customers, or suppliers etc., or not. The choices are of course not mutually exclusive. Ideally, one would estimate the simultaneous determination of all types of collaboration, but due to lack of reasonable methods the trivariate approach will suffice. Another possibility is to combine all collaborations into one variable to indicate whether or not the firm collaborated with any partner. In another paper this strategy is followed (Leiponen, 2000b), and the results concerning competencies and technological regimes are generally speaking very much in line with those obtained here. The downside is that the information about the differences in the determinants of collaboration with different types of partners is lost.

Statistics Finland collected and compiled the data combining the innovation survey concerning the years 1994-96 and employment register of 1995. The sampling frame of the innovation survey was the Statistics Finland enterprise register. All firms with more than 100 employees were included, together with a random sample stratified by size of smaller firms. The response rate was 71% representing 1126 firms, 1029 of which are included in the sample used here. This attrition stems from missing data. The Eurostat Community Innovation Survey methodology was applied. The list of variables is in Table 4.1 and basic descriptive statistics are presented in Table 4.2. These data are weighted to represent the Finnish manufacturing sector. Appendix 4 also provides correlations among the variables.

Table 4.1 Variables

Dependent variables					
RD_dum		Dummy for R&D_inv > 0			
COL_com		Dummy for R&D collaboration with competitors			
COL_cus		Dummy for R&D collaboration with customers			
COL_sup		Dummy for R&D collaboration with suppliers			
COL_uni		Dummy for R&D collaboration with universities			
OUTRD		Dummy for outsourced R&D investment > 0			
INNO		Dummy for successful product innovation (sales revenue from the commercialized new product >0)			
			Expected effect on		
Independent variables			R&D_ dum	COLLAB	INNO
COMPETENCIES	RES	Share of employees with a post-graduate degree (doctoral or licentiate)	+	+	+
	TECH	Share of employees with a <u>higher</u> technical or natural scientific degree (e.g. university engineer, Master of science in chemistry)	+	+	+
	RD_inv	Internal Research and Development investments/sales	n.e.	+	+
FIRM	EMPL	Number of employees	+	+	+
	GROUP	Membership in a group of firms	?	?	?
TECHNOLOGICAL REGIME	REG_com	Industry average for the importance of <u>competitors</u> as sources of knowledge	+/-	+/-	-
	REG_cus	Industry average for the importance of <u>customers</u> as sources of knowledge	+	+	+
	REG_sup	Industry average for the importance of <u>suppliers</u> as sources of knowledge	-	-	-
	REG_uni	Industry average for the importance of <u>universities</u> as sources of knowledge	+	+	+
	SCHUMP	Share of small firms (EMPL<100) among innovating firms in the industry	n.e.	+	n.e.
COMPETITION	EXPORT	Firm's exports/sales	+	+	+
	IMPORT	Total imports in the product category/domestic industry sales	n.e.	n.e.	+

n.e. = not estimated

The descriptive statistics for the collaboration variables show that more firms collaborate with customers (15%), suppliers (15%), or universities (14%) than with competitors (6%). Obviously, collaborating firms can have more than one type of partner. 19 percent of the firms reported product innovations between 1994-96, and 30 percent invested in R&D.[22] Average R&D investment is 0.7 percent of sales for the whole sample. There are 400 R&D firms (RD_inv>0) in the dataset, and their average R&D investment is 2.3 percent of sales revenue.

Table 4.2 Descriptive statistics (weighted)

	Mean	Std.Dev.	Minimum	Maximum	N
COL_com	0.057	0.232	0	1	1029
COL_cus	0.153	0.360	0	1	1029
COL_sup	0.150	0.357	0	1	1029
COL_uni	0.136	0.343	0	1	1029
INNO	0.194	0.396	0	1	1029
RD_inv (%)	0.7	2.4	0	31.6	1029
RD_inv > 0 (%)	2.3	3.9	0.0002	31.6	400
RD_dum	0.304	0.460	0	1	1029
OUTRD	0.228	0.420	0	1	1029
RES	0.001	0.005	0	0.082	1029
TECH	0.064	0.088	0	0.636	1029
EMPL	97.8	361.2	10	9602	1029
GROUP	0.30	0.46	0	1	1029
REG_com	1.500	0.136	1.27	2.67	1029
REG_cus	2.124	0.250	1.7	3	1029
REG_sup	1.514	0.264	1.04	2	1029
REG_uni	1.109	0.197	0.6	1.67	1029
SCHUMP	0.557	0.133	0	1	1029
EXPORT	0.187	0.273	0	1	1029
IMPORT	0.337	0.283	0.033	0.947	1029

Employees with advanced formal educational degrees (*RES*) are few, only 0.1 percent on average, while higher technical and natural scientific skills (*TECH*) are quite common. Six percent of the firms' employees have a higher (tertiary) degree in these fields. Among the knowledge *REGIME* variables, customers are the most important knowledge sources. Competitors and suppliers are recognized as next most important. Universities are the least commonly cited sources of knowledge among the sources considered here. Table 4.3 displays the 1029 firms broken down by industrial

[22] The reason for the mean of RD_dum, 0.304, being different from 400/1029=0.389 is that the former is a weighted mean.

classification. Metal industries are slightly over-represented in the sample, but sampling weights correct for most of this bias.

Table 4.3 Industry distribution in the sample

Industry	N	Share
Food	107	10.4 %
Textile	79	7.7 %
Wood	76	7.4 %
Paper	26	2.5 %
Printing, publishing	98	9.5 %
Oil, Chemical	43	4.2 %
Plastic, Rubber	47	4.6 %
Non-metallic minerals	44	4.3 %
Primary metals	26	2.5 %
Metal products	97	9.4 %
Machines, equipment	146	14.2 %
Electronics	133	12.9 %
Cars, vehicles	54	5.2 %
Furniture	53	5.2 %
Total	1029	100.0 %

4.5 Estimation Results

Estimation of the simultaneous equations in (2) for the joint determination of R&D-investment, R&D collaboration, and product innovation decisions is done by trivariate probit. To provide a baseline for comparison, each of the equations is estimated with simple one equation probit. The results are in Appendix 4 (Tables A4.2 - A4.8). The multivariate model accounts for some of the endogeneities between the different innovation activities by separating the effects of being an R&D firm, and the *level* of investment in R&D. Table 4.4 contains the results when collaboration with competitors is the dependent variable of the second equation.

Table 4.4 Collaboration with competitors (N=1029), 3-variate probit ML system, weighted

Dependent variable	RD_dum		COL_com		INNO	
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat
Constant	-0.88	-1.33	-1.77*	-1.77	-1.48**	-2.07
RES	18.98*	1.84	9.99	1.21	22.09**	2.14
TECH	2.00**	3.74	0.01	0.01	2.06**	3.61
RD_inv			2.42	1.25	2.77*	1.70
EMPL	0.16**	5.53	0.29**	4.09	0.64**	5.03
GROUP	0.94**	-2.39	0.38**	2.52		
EXPORT	0.97**	5.66	0.33	1.15	0.64**	3.40
REG_com	-0.98**	2.27	0.38	0.60	-0.75*	-1.74
REG_cus	0.60**	-2.87	-0.26	-0.57	0.55*	1.71
REG_sup	-0.63**	3.18	-0.57	-1.65	-0.45*	-1.88
REG_uni	0.81*	1.82	0.31	0.74	0.53*	1.85
SCHUMP			0.61	1.09		
IMPORT					0.51**	2.68
Correlation coefficients						
R(01,02)	0.66**	8.56				
R(01,03)	0.82**	24.73				
R(02,03)	0.53**	6.55				
Log Likelihood	-964.23					

Note: ** indicates 95% level significance, * indicates 90% level.
EMPL is in thousands in the estimations.

The probability of investing in internal R&D is associated with high research and technical competencies, and seems to be strongly driven by industry-specific factors measured here with the technological regime variables. In accordance with the hypotheses, firms in regimes where customers and universities are important sources of knowledge are more likely to carry out R&D internally, while firms in environments that rely on spillovers from competitors or suppliers are less likely to perform R&D in-house. In contrast, this model does not explain very well the variance in firms' engagement in collaborative arrangements with competitors. Only firm size and group membership play important roles. The third dependent variable, successful new product introduction (INNO), is closely associated with competence and R&D investments. In line with the demand and innovation opportunities hypotheses, firms in the customer driven and science based regimes are more likely to innovate. Also in line with the hypotheses, firms in supplier- or competitor-dominated regimes are somewhat less innovative. And as expected, international competition in terms of export intensity and import penetration is a positive driver of innovation.

Table 4.5 Collaboration with customers (N=1029), 3-variate probit ML, weighted

Dependent variable	RD_dum		COL_cus		INNO	
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat
Constant	-0.79	-1.22	-1.93**	-2.37	-1.42**	-2.01
RES	20.00**	2.08	16.82*	1.82	24.32**	2.16
TECH	2.04**	3.81	2.18**	3.69	2.05**	3.52
RD_inv			-0.46	-0.25	2.87*	1.78
EMPL	1.27**	8.34	0.64**	6.04	1.06**	5.15
GROUP	0.17*	1.93	0.43**	3.85		
EXPORT	0.99**	5.84	0.78**	4.04	0.66**	3.56
REG_com	-1.03**	-2.48	-0.54	-1.14	-0.83*	-1.87
REG_cus	0.61**	2.32	0.72**	2.03	0.60*	1.90
REG_sup	-0.62**	-2.87	-0.60**	-2.35	-0.46*	-1.88
REG_uni	0.76**	3.00	0.34	1.17	0.48*	1.69
SCHUMP			0.09	0.18		
IMPORT					0.50**	2.63
Correlation coefficients						
R(01,02)	0.74**	15.79				
R(01,03)	0.82**	24.17				
R(02,03)	0.69**	14.42				
Log Likelihood	-1064.06					

Collaboration with customers is much more closely associated with competence investments than collaboration with competitors (see Table 4.5). In this model, *RES* and *TECH* become statistically significant coefficients although *RES* only at the 90% level. However, collaboration does not seem to be complementary with the *level* of R&D investment. More R&D does not increase the likelihood of engaging in collaborative innovation. Nevertheless, the high correlation between the first two equations (74%) suggests a very close association between the activities. In the case of collaboration with customers, the technological environment is seen to come more significantly into play. Firms in regimes where "demand pull" is strong are more likely to collaborate, while those in supplier dominated regimes are less so.

Table 4.6 Collaboration with suppliers (N=1029), 3-variate probit ML, weighted

Dependent variable	RD_dum		COL_sup		INNO	
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat
Constant	-0.90	-1.38	-0.37	-0.46	-1.45**	-2.02
RES	19.09*	1.78	10.80	1.34	20.48	1.63
TECH	1.89**	3.44	1.74**	2.93	2.02**	3.53
RD_inv			-2.31	-1.26	2.69	1.61
EMPL	1.46**	9.64	1.12**	4.77	1.26**	5.90
GROUP	0.15*	1.74	0.33**	2.95		
EXPORT	0.95**	5.61	0.76**	3.89	0.65**	3.44
REG_com	-0.98**	-2.35	-1.13**	-2.62	-0.80*	-1.76
REG_cus	0.63**	2.40	0.42	1.33	0.59*	1.80
REG_sup	-0.63**	-2.99	-0.35	-1.46	-0.49**	-2.02
REG_uni	0.79**	3.08	0.28	0.92	0.51*	1.75
SCHUMP			-0.39	-0.82		
IMPORT					0.52**	2.73
Correlation coefficients						
R(01,02)	0.77**	18.87				
R(01,03)	0.81**	24.29				
R(02,03)	0.60**	11.50				
Log Likelihood	-1078.73					

Collaboration with suppliers requires internal competencies in the form of technical skills (Table 4.6). The technological regime variables do not capture variation in this type of collaboration very well. Only low appropriability is significantly negatively associated with supplier collaboration. The hazard of leaking strategic information to rivals may be aggravated by collaborating with suppliers, a potential spillover channel.

Collaboration with universities is associated with very high internal research competencies, relatively high technical competencies, and a large export share (Table 4.7). Firms in supplier dominated regimes are clearly not likely to collaborate with universities, but, quite intuitively, firms in science based regimes are.

Table 4.7 Collaboration with universities (N=1029), 3-variate probit ML, weighted

Dependent variable	RD_dum		COL_uni		INNO	
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat
Constant	-0.84	-1.29	-3.11**	-3.35	-1.30*	-1.84
RES	21.53**	2.05	30.03**	2.14	21.70	1.10
TECH	1.93**	3.56	1.68**	2.82	1.91**	3.35
RD_inv			-1.61	-0.75	3.17**	1.97
EMPL	1.45**	9.10	1.29**	5.36	1.23**	5.89
GROUP	0.16*	1.85	0.40**	3.61		
EXPORT	0.98**	5.74	0.88**	4.68	0.64**	3.38
REG_com	-1.03**	-2.47	0.01	0.01	-0.80*	-1.88
REG_cus	0.64**	2.41	0.33	0.87	0.54*	1.71
REG_sup	-0.64**	-2.96	-0.72**	-2.49	-0.49**	-2.03
REG_uni	0.78**	3.04	1.13**	3.24	0.48*	1.70
SCHUMP			0.68	1.25		
IMPORT					0.54**	2.84
Correlation coefficients						
R(01,02)	0.80**	17.58				
R(01,03)	0.81**	23.20				
R(02,03)	0.71**	13.21				
Log Likelihood	-1009.10					

The last type of external R&D arrangement is contract R&D. In Table 4.8, the likelihood of outsourced R&D is positively associated with internal research competencies, high export orientation, and science-based innovation opportunities. The connection between R&D outsourcing and science-intensity is interesting. Except for high innovation opportunities, science-intensity may reflect the potential for codification. It may be easier to both define the research project and communicate the results in a science-based environment, as opposed to environments with highly tacit and ill-defined underlying knowledge.

Table 4.8 R&D outsourcing (N=1029), 3-variate probit ML, weighted

Dependent variable	RD_dum		OUTRD_dum		INNO	
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat
Constant	-0.83	-1.30	-1.68**	-2.25	-1.36*	-1.91
RES	12.77	1.40	13.82**	2.05	17.47*	1.74
TECH	1.82**	3.40	0.87	1.53	2.02**	3.40
RD_inv			0.19	0.13	2.77	1.63
EMPL	1.02**	5.76	0.23**	4.98	0.86**	4.18
GROUP	0.19**	2.19	0.30**	3.16		
EXPORT	0.99**	5.86	0.96**	5.70	0.65**	3.45
REG_com	-1.01**	-2.45	-0.15	-0.33	-0.78*	-1.80
REG_cus	0.61**	2.30	0.22	0.80	0.52*	1.69
REG_sup	-0.64**	-2.94	-0.49**	-2.32	-0.47**	-1.99
REG_uni	0.83**	3.25	0.66**	2.52	0.55*	1.95
SCHUMP			0.35	1.09		
IMPORT					0.53**	2.80
Correlation coefficients						
R(01,02)	0.91**	47.83				
R(01,03)	0.81**	24.60				
R(02,03)	0.73**	18.35				
Log Likelihood	-1063.27					

The multivariate results differ slightly from the single equation probit results reported in the Appendix. The coefficients on competence measures are larger and more significant in explaining the probability of collaboration when the endogeneity of being an R&D firm is accounted for. Only the coefficient of the level of R&D investment has a different sign in some cases. Firms may do internal R&D perhaps in order to be able to benefit from external R&D arrangements, as indicated by the high correlations between the first and second equations. However, provided that the firm does some internal R&D, a higher level of investment does not necessarily increase the probability of collaboration further.[23]

As expected, in most cases the coefficient of the measure of the Schumpeterian regime (SCHUMP) is positive, but it is never significant. The variable was retained in the analysis nevertheless in order to ensure identification, which was sometimes difficult to obtain otherwise. Its presence does not impact the signs or significance of other coefficients.

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[23] The insignificance of the level of R&D holds even if one removes the RES variable, which is potentially endogenous, from the collaboration equation.

To check the ability of the regime variables to account for the knowledge accumulation patterns within industries, the trivariate systems were estimated with a full set of industry dummies as control variables in the collaboration equation. The system for collaboration with universities is provided in the Appendix (Table A4.9) as an example to demonstrate that the results on competencies do not depend on the control variables used. Research competencies and technical skills remain strong and significant determinants of collaboration with industry dummies.

To summarize, the multivariate model seems to work quite well in explaining how the three innovation related activities are jointly determined. The high correlations between the three equations indicate that assuming a joint distribution for the dependent variables is warranted. Thus, it makes sense to estimate their determination simultaneously. Skills play a significant and positive role in innovation. They may be complementary with R&D activities, independent of how R&D is organized. Moreover, internal competencies facilitate the internalization of the benefits of external R&D efforts. In particular, research skills appear to be necessary for benefiting from collaboration with universities and outsourcing of R&D, and technical skills are important in collaboration with customers, suppliers, and universities.

4.6 Discussion

This study took as its starting point the idea that organizational decisions related to R&D are simultaneous with the decisions to invest in innovation. The strong positive associations identified among internal competencies, R&D investment, R&D collaboration, contract R&D, and product innovation indeed are in line with the notion that they are complementary, although partial correlation does not constitute a rigorous test.

Collaboration can be thought of as a vehicle to transact in tacit knowledge. The firm would probably choose to buy the necessary capabilities or information in the spot markets, if such resources were available. However, exchanging sticky or tacit knowledge may require more intensive and prolonged interaction, creating a need for a governance structure as constituted by the collaboration agreement. Collaboration involves exchanging knowledge for knowledge, while in R&D outsourcing, knowledge is exchanged for money. Evidently, outsourced research involves less sticky and less firm-specific information, and is more often embodied in blueprints or artifacts.

Skills and competencies are important co-variates in the firm's "system of innovation" as defined by the various innovation activities (R&D, collaboration, outsourcing). This finding highlights the important role of absorptive capacity. Without internal capabilities the firm is not likely to be an attractive partner in collaborative arrangements or to benefit fully from externally sourced knowledge. Estimation results here support the interpretation that high internal skills and competencies, in addition to internal R&D, help build absorptive capacity and enhance firms' ability to engage in collaborative innovation. This is the basis for advantages accruing to incumbents, and public policies targeting small firms' capacity to compete. Of course, utilization of external sources of knowledge within innovation processes should not be over-emphasized. In-house competencies and internal R&D have very important roles in supporting innovation directly.

It is important to distinguish patterns of collaboration among different kinds of partners. First, this chapter demonstrates that competence requirements vary somewhat with the type of collaboration: research competencies are identified as more important for university collaboration than for the other types of collaboration. Second, horizontal collaboration is not so prevalent as the extant literature on research joint ventures between rivals would seem to imply. From a market structure or competition point of view, it may be relevant to study the implications of and reasons for cooperation among rivals. However, to understand innovation, technological change, and the evolution of firms and industries, it is equally important that we assess the knowledge transactions firms carry out with differently positioned actors in production systems.

The analysis accounted for industry differences with a set of proxies for the technological environment. It seems that using and further developing measures for technological regimes is a worthwhile endeavor. They enable us to see *how* industries differ in addition to controlling for these differences. However, the measures of technological regimes used here are not significant explanatory factors of horizontal collaboration, contrary to the results for other types of collaboration. Indeed, a casual account of the telecommunication firm Nokia's alliances suggests that regimes characterized by network technologies may be an important missing aspect. All of

Nokia's publicized horizontal collaborations are related to setting standards in the context of a network technology, while its vertical alliances have myriad goals and motivations. This aspect should be investigated in future surveys of innovations.

Understanding industry-specificities is highly relevant from the perspective of policy analysis. For instance, technological regimes may have a bearing on issues of antitrust and intellectual property rights. If patterns of cooperation in knowledge creation among firms depend on the technological environment, competition policies need to take this into account – cooperation may be beneficial in some environments, in others it may be an indication of collusion. Relatedly, firms' willingness to collaborate and thus the rate and nature of innovation may depend on intellectual property rights legislation and enforcement. Fruitful cooperation may be hindered by spillover hazards.

Limitations of this research include the structure of the data: innovation records are at the firm level, not R&D project level, potentially blurring some results. Also, the statistical association between competencies and collaboration is not sufficient evidence of complementarity – the two could be confounded. This question could be addressed, at least to some extent, with longitudinal data on innovation, collaboration, and related investments, enabling us to better control for endogeneities. Such data exist for patents, but as is well known, these are a relevant measure of innovation for only a few industries.

The econometric method used in this study could be improved to make use of all available data. Instead of three probit equations, the existing data could be used to estimate a system with a truncated regression of R&D investment, probit estimations of R&D collaboration, and an interval regression of innovation output (share of new products in current sales). As the econometric methods for limited dependent variable systems develop, this type of a system can be estimated. These shortcomings represent avenues for future work.

4.7 Conclusion

The principle results of this study include that competencies of firms are closely associated with organizational choices for innovation activities. High levels of internal capabilities make R&D investments, collaborative R&D arrangements, contract R&D, and innovation more likely. There are indications that skills contribute to absorptive capacity. In choosing partners for R&D, research competencies appear to be important determinants of collaboration with universities and customers, but not of collaboration with suppliers or competitors. Furthermore, firms with high research competencies engage in R&D outsourcing more often. Research skills are likely to be useful in monitoring external R&D activities. Additionally, firm size and business group membership correlate with external collaboration. These may reflect access to resources and experience that are useful for managing collaborative innovation and not available to small and independent firms. The flipside is that firms with low levels of internal or group level competencies are less likely to benefit from external forms of R&D. Technology policies could focus more on competence development and less on R&D to promote productive collaboration and innovation.

The results indicate that technological regimes affect firms' innovation behavior. Firms in regimes of low appropriability are not likely to collaborate with suppliers, and are also less likely to do R&D or innovate. Regimes of strong "demand pull," i.e., market opportunities are associated with high probabilities of R&D, collaboration with customers, and product innovation. Supplier dominated firms are significantly less likely to innovate or collaborate with customers or universities. Lastly, science based regimes with high innovation opportunities are associated with frequent contract R&D, collaboration with universities, internal R&D, and product innovation. Thus, technological regime and firms' competencies impact not only patterns of R&D investment and industrial structure, but also boundaries of firms as reflected in their knowledge procurement strategies.

Appendix 4

Table A4.1 Correlations

	COL_ com	COL_ cus	COL_ sup	COL_ uni	INNO	RD_ inv	RD_ dum	OUT RD	RES	TECH	EMPL	GROUP	REG_ com	REG_ cus	REG_ sup	REG_ uni	SCHUMP	EXPORT
COL_com	1																	
COL_cus	0.45	1																
COL_sup	0.39	0.65	1															
COL_uni	0.40	0.67	0.67	1														
INNO	0.31	0.56	0.49	0.56	1													
RD_inv	0.18	0.32	0.25	0.35	0.40	1												
RD_dum	0.36	0.59	0.59	0.63	0.66	0.44	1											
OUTRD	0.38	0.52	0.56	0.62	0.56	0.33	0.73	1										
RES	0.11	0.20	0.15	0.26	0.21	0.37	0.17	0.17	1									
TECH	0.10	0.31	0.22	0.32	0.31	0.48	0.30	0.23	0.27	1								
EMPL	0.21	0.26	0.29	0.31	0.27	0.18	0.27	0.22	0.12	0.17	1							
GROUP	0.16	0.33	0.29	0.35	0.25	0.17	0.31	0.28	0.19	0.24	0.25	1						
REG_com	0.04	0.07	0.04	0.09	0.07	0.04	0.05	0.07	-0.05	0.13	0.04	0.02	1					
REG_cus	0.03	0.15	0.07	0.13	0.17	0.16	0.14	0.10	-0.02	0.22	-0.01	0.04	0.55	1				
REG_sup	-0.04	-0.15	-0.09	-0.13	-0.15	-0.11	-0.15	-0.10	-0.05	-0.27	-0.01	-0.04	-0.02	-0.33	1			
REG_uni	0.05	0.11	0.10	0.19	0.12	0.13	0.17	0.14	0.13	0.14	0.10	0.18	0.15	-0.05	0.19	1		
SCHUMP	0.04	0.09	0.03	0.08	0.09	0.17	0.10	0.08	0.03	0.16	0.00	-0.01	-0.06	0.34	-0.42	-0.28	1	
EXPORT	0.12	0.32	0.28	0.35	0.31	0.28	0.39	0.34	0.12	0.29	0.23	0.28	0.06	0.12	-0.09	0.08	0.20	1
IMPORT	0.03	0.11	0.03	0.08	0.14	0.08	0.08	0.05	0.03	0.11	0.01	0.02	0.45	0.62	-0.32	-0.05	0.47	0.10

Table A4.2 Single equation probit ML estimation (N=1029). Dependent variable: RD_dum

	Coeff	t-stat	Marginal effects	t-stat
Constant	-1.02	-1.59	-0.34	-1.59
RES	20.61**	2.04	6.84**	2.03
TECH	1.98**	3.55	0.66**	3.53
EMPL	1.49**	5.29	0.49**	5.14
GROUP	0.20**	1.98	0.07**	1.99
EXPORT	1.01**	6.02	0.34**	6.01
REG_com	-0.92**	-2.18	-0.31**	-2.18
REG_cus	0.63**	2.54	0.21**	2.54
REG_sup	-0.63**	-3.24	-0.21**	-3.25
REG_uni	0.78**	3.10	0.26**	3.11
Log Likelihood	-534.10			
Pseudo R^2	0.25			

Note: ** indicates 95% level significance, * indicates 90% level.

Table A4.3 Dependent variable: COL_com

	Coeff	t-stat	Marginal effects	t-stat
Constant	-1.59	-1.52	-0.15	-1.51
RES	4.08	0.42	0.38	0.42
TECH	-0.69	-0.85	-0.06	-0.85
RD_inv	7.53**	3.34	0.70**	3.19
EMPL	0.29**	2.50	0.03**	2.42
GROUP	0.44**	3.05	0.04**	3.12
EXPORT	0.15	0.63	0.01	0.63
REG_com	0.56	0.91	0.05	0.91
REG_cus	-0.33	-0.79	-0.03	-0.79
REL_sup	-0.59*	-1.89	-0.05*	-1.92
REG_uni	0.16	0.42	0.01	0.42
SCHUMP	0.44	0.73	0.04	0.73
Log Likelihood	-273.58			
Pseudo R^2	0.04			

Table A4.4 Dependent variable: COL_cus

	Coeff	t-stat	Marginal effects	t-stat
Constant	-1.71	-2.04	-0.33	-2.06
RES	10.71	1.07	2.09	1.06
TECH	1.28**	2.09	0.25**	2.08
RD_inv	8.14**	3.90	1.59**	3.81
EMPL	0.61**	3.34	0.12**	3.27
GROUP	0.51**	4.41	0.10**	4.46
EXPORT	0.62**	3.34	0.12**	3.33
REG_com	-0.41	-0.84	-0.08	-0.84
REG_cus	0.65**	2.03	0.13**	2.04
REL_sup	-0.60**	-2.53	-0.12**	-2.55
REG_uni	0.26	0.87	0.05	0.87
SCHUMP	-0.19	-0.38	-0.04	-0.38
Log Likelihood	-431.91			
Pseudo R^2	0.20			

Table A4.5 Dependent variable: COL_sup

	Coeff	t-stat	Marginal effects	t-stat
Constant	-0.06	-0.08	-0.01	-0.08
RES	2.31	0.27	0.48	0.27
TECH	0.88	1.45	0.18	1.45
RD_inv	5.83**	2.84	1.20**	2.83
EMPL	1.08**	4.63	0.22**	4.43
GROUP	0.36**	3.18	0.08**	3.21
EXPORT	0.64**	3.47	0.13**	3.49
REG_com	-1.05**	-2.13	-0.22**	-2.14
REG_cus	0.37	1.22	0.08	1.22
REL_sup	-0.35	-1.53	-0.07	-1.54
REG_uni	0.16	0.51	0.03	0.51
SCHUMP	-0.67	-1.33	-0.14	-1.33
Log Likelihood	-449.78			
Pseudo R^2	0.16			

Table A4.6 Dependent variable: COL_uni

	Coeff	t-stat	Marginal effects	t-stat
Constant	-3.01**	-3.36	-0.50**	-3.36
RES	27.33**	2.65	4.52**	2.59
TECH	0.82	1.26	0.13	1.26
RD_inv	7.40**	3.52	1.22**	3.42
EMPL	1.24**	4.94	0.21**	4.57
GROUP	0.49**	3.96	0.08**	4.03
EXPORT	0.74**	3.79	0.12**	3.78
REG_com	0.14	0.25	0.02	0.25
REG_cus	0.37	1.05	0.06	1.06
REL_sup	-0.63**	-2.39	-0.10**	-2.43
REG_uni	0.93**	2.87	0.15**	2.90
SCHUMP	0.15	0.27	0.02	0.27
Log Likelihood	-379.53			
Pseudo R^2	0.26			

Table A4.7 Dependent variable: OUTRD

	Coeff	t-stat	Marginal effects	t-stat
Constant	-1.57**	-2.08	-0.42**	-2.09
RES	0.46	0.05	0.12	0.05
TECH	-0.47	-0.78	-0.13	-0.78
RD_inv	13.89**	6.00	3.69**	5.83
EMPL	0.22*	1.90	0.06*	1.89
GROUP	0.41**	3.89	0.11**	3.90
EXPORT	0.85**	4.96	0.23**	4.97
REG_com	0.13	0.29	0.04	0.29
REG_cus	0.08	0.28	0.02	0.28
REL_sup	-0.49**	-2.27	-0.13**	-2.28
REG_uni	0.52*	1.95	0.14**	1.96
SCHUMP	0.17	0.39	0.05	0.39
Log Likelihood	-513.87			
Pseudo R^2	0.17			

Table A4.8 Dependent variable: INNO

	Coeff	t-stat	Marginal effects	t-stat
Constant	-1.33*	-1.79	-0.33*	-1.80
RES	17.00	1.54	4.24	1.54
TECH	1.11*	1.81	0.28*	1.81
RD_inv	17.04**	6.98	4.25**	6.60
EMPL	1.14**	4.68	0.28**	4.54
EXPORT	0.41**	2.23	0.10**	2.24
REG_com	-0.69	-1.46	-0.17	-1.46
REG_cus	0.49	1.58	0.12	1.58
REL_sup	-0.44**	-1.97	-0.11**	-1.98
REG_uni	0.39	1.47	0.10	1.47
IMPORT	0.44*	1.90	0.11*	1.90
GROUP	0.11	0.94	0.03	0.95
Log Likelihood	-445.42			
Pseudo R^2	0.24			

Table A4.9 Multivariate probit with industry dummies for R&D and collaboration equations

	RD_dum	t-stat	COL_uni	t-stat	INNO	t-stat
Constant	-1.28**	-15.24	-2.38**	-5.38	-1.00	-1.59
RES	23.93**	2.17	34.22**	2.33	21.85	1.22
TECH	3.01**	6.01	2.35**	3.85	2.09**	3.20
RD_inv			-1.37	-0.60	3.53**	2.27
EMPL	1.43**	7.67	1.51**	7.65	1.22**	6.43
EXPORT	1.05**	6.01	1.03**	5.31	0.70**	3.81
REG_com					-0.73*	-1.68
REG_cus					0.36	1.19
REG_sup					-0.23	-1.01
REG_uni					0.09	0.35
IMPORT					0.49**	2.39
Food	0.29*	1.92	0.59	1.25		
Textile			0.56	1.18		
Wood			0.40	0.84		
Paper	0.78**	2.07	0.94*	1.81		
Printing, publishing			0.20	0.39		
Oil, Chemical	0.45**	2.11	0.84	1.57		
Plastic, Rubber	0.76**	4.40	0.72	1.49		
Non-metallic minerals	0.00	0.00	0.47	0.92		
Primary metals			1.10*	1.92		
Metal products	0.29**	2.32	0.70	1.51		
Machines, equipment	0.27**	2.15	0.74*	1.66		
Electronics			0.69	1.52		
Cars, vehicles	0.03	0.14	0.51	1.04		
Log Likelihood	-1032.85					
R(01,02)	0.77**	15.58				
R(01,03)	0.83**	26.84				
R(02,03)	0.71**	14.21				

Note: A full set of dummies could not be used for all equations due to identification problems.

5 COLLABORATION, INNOVATION, AND FIRM PERFORMANCE – INCREASING RETURNS FROM KNOWLEDGE COMPLEMENTARITIES?[24]

Abstract

This chapter examines the interactions among firms' competencies, organization of R&D, and innovation. Complementarities related to innovation may generate persistent differences in firm behavior and performance. Without sufficient internal capabilities, firms are hypothesized to profit less from innovation activities, particularly collaborative R&D. Hypotheses are tested with a panel dataset of Finnish manufacturing firms. Results indicate that technical skills support profiting from innovation and collaboration. Dynamic competencies, that is, a history of successful innovation or collaboration, complement firms' current innovation activities. Competencies, collaboration, and innovation are found to form a system of interdependent activities.

Key words: Innovation, R&D collaboration, competencies, complementarities

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5.1 Introduction

Innovation is generally viewed as the main engine of long run economic development. While it seems that the social returns to innovation can be enormous, at the level of individual firms it is not evident that the returns to innovation investments are always positive. Teece (1986) documented this phenomenon with case studies of product innovations. He concluded that profiting from innovation depends on access to complementary capabilities, especially marketing and distribution, without which the innovative idea cannot be profitably commercialized.

The idea of complementarities related to the nature of the firm is new in neither strategic management nor business history (*e.g.* Chandler, 1962), but until recently, organizational complementarities have not been a focus of inquiry in the theory of the firm. Studies of technological change and innovation, in contrast, have emphasized interactions among activities within the firm (Kline and Rosenberg, 1986) and the firm's relationship with external sources of knowledge (*e.g.* Levin, Cohen and Mowery, 1985). Essentially, organizational interactions stem from the need to combine different kinds of knowledge in the innovation process. Complementary knowledge sources are thus the basis of organizational complementarities.

Recent studies of innovation and firm capabilities have provided evidence that accumulation of knowledge may be a source of considerable variation in firms' behavior and performance (*e.g.*, Geroski, Machin and Reenen, 1993; Miyazaki, 1994; Henderson and Cockburn, 1996; Klette, 1996). According to Geroski *et al.* (1993), a firm's innovation record affects its profitability. These authors contend that innovation performance approximates the accumulation of knowledge capital, and this capital enables firms to continuously bring new products to market and improve productivity through process innovation. However, in their framework the fundamental factors behind knowledge accumulation remain unknown. Further, one can question the argument on the grounds that if possessing knowledge capital translates into improved market performance, and any firm can acquire knowledge, i.e. learn and innovate, then all firms facing the same opportunities should invest identically and no performance differences should be observed in the long run.

In real economies firms do perform and behave differently. In this study I examine the proposition that one of the reasons as to why firms make different learning investments are the combinatory characteristics of these investments. The "portfolio" of investments, collaborations, and capabilities may have an effect on the marginal productivity of each of the components. If the components of a firm's knowledge capital complement one another, then each of them is more productive in the presence of the other components. Systemic effects could also explain the persistent differences in firm performance. Firms that initially possess some components of the "knowledge system" perceive further investment to be more productive making virtuous cycles possible. In contrast, knowledge-poor firms are less likely to recognize productive learning investment opportunities because of the missing complementary components. Managers might be unaware of the complementarities, and creating a system of complementary capabilities from a non-existent foundation is a risky and expensive venture.

The learning processes to build competencies are likely to vary across industries and sectors. Within manufacturing, investments in learning often include research and development (R&D), hiring skilled employees, on-the-job learning and training, technology licensing and other intellectual property acquisitions, collaboration with other organizations, and designing the internal organizational such that it promotes communication and provides proper incentives. Brynjolfsson and Hitt (1995) and Bresnahan *et al.* (1999) have examined the interactions between skills, information technologies, and internal organizational design. Geroski *et al.* (1993) found evidence of complementarity between external and internal sources of knowledge, as the effects of knowledge spillovers were larger and more significant for innovating firms. Helfat (1997) argued that there are economies of scope among different fields of R&D within the petroleum industry. In her study, R&D in coal conversion depends positively on complementary R&D in refining. Apart from these studies, however, the relationships between competencies and technological change remain poorly understood.

This chapter seeks to assess the scope of interactions among competencies, organization of innovation activities, and innovation output. In an earlier study, skills and competencies of a firm's employees were found to have an impact on its profits (Leiponen, 2000a). Most interestingly, skills interacted with one another. The positive effect of research skills on profits was conditioned by a sufficiently high level of "general" skills in the firm. Moreover, the impact of skills on profitability was larger for innovating firms than for non-innovating firms. This suggests that competence accumulation and innovation interact in the determination of economic performance. Here I build on these results and analyze 1) the effects of R&D collaboration and innovation on profitability, and 2) how competence investments complement these strategies. The following section develops the hypotheses. The data are presented in section 5.3, and the estimation results in section 5.4. Section 5.5 concludes.

5.2 Conceptual framework and hypotheses

Literature in the evolutionary economics tradition suggests that firms' economic performance is largely based on the accumulation of knowledge and capabilities (Nelson and Winter, 1982). Taking this view as a starting point, this study asks whether there is "chemistry" involved in the process of accumulation, in addition to the "physics" of investment dynamics. Can we identify some combinations of capabilities and activities that jointly affect economic outcomes? If this is the case, then the organization of capabilities can be as important a performance factor as knowledge and capabilities, *per se*, because organization affects the interactions among capabilities (cf. Marshall, 1890).

Theoretical and empirical research shows that organizational complementarities can be a source of increasing returns (see *e.g.*, Athey and Schmutzler, 1995; Ichniowski, Shaw and Prennushi, 1997). Teece (1986) argued that the organization of a firm's complementary capabilities is an important determinant of profitability of innovation. In order to profit from new products and technologies, the firm needs to have access to the requisite capabilities to leverage the positive effects of innovation. In this chapter, complementarities are explored from a slightly different angle. The focus is on technical and accumulated innovation competencies, not functional capabilities such as marketing and distribution. Specifically, I investigate the interactions among R&D collaboration, competencies, and innovation in determining the profitability of Finnish manufacturing firms.

The first hypothesis is that to benefit from product and process innovation the firm must have sufficient internal competencies. Having an innovative idea is only a relatively small part of the development of a successful new product or process. To develop the idea into a well-functioning technology that can be profitably manufactured and marketed the firm needs high technical, marketing, and "integrative" competencies (Iansiti and Clark, 1994).

H1: A firm's competencies complement innovation in its effects on profitability.

The second hypothesis concerns the profitability effects of R&D collaboration. In theoretical studies of the economics of R&D collaboration (d'Aspremont and Jacquemin, 1988; Kamien, Muller and Zang, 1992, and others), the focus is usually on horizontal and industry-wide cooperation, and there are no additional costs associated with collaboration. This setup gives rise to the conclusion that collaboration is always profitable. However, Harrigan (1988) found a relatively high likelihood of failure in collaborative arrangements.

Extant management literature suggests that firms engage in collaborative arrangements in order to cope with technological complexity, reduce the uncertainty and costs of R&D, capture partner's knowledge, and reduce product development times (Hagedoorn, 1993; also Contractor and Lorange, 1988; Coombs et al., 1996, among others). As in the economic literature, the reasons for *not* collaborating – costs of collaboration rather than benefits – have not been sufficiently examined. Notable exceptions are the studies by Pisano *et al.* (1988) and Oxley (1997) arguing that collaborative ventures are aligned with strategies to minimize transaction costs.

Here I propose another explanation for why some firms are less likely than others to externalize innovation activities. Collaborative R&D is always costly, because it entails investments of time and resources. However, the costs and benefits of collaborative projects are a function of the existence and scope of the firm's complementary internal knowledge assets. Without sufficient internal competencies, the firm will not be able to internalize and utilize effectively the knowledge created or accessed through collaboration (*cf.* Cohen and Levinthal, 1989). Recognizing that employees' skills and competencies are an important component of absorptive capacity positions us to analyze the relationships between internal and external knowledge sources:

H2: Internal competencies of a firm reinforce the profitability effects of collaborative R&D, i.e., collaborative R&D is complementary with internal competencies.

5.3 Data

The empirical analysis makes use of data from the two available Finnish innovation surveys, national business surveys, the register for domestic patent applications and the employment register for each of the years 1990 through 1996. The innovation survey datasets contain information about product and process innovations, R&D investments, and innovation collaboration during the periods 1989-1991 (first survey; see SF 1992) and 1994-96 (second survey; see SF 1998).[25] Innovation and business survey questionnaires were sent to all manufacturing firms with more than 100 employees, and to a random sample stratified by size and industry for smaller firms. Response rates were around 70% in both innovation surveys. The patent and employment registers cover all establishments.

From these sources, I constructed a panel dataset of 159 manufacturing firms over the period 1990-1996. To be included in the sample, firms must have participated in both innovation surveys and all or all but one of the annual business surveys for the period 1990-1996.[26] This construction creates some bias toward larger firms because large firms are slightly over-represented in the innovation surveys, and larger firms are both more likely to show up in the business surveys and survive over the seven-year period. All manufacturing industries are included (see Table 5.1 for industry breakdown). For comparison, Table 5.1 also provides the breakdown for the more representative innovation survey sample of 1029. Printing and publishing industry is slightly over-represented, possibly due to the stable industry conditions leading to a higher probability of firms surviving through hard times, while the car and motor vehicle industry is under-represented in the panel sample.

The period of study coincides with an economic recession and subsequent recovery in Finland. This turbulence in the environment is reflected in firms' behavior and performance. Several outliers were eliminated from the dataset due to dramatic changes in firm size, profitability, or other variables.[27] Still, the remaining data can hardly be

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[25] Statistics Finland has adhered to the Eurostat guidelines for European Community Innovation Surveys in designing the Finnish innovation surveys.
[26] The missing observation has to be for either the first or the last year.
[27] "Dramatic" is defined as more than 100% growth or 50% reduction in sales or number of employees, or negative 3-digit profit margins.

described as stationary. Because of these historical events, the analysis could alternatively be interpreted as a study of the factors of rapid recovery from a large external shock. Some of the estimation results may be weakened by this source of environmental noise.

Table 5.1 Industries

Industry	NACE	N	Share	Innovation survey N	Share
Food	15-16	21	13.2 %	107	10.4 %
Textile	17-19	13	8.2 %	79	7.7 %
Wood	20	11	6.9 %	76	7.4 %
Paper	21	5	3.1 %	26	2.5 %
Printing, publishing	22	25	15.7 %	98	9.5 %
Oil, Chemical	23-24	10	6.3 %	43	4.2 %
Plastic, Rubber	25	8	5.0 %	47	4.6 %
Nonmetallic minerals	26	4	2.5 %	44	4.3 %
Primary metals	27	6	3.8 %	26	2.5 %
Metal products	28	4	2.5 %	97	9.4 %
Machines, equipment	29	25	15.7 %	146	14.2 %
Electronics	30-33	16	10.1 %	133	12.9 %
Cars, vehicles	34-35	3	1.9 %	54	5.2 %
Furniture	36	8	5.0 %	53	5.2 %
Total		159	100.0 %	1029	100.0 %

Variables are listed and described in Table 5.2 and descriptive statistics are displayed in Table 5.3. The data are at the level of the firm, not business group. The dependent variable, operating profit margin is derived from the business survey information. It is a rather standard profitability measure (see e.g. Geroski et al. 1993). Operating profit levels tend to vary systematically across industries, which can be sufficiently controlled for with industry capital intensity. An average firm in the dataset had 506 employees in 1995. 79 percent of firms reported positive R&D expenditures that year. On average these firms invested 1.8 percent of their sales revenue in R&D.[28]

[28] There are some problems of missing data. Not all firms were included in the R&D surveys, but because the R&D surveys include all large firms (EMPL>100), a missing observation means that R&D investment is probably zero. However, because of potential measurement error, this variable is used mainly as an instrument in the econometric analysis.

Table 5.2 Variables (data available for 1990-1996 unless otherwise indicated)

Dependent variable	PROF	Operating profit/sales
Explanatory variables		
INNOVATION ACTIVITIES	PROD96	Dummy for successful product innovation (sales revenue from commercialised new product(s) >0), 1996
	PROC96	Dummy for process innovation (survey question about whether the firm process innovated or not), 1996
	INNO96	Dummy for any innovation (PROD96, PROC96 or both)
	RDINV	Internal Research and Development investments/sales
	RDDUM	Dummy for R&D investment > 0
	COLLAB96	Dummy for R&D collaboration with competitors, customers, suppliers or universities, 1996
COMPETENCIES	TECH	Share of employees with a higher technical or natural scientific degree (e.g., university engineer, master of science in chemistry)
	TECHDUM	Dummy for value of TECH higher than in the average firm
	PAT	Number of domestic patent applications
	RES	Share of employees with a post graduate degree (licentiate, PhD)
	PROD91	Product innovation dummy ("dynamic competence"), 1991
	PROC91	Process innovation dummy ("dynamic competence"), 1991
	COLLAB91	Dummy for R&D collaboration ("dynamic competence"), 1991
FIRM	EMPL	Number of employees
	KINT	Capital intensity (fixed capital/sales)
	MS	Domestic market share in the 2-digit industry
INDUSTRY	CONC3	3-firm concentration ratio in the domestic 2-digit industry
	INDKINT	Average capital intensity in the industry
	INDPAT	Average number of patents in the industry among patenting firms

Table 5.3 Descriptive Statistics (N=159, Year=1995)

	Mean	Std. Dev.	Min.	Max.	Mean for the Innovation Survey sample (1996, N=1029, weighted)
PROF (%)	7.5	8.5	-24.0	42.8	6.8
EMPL	506	897.7	25	6650	98
KINT (%)	16.3	15.5	0.4	142.3	13.8
MS (%)	1.9	6.0	0.03	56.0	0.4
PAT	1.4	6.1	0	54	0.3
RES (%)	0.20	0.50	0	3.63	0.10
TECH (%)	6.7	7.5	0.0	48.0	6.4
TECHDUM	0.36	0.48	0	1	n.a.
RDDUM	0.79	0.41	0	1	0.30
RDINV>0 (N=107) (%)	1.8	2.0	0.03	13.0	2.4 (N=400)
PROD91	0.61	0.49	0	1	n.a.
PROC91	0.60	0.49	0	1	n.a.
COLLAB91	0.56	0.50	0	1	n.a.
PROD96	0.37	0.48	0	1	0.19
PROC96	0.40	0.49	0	1	0.21
INNO96	0.50	0.50	0	1	0.28
COLLAB96	0.47	0.50	0	1	0.22
INDKINT (%)	15.6	5.3	9.9	28.9	14.8
INDPAT	2.8	2.4	0.0	8.9	3.7
CONC3 (%)	26.7	10.9	8.8	50.2	34.8

Notes: n.a. = not available.

Competencies are proxied here by educational levels and fields of employees and past innovation activities of firms. While these indicators could surely be criticized for not reflecting directly the organizational and tacit dimensions of firms' capabilities, I argue that they are sufficiently correlated with the unobservable variable of interest. 6.7 percent of the employees in an average firm have a higher university degree in technical or natural sciences.

According to the 1991 innovation survey data, 61 percent of firms introduced new products in the markets (with positive sales revenue), 60 percent adopted new processes, and 56 percent of firms engaged in collaborative R&D that year. In the 1996 innovation questionnaire, the wording was changed to emphasize *technological* product and process innovations, and perhaps partly for this reason the share of innovating firms dropped to 37% for product and 40% for process innovators. 47% of firms reported collaborating with customers, suppliers, universities, or competitors.

In comparison to the more or less representative innovation survey sample of 1996 (1029 firms unless otherwise indicated), as expected, the panel sample is considerably biased toward larger firms. There is also a bias toward innovating firms. This can be attributed to survivor bias as innovative firms generally perform better economically and therefore were more likely to survive the hard times of the Finnish economy in the early 1990s. Somewhat surprisingly, however, although firms in the panel sample are much more likely to engage in R&D, their investments in R&D are smaller. This may relate to the size bias: smaller R&D performing firms are perhaps more likely to be highly R&D intensive (R&D investments / sales revenue).

Correlations among the original variables and among the first-differenced variables to be used in the estimation can be found in the Appendix 5.1. To examine the relationships among variables related to innovation activities, Table 5.4 provides means for different kinds of R&D investing firms, non-investors, and all firms in the sample for 1995. The first 8 data columns show means of the variables on the left for firms that invested in R&D in 1995 *and* engaged in the activity indicated at the head of the column. For example, the average sales of product innovating firms engaged in R&D (PROD96 column) were 1422 million FIM.

Table 5.4 Innovator profiles of firms investing in R&D (N=159, Year=1995)

	PROD96	PROC96	INNO96	COLLAB96	PROD91	PROC91	COLLAB91	All R&D investing firms	Non R&D firms	All firms
PROF (%)	9.9	10.0	9.6	8.8	8.2	9.6	9.9	8.2	6.1	7.5
SALES	1422	1454	1218	1223	1104	1215	1238	889	197	663
EMPL	881	919	807	800	742	782	808	633	245	506
PROD96	1	0.75	0.80	0.72	0.60	0.60	0.63	0.52	0.06	0.37
PROC96	0.73	1	0.79	0.72	0.55	0.63	0.60	0.51	0.15	0.40
INNO96	1	1	1	0.90	0.73	0.76	0.75	0.65	0.17	0.50
COLLAB96	0.89	0.91	0.89	1	0.69	0.72	0.72	0.64	0.10	0.47
PAT	3.09	3.29	2.61	2.90	2.4	2.6	2.69	1.9	0.2	1.4
TECH	0.10	0.08	0.09	0.09	0.09	0.09	0.10	0.08	0.04	0.07
TECHDUM	0.61	0.51	0.54	0.57	0.46	0.51	0.72	0.47	0.15	0.36
RDINV	2.3%	1.8%	2.1%	2.0%	2.0%	1.9%	2.1%	1.8%	0	1.2%
PROD91	0.86	0.80	0.83	0.80	1	0.81	0.88	0.75	0.33	0.61
PROC91	0.77	0.82	0.79	0.75	0.73	1	0.79	0.67	0.44	0.60
COLLAB91	0.80	0.78	0.77	0.75	0.79	0.79	1	0.67	0.33	0.56
N	56	55	70	69	80	72	72	107	52	159

Note: The 8 first columns present mean statistics for R&D firms, for which the respective innovation indicator is equal to 1.

There is some evidence of temporal persistence in innovation activities among firms. About 50% of all R&D investing firms made product or process innovations in 1994-96. Among firms that innovated 1989-91, the likelihood of innovating in 1994-96 is some 10 percentage points higher, and more than 80% of 1994-96 product or process innovators innovated also in 1989-91. Similarly for R&D collaboration: 64% of all R&D firms collaborated in 1994-96, while 72% of firms that engaged in collaborative innovation in 1989-91 collaborated also in 1994-96.

Collaboration increases firms' likelihood of innovation. In particular, 90 percent of collaborating firms made product or process innovations, against 65 percent for all R&D investing firms. This finding may reflect either that collaboration increases innovativeness or that collaboration and innovation both depend on some unobserved firm characteristics such as their knowledge assets. Skills are also seen to be closely associated with innovation activities. Eight percent of R&D investing firms' employees have a higher technical or scientific degree. Among product innovators, this figure is 10%, while in non-R&D firms, it is only 4%.

To summarize, the data in Table 5.4 are in line with the interpretation that there are both dynamic and contemporaneous complementarities. Past innovation activities increase the likelihood of current collaboration and innovation, particularly process innovation. Higher than average skills and R&D investments are observed in firms that innovate or collaborate. Profitability also correlates with innovation activities. However, these observations do not yet establish complementarity as they could be driven by unobserved heterogeneity. The next section presents an explicit test as to whether firms' competencies and innovation activities are indeed complementary in terms of their effects on profitability.

5.4 Econometric method

Generalized method of moments (GMM) for panel data is used for estimation in order to account for the potential heterogeneity and simultaneous or predetermined variables (see Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998). These characteristics of the dataset lead to inconsistent estimates with such methods as fixed effects or three stage least squares. The econometric model is as follows:

$$(1) \qquad \Pi_{it} = \alpha'\Pi_{it-1} + \beta^{E}{}'X_{it}^{E} + \beta^{P}{}'X_{it}^{P} + \gamma'Y_{it} + \mu_i + \varepsilon_{it} + \delta_t$$

Π_{it} denotes profits for firm i in period t, X^{E}_{it} are the strictly exogenous industry level control variables, X^{P}_{it} are potentially predetermined firm-level explanatory variables, μ_i are unobserved firm-specific fixed effects, δ_t are time dummies and ε_i are *iid* error terms. α, β^E, β^P, and γ are the parameters to be estimated. Y_i is a vector of the interactions of the X^{P}'s to test for the presence of complementarities. In general, positive cross-partial derivatives of continuous X_i variables imply complementarity. This is equivalent to the γ parameters being positive.[29]

However, in the case of binary variables such as the innovation and collaboration indicators, simple interaction terms are not necessarily the best way to identify potential complementarities. Identification of the simple interaction terms is difficult because the variables to be interacted tend to be highly correlated, and each variable can only obtain values of 0 or 1.

The method used here builds on Bresnahan *et al.* (1999). The starting point is the definition of complementarity for a two-dimensional function $f(x,y)$, where $x = \{0,1\}$ and $y = \{0,1\}$ (see Topkis, 1998, Theorem 2.6.2, p.45):

$$(2) \qquad f(1,1) - f(0,1) \geq f(1,0) - f(0,0)$$

Complementarity thus implies increasing differences: the effect of increasing x from 0 to 1 is larger when $y = 1$ than when $y = 0$. In the estimation we can normalize $f(0,0) = 0$, and thus the complementarity condition is:

$$(3) \qquad f(1,1) \geq f(0,1) + f(1,0)$$

The estimation will generate coefficients for the mutually excluding dummies for the different combinations. Combinations include, for instance, high competence innovator ("high-high" combination), low competence innovator ("low-high"), and high competence non-innovators ("high-low"), while low competence non-innovator ("low-low") is the reference case. A result in line with the complementarity condition (3)

[29] See the Appendix 5.2 for more discussion of the identification of complementarities.

would imply then that the effect of "adopting" innovation activities on profitability is greater in the presence of high competencies than in the presence of low competencies.

To control for fixed effects in (1), with which the *X*'s may correlate, the model can be estimated in first differences:

(4) $$\Delta\Pi_{it} = \alpha'\Delta\Pi_{it-1} + \beta^{E}{}'\Delta X_{it}^{E} + \beta^{P}{}'\Delta X_{it}^{P} + \gamma'\Delta Y_{it} + \Delta\varepsilon_{it} + \Delta\delta_{t}$$

Some of the firm-level variables are likely to be predetermined, that is, correlated with the previous period's error term, rather than strictly exogenous. Therefore, some undesirable correlation between the explanatory variables and the error terms may still remain. Instruments are used to correct for this. Values of the dependent variable lagged two or more periods are valid instruments, as the model is dynamic (AR1), as well as the values of explanatory variables lagged one or more periods. The orthogonality conditions are

(5) $$E(\Pi_{i,t-s}\Delta\varepsilon_{it}) = 0 \quad \text{for } t=3,\ldots,T \text{ and } s \geq 2.$$

$$E(X_{i,t-s}\Delta\varepsilon_{it}) = 0 \quad \text{for } t=3,\ldots,T \text{ and } s \geq 1.$$

Additionally, current exogenous variables X^E are valid instruments. Second-order serial uncorrelation of the error terms is required for the consistency of this model. The Sargan test statistic of overidentifying restrictions (stacked instrumental variables) is also reported with the results (see Arellano and Bond, 1991).

Arellano and Bover (1995) argued that first-differenced estimation loses information particularly useful with short panels. They propose a system method that estimates the level equations together with the differenced equations to increase precision. Then lagged first differences are used as instruments for the level equations, and lagged levels are used as instruments for the differenced equations.

Blundell and Bond (1998) found that the system estimator can alleviate the problem of weak instruments in cases where α is close to one. Moreover, this estimator preserves information from the level equations enabling the identification of time-invariant effects. This is essential applied to the cross-sectional innovation variables in this study.[30] The additional moment conditions are:

(6) $$E(\varepsilon_{it}\Delta\Pi_{i,t-1}) = 0 \qquad \text{for } t = 3,4,\ldots,T$$

$$E(\varepsilon_{it}\Delta X_{i,t-1}) = 0 \qquad \text{for } t=3,\ldots,T$$

The requirement for the validity of the instruments for the level equations is that they be uncorrelated with the fixed effect. Validity of these moment conditions will be tested with the Difference Sargan test, comparing the instruments for the differenced estimator (DIF) with those for the system estimator (SYS).

5.5 Estimation results

The objective of the econometric analysis is to test for complementarities among competencies, innovation, and collaborative R&D. Estimation results for the specification without interaction effects are shown in Table 5.5 to provide a base case. For comparison, the model is estimated here with both the standard fixed effects method, one-step differenced GMM ("DIF"; Arellano and Bond, 1991) and one-step system GMM ("SYS"; Arellano and Bover, 1995).[31]

All specifications include a set of standard economic control variables: lagged dependent variable, size proxied by number of employees, capital intensity, market share, 3-firm concentration ratio, and capital intensity in the industry. Among these, lagged profitability, firm size, capital intensity, and market share are assumed to be predetermined (endogenous) variables, and they are instrumented (DIF and SYS estimations). In addition, patenting intensity in the industry and full sets of year dummies are used as control variables. The base case also contains dummy variables for technical competencies and innovation activities and outputs, which are predetermined variables and thus instrumented.

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[30] Time invariant effects are "differenced" away in the difference equations, and only included in the level equations. They are instrumented with lagged differences of the competence variables, which are valid because they are likely to correlate with the innovation activities but not with the fixed effect.

[31] See the Appendix A5.2.2 for the differences between the one-step and two-step system estimators.

Table 5.5 Baseline regressions (1993-96, N_max=159, T=4, N*T=622)

	Fixed Effects		DIF 1-step		System 1-step	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
CONST	-1.88**	-2.80	1.45**	1.99	3.84	1.51
$\underline{PROF_{-1}}$	0.09**	1.97	0.11	1.54	0.30**	5.43
EMPL	-0.002**	-2.36	-0.005**	-2.53	-0.001*	-1.86
KINT	-0.07	-1.54	-0.13**	-2.90	0.05*	1.87
MS	11.73	1.61	8.87	0.98	9.52	1.12
CONC3	-0.01	-0.47	-0.0003	-0.01	0.05	1.47
INDKINT	-0.30**	-2.91	-0.21**	-2.12	-0.14*	-1.75
INDPAT	-0.32*	-1.82	-0.27	-1.47	-0.37**	-2.82
TECHDUM	0.57	1.05	0.32	0.35	1.13	0.54
COLLAB96	0.53	0.74	0.32	0.17	-0.23	-0.07
INNO96	0.14	0.19	-2.50	-1.32	3.89	1.35
RDDUM	-0.48	-0.73	0.90	1.33	-0.23	-0.08
1st order serial correlation (p)	-5.3	0.00	-3.7	0.00	-5.9	0.00
2nd order serial correlation (p)	-1.0	0.32	-0.6	0.53	-0.7	0.45
Sargan test (p)			79.5 (d.f. 76)	0.37	122.9 (d.f. 120)	0.41
Difference Sargan (p)					43.4 (d.f. 44)	(0.50)

Notes: Estimations are carried out with the DPD98 for Gauss by Arellano and Bond. Dependent variable: operating profit margin (PROF). Specifications include time dummies.
Instruments for the differenced equations (DIF- and SYS-estimators): Const, PROF(gmm), EMPL(gmm), KINT(gmm), MS(gmm), PAT(gmm), TECH(gmm), RES(gmm), $RDDUM_{-2}$, PROD91, PROC91, COLLAB91, CONC3, INDKINT, INDPAT. "gmm"-instruments are the stacked overidentifying moment restrictions as in (5) above. Due to the matrix size limitations of GAUSS, a maximum of 4 lags are used.
Instruments for the level equations in SYS include differences of the following variables: $PROF_{-2}$, $EMPL_{-1}$, $KINT_{-1}$, MS_{-1}, CONC3, INDKINT, INDPAT, PAT_{-2}, RES_{-2}, $TECH_{-2}$, RD_INV_{-2}. Two first levels equations are omitted for lack of instruments.
** denotes significance at the 95% confidence level, * denotes significance at the 90% level.
Underlined variables are instrumented.

The three estimation methods agree on most signs of the coefficients, but the level of significance varies. The clearest difference concerns the coefficient for firm-level capital intensity. With the DIF-estimator we obtain a significant negative coefficient, while the SYS-estimator yields a positive weakly significant coefficient. The estimators diverge on the signs of the coefficients for concentration ratio, too, but these are not significant. The system estimator is better able to identify the dynamic process (lagged dependent variable) and the effects of time-invariant innovation variables, at least technical skills and innovation output, although they still do not have any significant profitability implications here. In the fixed effects and DIF-estimations, however, the coefficients of the time-invariant variables in fact measure their effect on the growth rates, not levels, as in the original econometric model of (1).

These empirical results thus lend support for the previously discussed theoretical advantages of the system estimator. Another issue is that the discrepancies between the results with DIF- and SYS-estimators may partly reflect the non-stationarity of the dataset (see Blundell and Bond, 1998, p. 124). However, based on their Monte Carlo simulations, Blundell and Bond suggest that Sargan test is able to detect possible problems related to this. In Table 5.5 the Difference Sargan test assessing the validity of the additional moment conditions defined by (5) does not indicate specification problems. This test will also reject in case the overidentifying moment conditions for the level equations are not valid in respect of correlation with the error terms. Hence, no specification problems are indicated vis à vis the system estimation method.

Also in line with Blundell and Bond's results, one-step system estimator appears to inflate standard errors somewhat.[32] Therefore, coefficients that are significant with the one-step procedure used here are likely to be strongly statistically associated with the dependent variable, but this test may be too strict. In spite of this, Blundell and Bond recommend the one-step results instead of the efficient two-step ones, which deflate standard errors and may produce "too" significant coefficients, particularly if the data are heteroskedastic.

The specifications in Table 5.5 account for industry differences with three variables: concentration ratio, capital intensity, and patenting intensity. To assess their ability to control for industry-specificities I estimated the SYS-equation with a full set of industry dummies instead of the aforementioned industry variables (see Table A5.3 in Appendix 5.3). The coefficients of *TECHDUM* and *INNO96* become larger and statistically significant at the 90% level. This suggests that the three industry controls used here account better for industry-specificities with respect to the competence and innovation variables than the industry dummies.[33]

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[32] The one-step weighting matrix is arbitrary, which can have considerable effects in finite samples.

[33] Time dummies interacted with industry dummies would be an even stronger test, but the estimation with 13 dummies for 4 periods as explanatory variables and instruments generates a too large matrix for Gauss to handle.

Finally, to examine the performance of the instruments I estimated the model with system GMM but predetermined variables' instruments lagged by two (employees, market share, capital intensity) and three (patenting and skill variables) instead of by one and two, respectively. This had no substantial effects on the results.

Subsequent analysis is based on the system estimator, using the industry control variables instead of dummies. Fixed effects results will not be considered, because they are inconsistent for dynamic models and cannot identify the time-invariant innovation dummy variables. The latter also applies for the DIF-estimator.

5.5.1 Testing for complementarities: innovation and competencies (H1)

Competencies are measured first with the dummy for technical competencies *TECHDUM*. The estimation results in Table 5.6 indicate that these competencies strongly support profiting from both product and process innovation. The coefficient estimates fulfill the complementarity condition (3).

Table 5.6 Interactions between technical competencies and innovation outcomes 1996 (N*T=622), one-step GMM system estimator, 1993-96

	Product innovation (PROD)		Process innovation (PROC)		Product or process innovation (INNO)	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
CONST	4.82**	2.90	5.51**	2.84	5.14**	2.68
$PROF_{-1}$	0.30**	5.59	0.28**	4.77	0.27**	4.77
EMPL	-0.001	-1.41	-0.001	-1.63	-0.001*	-1.72
KINT	0.05	1.60	0.03	1.24	0.04	1.40
MS	8.05	0.88	5.00	0.59	5.80	0.64
CONC3	0.05	1.50	0.04	1.31	0.05*	1.67
INDKINT	-0.13	-1.56	-0.14*	-1.78	-0.11	-1.26
INDPAT	-0.39**	-3.00	-0.24*	-1.73	-0.37**	-2.82
TECH(high) & Innovator 1996	4.44**	2.30	5.95**	2.30	5.23**	2.66
TECH(low) & Innovator 1996	0.75	0.26	-0.21	-0.06	-6.46	-1.46
TECH(high) & Non-innovator 1996	-1.02	-0.25	-1.68	-0.60	-0.81	-0.26
1^{nd} order serial correlation (p)	-5.8	0.00	-5.5	0.00	-5.6	0.00
2^{nd} order serial correlation (p)	-0.7	0.47	-0.7	0.48	-0.8	0.44
Sargan test (p), d.f. 121	125.4	0.37	122.1	0.45	128.8	0.30

See notes about specification and instrumentation for table 5.5.

Table 5.7 examines the complementarity between past innovation, *i.e.*, accumulated innovation capabilities, and current innovation. Cumulativeness of innovation is rather strong in process innovation, as demonstrated by the results. Successful innovation in the past clearly enhances the returns to current innovation. Profiting from product innovation, in contrast, does not depend statistically significantly on past innovation, although the coefficients are aligned with the complementarity condition.

Table 5.7 Interactions between past innovation performance and innovation outcomes (N*T=781), one-step GMM system estimator

	Product innovation (PROD)		Process innovation (PROC)		Product or process innovation (INNO)	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
CONST	5.95**	2.97	1.29	0.53	3.58	1.37
$PROF_{-1}$	0.31**	5.68	0.32**	5.53	0.30**	5.62
EMPL	-0.001	-1.56	-0.002**	-2.54	-0.001*	-1.89
KINT	0.04	1.39	0.04	1.19	0.06*	1.94
MS	8.80	0.99	12.04	1.43	9.98	1.18
CONC3	0.06	1.99	0.04	1.21	0.05	1.59
INDKINT	-0.13	-1.52	-0.18*	-1.90	-0.15*	-1.74
INDPAT	-0.37**	-2.95	-0.22*	-1.74	-0.35**	-2.74
Innovator 1991 & Innovator 1996	2.58	1.40	7.43**	2.66	4.24*	1.70
Innovator -91 & Non-innovator -96	-4.41**	-1.97	1.41	0.48	-0.21	-0.07
Non-innovator -91 & Innovator -96	0.82	0.19	4.33	0.95	7.31	0.93
1st order serial correlation (p)	-5.9	0.00	-6.5	0.00	-5.9	0.00
2nd order serial correlation (p)	-0.7	0.51	0.0	0.99	-0.7	0.47
Sargan test (p), d.f. 121	125.2	0.38	126.0	0.61	121.3	0.48

See notes for table 5.5.

5.5.2 Collaborative R&D and competencies (H2)

Internal competencies were hypothesized to be prerequisite to benefiting from collaborative R&D. The original absorptive capacity proposition by Cohen and Levinthal (1989) concerned the role of R&D in learning about external technological developments. However, results here indicate that skills and accumulated competencies are more relevant in making use of external knowledge than R&D.

Technical competencies strongly complement collaborative innovation arrangements (Table 5.8). Dynamic competencies as measured by the firm's history of collaborative arrangements also significantly reinforce the profitability effects of current R&D collaboration (Table 5.9). Thus there is cumulative learning in collaboration, as well. Table 5.10 displays the interaction between current collaboration and whether the firm is engaged in R&D or not. Collaboration *without* R&D has the largest and most significant coefficient, thus the original absorptive capacity argument is not supported by the Finnish data. However, the coefficients suggest that if the firm does R&D, it is better off collaborating as well. Moreover, there are only 5 firms in the sample that collaborate but do not invest in internal R&D, which may give rise to the unexpected outcome.

Table 5.8 Interactions between technical competencies and innovation collaboration 1993-96 (N =622)

	Coeff.	t-stat
CONST	4.56**	2.62
$PROF_{-1}$	0.30**	5.14
EMPL	-0.001*	-1.78
KINT	0.04	1.53
MS	8.58	0.92
CONC3	0.05	1.59
INDKINT	-0.11	-1.36
INDPAT	-0.36**	-2.71
TECH high & Collaborator 1996	4.99**	2.26
TECHNIC high & Non-collaborator 1996	-3.63	-0.83
TECHNIC low & Collaborator 1996	0.47	0.17
1^{st} order serial correlation (p)	-5.8	0.00
2^{nd} order serial correlation (p)	-0.7	0.47
Sargan test (p) d.f. 121	120.5	0.50

Note: The same estimation method, control variables and instruments were used as in Table 5.

Table 5.9 Interactions between past collaborative arrangements and collaboration in 1996, 1993-96

	Coeff.	t-stat
CONST	2.72	1.36
PROF-1	0.29**	4.87
EMPL	-0.001**	-2.20
KINT	0.03	1.36
MS	10.53	1.20
CONC3	0.04	1.49
INDKINT	-0.13	-1.53
INDPAT	-0.39**	-2.96
Collaborator 1991 & Collaborator 1996	6.61**	2.89
Collaborator 1991 & Non-collaborator 1996	5.45	1.65
Non-collaborator 1991 & Collaborator 1996	0.58	0.14
1^{st} order serial correlation (p)	-5.9	0.00
2^{nd} order serial correlation (p)	-0.7	0.47
Sargan test (p), d.f. 117	123.7	0.42

Table 5.10 Interactions between R&D and collaboration in 1996

	Coeff.	t-stat
CONST	0.91	0.27
PROF-1	0.28**	5.07
EMPL	-0.001	-1.51
KINT	0.05**	2.05
MS	8.87	1.09
CONC3	0.04	1.15
INDKINT	-0.15*	-1.87
INDPAT	-0.31**	-2.33
R&D firm & Collaborator 1996	6.51**	2.24
R&D firm & Non-collaborator 1996	4.85	1.20
Non-R&D firm & Collaborator 1996	22.01**	2.07
1st order serial correlation (p)	-5.9	0.00
2nd order serial correlation (p)	-0.8	0.45
Sargan test (p), d.f. 121	125.4	0.37

5.5.3 "Systemic" interactions among collaborative R&D, competencies, and innovation

The last set of estimations takes a more systemic approach and examines three- and four-way interactions among innovation and competence variables. In the previous subsections, competencies were found to complement the profitability effects of collaboration and innovation output. A potential weakness of the estimation approach is that interactions are assessed one at a time, because the two-way interaction dummies for competencies and innovation are difficult to identify simultaneously with those for collaboration and competencies. Here I construct a new set of dummies, where the joint profitability effects of three characteristics or activities, such as high technical competencies, R&D collaboration, and innovation, are compared with those of only two activities, or a single activity. Thus I create mutually excluding dummies for firms engaged in all three activities, for firms engaged in any two but only two, and for firms which are engaged in a single activity. Again, low competencies and no innovation activities is the reference case. To reduce the number of interactions, I use here the variable INNO96 (either product or process innovation, or both) as the measure of innovativeness, instead of treating product and process innovation separately.

Now the complementarity condition needs to be extended for three variables. I will simplify by focusing on the increasing differences of one variable at a time. Based on the definition of complementarity, for a function $f(x_1,x_2,x_3)$ the effect of adopting x_1

should be stronger in the presence of x_2 and x_3 than in their absence. This translates to the following conditions:

$$f(1,1,1) - f(0,1,1) \geq f(1,0,0) - f(0,0,0)$$

(7) $$f(1,1,1) - f(1,0,1) \geq f(0,1,0) - f(0,0,0)$$

$$f(1,1,1) - f(1,1,0) \geq f(0,0,1) - f(0,0,0)$$

Normalizing f(0,0,0) = 0 I need to estimate coefficients for seven combinations to assess whether the following conditions hold:

$$f(1,1,1) - f(0,1,1) \geq f(1,0,0)$$

(8) $$f(1,1,1) - f(1,0,1) \geq f(0,1,0)$$

$$f(1,1,1) - f(1,1,0) \geq f(0,0,1)$$

The problem that is aggravated in estimating the three-variable interactions is that if the complementarity is strong, most observations are likely to cluster into the combinations (1,1,1) and (0,0,0) leaving few observations of mixed combinations. The last column in Table 5.11 shows the number of observations for each three-way combination for the variables *TECHDUM, COLLAB96, INNO96.* Indeed, 37 firms engage in all activities exhibiting the combination (1,1,1) and 59 firms engage in none of the activities and thus have the combination (0,0,0). In addition, the combination (0,1,1), that is, collaboration and innovation combined with low technical competencies is found in 30 firms. Other combinations have less than 10 observations each. Few observations may complicate the identification of the effects in some cases.

Results in the previous subsections suggested that competencies exhibit complementarities with both collaboration and innovation in terms of profitability. The results in Table 5.11 here show that the pairwise complementarities are even stronger in the presence of the third activity. The complementarity between high technical competencies and innovation is thus reinforced by R&D collaboration.

Table 5.11 Interactions among technical competencies, collaboration, and innovation (1993-96, N_max=159, N*T=622)

	Coeff.	t-stat	N
CONST	5.51**	2.80	
PROF-1	0.26**	4.50	
EMPL	-0.001*	-1.75	
KINT	0.03	1.18	
MS	4.01	0.46	
CONC3	0.05*	1.77	
INDKINT	-0.10	-1.19	
INDPAT	-0.36**	-2.53	
TECH(high), COLLAB96=1, INNO96=1	5.78**	2.46	37
TECH(high), COLLAB96=1, INNO96=0	-10.19	-1.04	4
TECH(high), COLLAB96=0, INNO96=1	5.61	0.72	3
TECH(low), COLLAB96=1, INNO96=1	-0.19	-0.06	30
TECH(high), COLLAB96=0, INNO96=0	-7.14	-1.22	14
TECH(low), COLLAB96=1, INNO96=0	-2.73	-0.38	3
TECH(low), COLLAB96=0, INNO96=1	-7.76	-1.23	9
1st order serial correlation (p)	-5.5	0.00	
2nd order serial correlation (p)	-0.8	0.44	
Sargan test (p) d.f. 117	121.3	0.37	

The three-way estimation also highlights the dynamics of knowledge accumulation. Table 5.12 shows results for the three-way interaction of collaboration in 1991, collaboration in 1996, and innovation in 1996. Again, most observations have either the combination (1,1,1) – 51 firms – or (0,0,0) – 43 firms. Additionally, there seems to be some separation of firms active in collaboration in 1991, and those active in collaboration and innovation in 1996. 30 firms collaborated in the earlier period, but discontinued innovation activities. This strategy also obtains a positive and significant coefficient. Similarly, the combination of collaboration in 1991 and innovation in 1996 obtains a large coefficient significant at the 90% level. However, the most significant coefficient is on the (1,1,1) combination suggesting that the systemic effect exists. In contrast, the coefficient for collaboration in 1991 and 1996 but no innovation is large but not significant and based on only 3 observations.

Table 5.12 Interactions among past collaboration, collaboration in 1996, and innovation (1993-96, N_max=159, N*T=622)

	Coeff.	t-stat	N
CONST	2.17	1.08	
PROF-1	0.26**	4.32	
EMPL	-0.002**	-2.17	
KINT	0.03	1.30	
MS	13.73	1.59	
CONC3	0.05	1.51	
INDKINT	-0.14*	-1.79	
INDPAT	-0.43**	-3.16	
COLLAB91=1, COLLAB96=1, INNO96=1	6.89**	2.90	51
COLLAB91=1, COLLAB96=1, INNO96=0	18.62	1.53	3
COLLAB91=1,COLLAB96=0, INNO96=1	7.90*	1.73	5
COLLAB91=0, COLLAB96=1, INNO96=1	5.42	1.17	16
COLLAB91=1,COLLAB96=0, INNO96=0	7.92**	2.16	30
COLLAB91=0,COLLAB96=1, INNO96=0	-11.79	-1.44	4
COLLAB91=0,COLLAB96=0, INNO96=1	0.50	0.08	7
1st order serial correlation (p)	-5.7	0.00	
2nd order serial correlation (p)	-0.8	0.45	
Sargan test (p) d.f. 117	120.8	0.39	

It would be interesting to know whether all of the variables examined so far – technical competencies, accumulated collaboration capabilities, current collaboration, and current innovation – form a system of complementarities. Unfortunately in this case the observations for most of the mixed combinations become much too few. However, it is possible to simplify the complementarity condition such that identification becomes possible. Here I assess the hypothesis that these four variables are more profitable when observed all together (1,1,1,1) than when observed in any other combination:

(9)

$$f(1,1,1,1) \geq f(1,x_2,x_3,x_4) \quad \text{where } x_i = 0 \text{ for at least some } i = 2,3,4.$$

$$f(1,1,1,1) \geq f(x_1,1,x_3,x_4) \quad \text{where } x_i = 0 \text{ for at least some } i = 1,3,4.$$

$$f(1,1,1,1) \geq f(x_1,x_2,1,x_4) \quad \text{where } x_i = 0 \text{ for at least some } i = 1,2,4.$$

$$f(1,1,1,1) \geq f(x_1,x_2,x_3,1) \quad \text{where } x_i = 0 \text{ for at least some } i = 1,2,3.$$

Table 5.13 presents the results. The variable (1,1,1,1) thus refers to the combination with all four variables obtaining the value of 1. In line with the hypothesis, the (1,1,1,1) combination has the largest and most significant coefficient. *COLLAB91* is almost significantly positively associated with profitability also in other combinations, but the coefficient is smaller implying that the adoption of the missing components of the system has positive profitability effects. Now the last column does not add up to 159 as the dummies for *TECH*(high), *COLLAB91*, *COLLAB96*, and *INNO96* but not (1,1,1,1) are not mutually excluding. They only exclude the firms with all activities present, i.e., (1,1,1,1).

Table 5.13 Interactions among technical competencies, past collaboration, current collaboration, and innovation (1993-96, N_max=159, N*T=622)

	Coeff.	t-stat	N
CONST	3.44*	1.68	
PROF-1	0.27**	4.22	
EMPL	-0.002**	-2.25	
KINT	0.02	1.01	
MS	8.71	0.93	
CONC3	0.05*	1.67	
INDKINT	-0.11	-1.29	
INDPAT	-0.40**	-3.02	
(1,1,1,1)	7.70**	3.05	33
TECH(high), not (1,1,1,1)	-3.12	-1.00	25
COLLAB91, not (1,1,1,1)	4.35*	1.80	56
COLLAB96, not (1,1,1,1)	-0.24	-0.07	41
INNO96, not (1,1,1,1)	0.01	0.00	46
1st order serial correlation (p)	-5.7	0.00	
2nd order serial correlation (p)	-0.8	0.45	
Sargan test (p) d.f. 119	119.4	0.47	

To sum up, the results provide support for the hypotheses that technical and dynamic competencies help firms to profit from both innovation and collaboration, and they may be more important than R&D in building absorptive capacity. The magnitudes of the coefficients – which must be treated as suggestive at best – imply that adopting the complementary competencies and activities boosts the firm's profit margin by some 5-8 percentage points. Thus innovation may have substantial effects on firm performance, but realization of these effects depends on complementary assets.

5.6 Conclusions

I have argued that a firm's knowledge assets critically affect its profitability. Knowledge is accumulated by investing in various learning processes, including internal and collaborative R&D and hiring skilled employees. In addition to examining the profitability effects of a range of firm-level competence measures and innovation activities, this study explicitly focuses on the interactions among them. Identifying complementarities sheds new light on the effects of organization on firms' innovative and economic performance.

The main results are the following. First, innovation output alone is not a significant explanatory factor of profitability. Both technical and dynamic competencies – cumulative learning based on a history of innovation – reinforce the profitability effects of innovation. Second, collaborative R&D has stronger positive economic effects when the firm has already accumulated collaboration capabilities or possesses considerable technical competencies. Thus, both dynamic complementarities related to firms' innovation activities – past innovation activities affect the profitability of current activities – and short-term complementarities – employees' skills support profiting from collaboration and innovation – are demonstrated. Third, these positive interactions represent a system of complementarities, where technical and dynamic competencies, collaboration, and innovation reinforce one another. These results imply that complementarities exist between competencies and innovation activities, and that the choice of how to organize innovation activities matters.

A potential problem with the dataset is that performance is measured at the same time as innovation and R&D collaboration take place. The panel of profitability used in the estimation extends from 1993 to 1996 (observations from 1990-1992 are used as instruments), while innovation survey concerns the period 1994-96. Thus all performance implications of innovation may not have yet materialized by the end of 1996. My results may therefore be interpreted to say that firms with technical and accumulated competencies are *faster* to benefit from innovation activities.

This study sheds new light on the economic effects of collaborative innovation among firms. Theoretical work in the economics of research joint ventures has ignored the central role of learning within these arrangements. In particular, not all firms are equally capable of synthesizing knowledge from various sources. Empirical studies of the impact of collaborative innovation on firm performance are scarce and biased toward success stories. However, high failure rates of collaborative arrangements observed in the available studies suggest that it is difficult to benefit from collaboration (see Harrigan, 1988). My findings show that internal capabilities complement external collaboration strategies and thus may be prerequisites of successful collaboration, or alternatively, explanations for failure.

The results obtained here are in line with the view of the firm as a bundle of complementary capabilities and activities. Internal R&D alone is not sufficient for making profitable innovations or learning about external developments. Internal competencies and collaboration with other organizations complement firms' R&D activities. Viewing the firm as a bundle of discrete yet interdependent activities represents a new perspective from which to study the economics of firm structure and behavior. Consideration of complementarities in future research may help us to understand patterns of diversification, inter-firm collaboration, and intra-firm organization.

In terms of strategic management, implications of the study include the need to think carefully about which learning investments may be complementary. Managers should maintain coherence among competence investments, organization of R&D, and innovation strategy in order to leverage the interaction effects and realize the potential increasing returns to learning. Underinvestment in one aspect of the competence "portfolio" may jeopardize full realization of the returns to others. In particular, externally organized R&D may yield low returns in the absence of internal competencies. These findings also have relevance for technology policy. Subsidies for R&D or promotion of consortia may disappoint unless targeted firms possess the requisite complementary capabilities.

Appendix 5.1

Table A5.1 Correlations among the original variables, 1995, N=159

	SALES	EMPL	KINT	MS	PROF	PAT	RES-DUM	RES	TECH	TECH-DUM	RD-DUM	PROD 91	PROC 91	COL-LAB91	PROD 96	PROC 96	INNO 96	COL-LAB 96	IND KINT	IND PAT
SALES	1																			
EMPL	0.71	1																		
KINT	-0.01	0.04	1																	
MS	0.85	0.79	0.03	1																
PROF	-0.01	0.05	0.22	0.04	1															
PAT	0.52	0.46	-0.05	0.32	-0.06	1														
RESDUM	0.26	0.41	0.06	0.29	0.11	0.25	1													
RES	0.25	0.17	0.16	0.17	0.15	0.19	0.58	1												
TECH	0.18	0.16	-0.02	0.12	0.14	0.29	0.22	0.27	1											
TECHDUM	0.17	0.19	0.01	0.20	0.18	0.25	0.21	0.25	0.71	1										
RDDUM	0.12	0.18	0.07	0.13	0.09	0.11	0.13	0.11	0.23	0.19	1									
PROD91	0.17	0.24	0.05	0.16	0.05	0.15	0.16	0.14	0.27	0.15	0.54									
PROC91	0.17	0.23	0.12	0.16	0.21	0.15	0.17	0.17	0.22	0.20	0.50	0.34	1							
COLLAB91	0.19	0.28	0.17	0.20	0.21	0.18	0.30	0.24	0.31	0.33	0.51	0.51	0.38	1						
PROD96	0.22	0.29	0.08	0.23	0.22	0.20	0.34	0.19	0.35	0.39	0.30	0.35	0.23	0.34	1					
PROC96	0.20	0.28	0.20	0.24	0.20	0.20	0.25	0.11	0.09	0.16	0.29	0.17	0.30	0.23	0.52	1				
INNO96	0.17	0.25	0.10	0.20	0.23	0.15	0.26	0.11	0.25	0.29	0.35	0.30	0.33	0.30	0.77	0.82	1			
COLLAB96	0.18	0.26	0.17	0.20	0.13	0.20	0.28	0.13	0.29	0.37	0.32	0.31	0.28	0.32	0.67	0.64	0.76	1		
INDKINT	0.14	-0.03	0.31	0.10	0.13	-0.09	0.05	0.16	-0.08	-0.10	-0.07	-0.10	0.01	-0.03	-0.08	0.02	-0.05	-0.11	1	
INDPAT	0.15	0.12	-0.12	0.01	0.03	0.28	0.13	0.11	0.44	0.46	0.21	0.34	0.17	0.24	0.38	0.10	0.26	0.28	-0.22	1
CONC3	0.25	0.20	0.07	0.17	0.16	0.17	0.13	0.18	0.33	0.36	0.19	0.25	0.24	0.21	0.26	0.14	0.20	0.22	0.33	0.70

Table A5.2. Correlations among the differenced variables (N_max=159), 1993-96

	dPROF	dPROF(-1)	dEMPL	dKINT	dMS	dCONC3	dINDKINT	dINDPAT
dPROF	1							
dPROF(-1	-0.29	1						
dEMPL	0	-0.01	1					
dKINT	-0.16	0	-0.06	1				
dMS	0.09	0.05	0.1	-0.03	1			
dCONC3	0.03	-0.04	-0.01	-0.13	-0.06	1		
dINDKINT	-0.17	-0.03	0.01	0.21	-0.01	-0.27	1	
dINDPAT	-0.05	0.04	-0.01	-0.04	0.06	0.1	-0.04	1
TECHDUM	-0.07	0	0.05	0.06	-0.11	0.02	0.08	-0.06
COLLAB96	-0.04	0	0.05	-0.01	-0.12	0.02	0	0.03
INNO96	-0.04	0.01	0.02	-0.01	-0.13	0.03	0.01	0.04
RDDUM	-0.02	-0.01	0	0.04	-0.1	0.01	0.03	0.01

Notes: *d* indicates first-differenced variables.

Appendix 5.2

A5.2.1 Identification of complementarities

According to Arora (1996) there are two problems in identifying complementarities in a cross-sectional dataset. First, X_i and X_j may appear to be complements, even though they really are not, if they are each positively related to an omitted variable. Second, X_i and X_j may appear negatively associated, even though they are complements in reality, if there is another variable, which is a complement of X_i and a substitute of X_j. Since the data on innovation outcomes here are effectively cross-sectional too, the same problems may be an issue. In particular, since the innovation outcomes are measured as dummies, which may be correlated with the unobserved characteristics, it is possible that the interaction effects are biased upward. However, this is not really different from the usual problem of omitted variables.

The approach here with respect to Arora's observations is pragmatic. By instrumenting with the competence factors that correlate with innovativeness (technical and research skills, past innovation activities; see notes for Table 5.5), I attempt to control for the "technological capability" that would otherwise confound the decisions to invest in R&D, engage in R&D collaboration, and innovate.[34] The second point raised by Arora, namely, that two variables may appear substitutes even though they are complements in reality, if one is a complement and the other is a substitute with a third variable, is another case of omitted variable problem. One scenario where this would arise is when internal R&D activities are a substitute with external collaborative R&D, while they complement benefiting from innovation output. This is controlled for by using past investments in R&D (differenced) as an instrument for the level equation. Indeed, introducing this instrument strengthens the interaction coefficients, implying that the system might be characterized by both complementarities and substitutabilities.

Athey and Stern (1998) also discuss testing for organizational complementarities. They suggest controlling for the biases arising from unobserved heterogeneity by a system of equations approach. They propose a framework for estimating simultaneously the

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[34] The competence and other firm level variables used here provided a reasonable prediction of innovation outcomes in Chapter 4.

"adoption equations" – in this case the determination of competencies, innovation, and R&D collaboration – and the main equation of interest – here the profitability equation (1). However, there are not many practical alternatives for estimating the multivariate probability distributions related to the adoption equations. It is well known that these kinds of multivariate distributions of more than two dimensions are intractable with standard parametric techniques. Semiparametric and simulation methods have been developed for limited dependent variable systems, but they are left for future work here.

A5.2.2 Generalized Method of Moments for dynamic panel data

The two-step estimation procedure developed by Arellano and Bond (1991) is the following. The estimator

(5) $$\hat{\delta} = (\Delta X' Z A_N Z' \Delta X)^{-1} \Delta X' Z A_N Z' \Delta \Pi$$

is used with respect to equation (1) in two stages, first utilizing an initial weights matrix

(6) $$A_N = \left(N^{-1} \sum_{i=1}^{N} Z_i' H Z_i \right)^{-1}$$

with (T-2)×(T-2) matrix

(7) $$H = \begin{pmatrix} 2 & -1 & 0 & \dots & 0 \\ -1 & 2 & -1 & \dots & 0 \\ 0 & -1 & 2 & \dots & 0 \\ \dots & \dots & \dots & \dots & -1 \\ 0 & 0 & 0 & -1 & 2 \end{pmatrix}$$

which is then replaced in the second step by the estimate $u_i u_i'$:

(8) $$A_N = \left(N^{-1} \sum_{i=1}^{N} Z_i' \hat{u}_i \hat{u}_i' Z_i \right)^{-1}$$

where $\boldsymbol{u}_i'$ are residuals from the 1-step estimation. This estimator is asymptotically efficient in its class. However, it is well known that for finite samples this estimator deflates the standard errors, especially in the presence of heteroskedasticity, which is likely to be the case here (Blundell and Bond, 1998, Appendix A). Blundell and Bond recommend the one-step estimates as "empirically right," even though the estimator is inefficient.

Appendix 5.3

Table A5.3 Baseline regressions with industry dummies (1993-96, N_max=159, T=4, N*T=622)

	System 1-step	
	Coeff.	t-stat
CONST	3.60	0.82
$PROF_{-1}$	0.24**	3.73
EMPL	-0.002**	-2.13
KINT	0.02	0.58
MS	0.51	0.06
TECHDUM	6.38*	1.67
COLLAB96	1.61	0.44
INNO96	8.17*	1.85
RDDUM	-6.48	-1.28
I2	2.21	0.73
I3	-3.22	-1.22
I4	6.79	1.53
I5	1.67	0.68
I6	-2.17	-0.49
I7	-0.84	-0.29
I8	-2.58	-0.60
I9	1.27	0.35
I10	1.14	0.30
I11	-3.96	-1.30
I12	-6.22*	-1.81
I13	0.47	0.11
I14	2.15	0.88
1^{st} order serial correlation (p)	-5.22	0.00
2^{nd} order serial correlation (p)	-0.83	0.40
Sargan test (p) d.f. 101	114.61	0.17

6 MAIN RESULTS AND POLICY IMPLICATIONS

The theoretical analyses in this dissertation focus on the incentives to invest in learning and cooperation in an incomplete contracting environment subject to transaction costs. The first essay in Chapter 2 examines the dynamic costs of external organization of innovation. These costs have largely been ignored both in the theoretical literature on research joint ventures and economic agency. The "make-or-buy" decision must be evaluated in a broader and more dynamic context. If knowledge is cumulative and does not transfer well across organizational boundaries, contract R&D has a cost to the firm of under-exploited complementarities among knowledge assets.

It follows that external innovation arrangements are likely to be more attractive to firms in turbulent technological environments, where the cumulativeness of knowledge is low. Under these conditions the advantages to internal organization are diminished. Policy measures could then be targeted to support long-term collaboration among organizations in order to foster knowledge sharing (cf. the results of the second essay), for instance by favoring collaborating firms with complementary capabilities in public R&D funding. In contrast, policy measures such as tight labor market regulation increase the costs of internal organization and can under conditions of higher cumulativeness of knowledge constrain firms' internal learning and knowledge sharing. Policy makers thus need to understand the technological regime in question.

The second essay (Chapter 3) examines the incentives to invest in communication and cooperation in a collaborative innovation arrangement. The repeated incomplete contracting framework assumes identical incentive structures for long-term relational contracts and long-term employment relationships. However, the sustainability of the two forms may differ because of the different fallback options. In case the "relational contract" unravels, short-tem market transactions will take place, while if a "firm" contract dissolves, spot employment will follow. Both fallback options are socially suboptimal, but depending on the revenue functions and the strength of knowledge spillovers, they may yield higher expected returns to the partners. Fallback options determine the long-run sustainability of "firms" and "relational contracts."

The proposed model shows that a "firm" is relatively less sustainable than "relational contract" in the case of high knowledge spillovers, contrary to what has been argued in the extant literature. This stems specifically from the effects of spillovers on the investment incentives in the fallback options. The analysis illustrates that empirical and theoretical study of organizational choices should pay more attention to the fallback and outside options related to different alternatives. These strategic factors may be critical drivers of the choice of organizational form, in addition to the incentive structure *per se*.

Theoretical essays here provide some preliminary results on the interplay of technologies and institutions. Technological regimes indirectly impact the organizational choices, which then feed to the productivity of innovation activities and eventually the firm's performance over time. On the other hand, institutional environment may have direct effects on organization choices through costs of contracting, and indirect effects on incentives to invest in learning and innovation. The studies reported here suggest that technology policy makers should be aware of these interactions. For instance, the results in Chapter 2 imply that competition policies may need to account for the technological conditions in industries – collaborative innovation arrangements may be socially more desirable in some learning environments than in others. The analysis in Chapter 3 suggests that strong intellectual property rights may reduce socially beneficial cooperation and knowledge exchange, because they support short-term market transactions instead of long-term relationships.

The empirical chapters in the thesis focus on the importance of absorptive capacity in collaborative innovation. The essays provide evidence of the role of competencies and accumulated "dynamic capabilities" in benefiting from collaborative arrangements. Chapter 4 shows that it is important for researchers of innovation to have information about the firms' collaboration partners to understand the logic and requirements of the collaborative arrangement. It turns out that collaboration with competitors is the least prevalent choice of partners, despite the relatively large number of studies in industrial economics devoted to the analysis of research joint ventures among rivals (see e.g. Veugelers, 1999, for a survey). "Vertical" collaboration with equipment suppliers and customers are more commonly observed. Even collaboration with universities is more common in Finnish manufacturing than that with competitors.

The results indicate that innovation collaboration requires high internal skills and competencies. Particularly collaboration with universities is associated with high research and technical skills. Contract R&D also requires research competencies, perhaps to be capable of monitoring the external R&D activities. Absorptive capacity can thus be built both by investing in internal R&D and by employing highly qualified researchers and engineers. Chapter 4 also shows that firms' organizational choices related to R&D indeed vary with the technological regime, as proposed in the first chapter. Environments characterized by abundant innovation opportunities support external organization of innovation, while firms in regimes of low appropriability or high supplier domination tend to externalize innovation less frequently.

The longitudinal analysis of chapter 5 suggests that innovation and R&D collaboration alone are not necessarily associated with better economic performance. They require internal competencies to be beneficial. Based on the econometric estimations, technical competencies are important in profiting from product and process innovation, while firms that benefit the most from collaborative arrangements have both technical competencies and a history of successful collaboration. Capabilities to collaborate are accumulated over a long period of time, and they may be complementary with other innovation activities.

Not all "networking" and collaboration is necessarily productive. Firms with high competence levels and experience in innovation and collaboration activities benefit the most from these arrangements. R&D collaboration should therefore not be imposed by public policy on firms that are not capable or willing to invest best effort and resources into the activity. Additionally, R&D subsidies will yield less than best results in cases where firms do not possess sufficient complementary skills and capabilities. Innovation policies focused on R&D subsidies and collaborative R&D programs as instruments of development should account for the competence requirements of firms and learning dynamics within the technological regime in question. Such targeted policy measures could support accumulation of missing complementary capabilities by participants and exploitation of knowledge complementarities.

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