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Keskusteluaiheita – Discussion papers

No. 703

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COMPETENCIES AND FIRM PERFORMANCE - INCREASING RETURNS FROM KNOWLEDGE COMPLEMENTARITIES ?

I'm grateful to discussions with Ari Hyytinen, José M. Labeaga, Emmanuel Duguet, Petri Rouvinen, and Eve Caroli. The paper also benefited from the comments of the participants in the European Meeting on Applied Evolutionary Economics in Grenoble, June 1999, especially Edward Lorenz, and the Helsinki School of Economics workshop "Firms in Global Competition," in Tuusula, October 1999, particularly Connie Helfat. Remaining errors are mine alone. The Technology Development Center of Finland (TEKES) provided financial support and Statistics Finland compiled the data.

ISSN 0781-6847 28.01.2000

LEIPONEN, Aija, **COMPETENCIES AND FIRM PERFORMANCE – INCREASING RETURNS FROM KNOWLEDGE COMPLEMENTARITIES?** Helsinki: ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 2000. 28 p. (Keskusteluaiheita, Discussion Papers, ISSN 0781-6847; No. 703).

ABSTRACT: This paper investigates the relationships between competencies, organization of R&D, and innovation in determining firms' profitability. It is hypothesized that innovation activities are complementary with competencies, proxied here by the levels and fields of education of the employees and by past innovation performance. Without sufficient internal capabilities, firms are expected to benefit less from investment in innovation activities. This may be one reason for the persistent differences in behavior and performance among firms. Complementarities based on "sticky" organizational knowledge can be a source of increasing returns to firms that possess the requisite capabilities, but for firms that do not, investments toward learning and innovation may not be a profitable option.

These ideas are tested with a panel dataset of 165 Finnish manufacturing firms over the period of 1990-96. The estimation results suggest that the profitability effects of both product and process innovation, and collaborative innovation arrangements depend on internal capabilities. Patenting is important for realizing the economic benefits from collaborative R&D with competitors.

KEY WORDS: Competencies, profitability, complementarities

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TIIVISTELMÄ: Tässä raportissa tutkitaan yritysten osaamisen, T&K-toiminnan organisoinnin ja innovaatioiden vaikutuksia kannattavuuteen. Hypoteesinä on, että osaaminen ja innovaatiotoiminnan investoinnit täydentävät toisiaan. Osaamista mitataan henkilöstön koulutusaloilla ja –tasoilla sekä aiemmalla innovaatiomenestyksellä. Osaamisen ja investointien komplementaarisuus saattaa selittää yritysten välisiä varsin pysyviä kannattavuuseroja. Organisaation osaamiseen liittyvät komplementaarisuudet voivat synnyttää kasvavia tuottoja ja hyviä tai huonoja kierteitä. Osaamista omaavien yritysten kannattaa investoida erilaisiin innovaatiotoimintoihin, jotka synnyttävät lisää osaamista. Yritysten, joissa osaamista on vähän, ei kannata investoida.

Näitä ajatuksia testataan 165 suomalaisen teollisuusyrityksen paneeliaineistolla. Estimointitulosten mukaan tuote- ja prosessi-innovaatioiden samoin kuin innovaatio-yhteistyön vaikutukset kannattavuuteen riippuvat yritykseen kertyneestä osaamisesta. Kilpailijoiden kanssa tehtävää yhteistyötä täydentää oman teknologian patentoiminen.

ASIASANAT: Osaaminen, kannattavuus, komplementaarisuudet

Yhteenveto

Lisääkö kaikki innovaatiotoiminta yritysten taloudellista menestymistä? Vaikka tutkimus- ja kehitystoiminnan (T&K) vaikutukset kansantalouden tuottavuuskehitykseen ovat kiistattoman positiivisia, ei yksittäisten yritysten tasolla ole itsestään selvää, että T&K ja sen tuloksena syntyneet innovaatiot aina parantavat yrityksen taloudellista menestymistä. Yhden toimialan sisältä voidaan löytää yrityksiä, jotka saavat toistuvasti innovaatiotoiminnan investoinneistaan suuremman taloudellisen hyödyn kuin kilpailijansa. Mikä tähän voi olla syynä?

Tässä tutkimuksessa ehdotetaan, että yritysten pitkän aikavälin kannattavuuserojen taustalla ovat tietoon ja osaamiseen liittyvät täydentävyydet eli komplementaarisuudet. Yrityksen oma T&K, innovaatioyhteistyö ja ulkoistettu T&K voivat olla kannattavampia investointeja yrityksille, joilla on korkea sisäinen osaamisvaranto niin tutkimuksessa ja teknisessä osaamisessa kuin hallinnossa ja markkinoinnissa. Tämä saattaa olla syynä siihen, että erilaiset innovaatiotoiminnot kasautuvat yrityksiin: Sama yritys investoi T&K-toimintaan sekä yrityksen sisällä, yhteistyössä useiden erilaisten partnerien kanssa että ostaa sitä ulkopuolelta. Tuloksena syntyy tuote- ja prosessi-innovaatioita. Monenlaista innovaatiotoimintaa harrastavissa yrityksissä henkilöstön koulutustaso on yleensä selvästi keskimääräistä korkeampi, niillä on pitkä innovaatiohistoria ja ne ovat kannattavampia. Liittyvätkö nämä asiat jotenkin toisiinsa myös tilastollisessa tarkastelussa?

Tutkimuksessa tarkastellaan innovaatiotoiminnan erilaisten investointien ja yrityksen osaamispääoman vuorovaikutusta yrityksen kannattavuuden määräytymisessä. Hypoteeseinä on, että yritys hyötyy taloudellisesti innovaatioista enemmän, jos sillä on korkea osaamistaso, ja että innovaatioyhteistyö vaikuttaa enemmän kannattavuuteen korkean osaamistason yrityksissä. Osaamista mitataan paitsi henkilöstön koulutustasoilla ja –aloilla, myös yrityksen innovaatiohistorialla. Jos yritys on innovoinut menestyksekkäästi aiemmin, on sille kertynyt ns. dynaamista osaamista. Näitä ajatuksia testataan suomalaisen teollisuusyritysaineiston avulla. Paneeliaineistossa on 165 yritystä vuosilta 1990-1996. Kaikki pääteollisuustoimialat ovat edustettuina.

Estimointitulokset osoittavat ensinnäkin, että innovaatioiden vaikutukset kannattavuuteen voimistuvat yrityksen osaamispääoman noustessa. Toiseksi, T&K-yhteistyön kannattavuusvaikutukset vahvistuvat erityisesti kertyneen "innovaatio-osaamisen" myötä. Yhteistyöstä hyötyvät taloudellisesti eniten siis kokeneet innovoijat. Kolmanneksi, patentointi lisää kilpailijoiden kanssa tehtävän innovaatioyhteistyön positiivisia vaikutuksia. Ilman keinoa suojautua tietovuotoja vastaan yrityksen kilpailukyky saattaa heiketä kilpailijoiden yhteistyön aikana omaksuman osaamisen vuoksi.

Tutkimustulosten mukaan yrityksen osaamisvarantojen, T&K-toiminnan ja sen organisoinnin sekä innovoinnin välillä on merkittäviä vuorovaikutuksia, jotka vahvistavat yrityksen taloudellista menestymistä. Tulokset viittaavat siihen, että innovaatioinvestoinneista päätettäessä yrityksen tulee ottaa samanaikaisesti huomioon T&K-toiminnan osaamisedellytykset sekä organisointitapa. Muuten näiden tekijöiden väliset komplementaarisuudet saattavat jäädä hyödyntämättä.

Yritysjohdon strateginen päätöksenteko on siis tehokkaampaa jos innovaatiotoimintaan liittyvien tekijöiden väliset vuorovaikutukset otetaan huomioon. Teknologiapolitiikan kannalta tulokset merkitsevät, että innovaatiotoiminnan tai siihen liittyvän yhteistyön tukeminen on tehotonta yrityksissä, joissa ei ole riittävästi omaa osaamista hyödyntää innovaatioita täysimääräisesti kaupallisesti.

1 Introduction

Innovation is the phenomenon behind productivity growth that drives 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 economic returns to product and process innovations are always positive. Casual observation of Finnish manufacturing firms suggests that a considerable number of technological innovations do not meet the "market test." Teece (1986) documented this phenomenon with case studies on 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 (see e.g. Chandler, 1990), but until recently in the literature on economic theory of the firm, organizational complementarities have not been a focus of inquiry. Studies of technological change and innovation at the level of the firm have examined interactions among activities within the firm (Kline and Rosenberg, 1986) and the firm's relationship with external sources of knowledge (e.g. Levin, Cohen et al., 1985). Essentially, refinement of patterns of interaction and the search to understand the nature of associated organizational tradeoffs stem from the need to combine different kinds of knowledge in the innovation process. Thus, complementary knowledge sources are identified as the basis of organizational complementarities.

Recent studies on innovation and firm capabilities have provided evidence that accumulation of capabilities and knowledge may be a source of considerable variation in firms' performance (e.g., Henderson and Cockburn, 1994, Miyazaki, 1994). According to Geroski *et al.* (1993), a firm's innovation record affects its profitability. These authors argue that innovation performance approximates the underlying knowledge capital, and this capital enables firms to continuously bring new products to market and improve productivity through process innovation. However, the fundamental factors behind knowledge accumulation remain unknown. And further, if possessing knowledge capital translates directly 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.

Of course in real economies firms do perform and behave differently. In this study I propose that one of the reasons as to why firms' learning investments impact profitability differently are their combinatory characteristics. The "portfolio" of investments and knowledge may have an effect on the marginal productivity of each of the components. If the various components of a firm's knowledge capital and learning investments complement one another, then they are more productive in the presence of the other components. Synergy and 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, and hence virtuous cycles are possible. In contrast, knowledge-poor firms are not likely to recognize productive learning investment opportunities because of the missing complementary components.

What are then the potential components of the competence building system? These are likely to vary across sectors, but within manufacturing, likely candidates include research and product development (R&D) activities; skills, training and accumulated experience of the employees; technology and knowledge acquisitions; cooperative arrangements with other organizations; and internal organizational design including compensation and promotion schemes.

This paper seeks to assess the scope of positive interactions among investments in competencies, organization, and innovation. The question posed is, how do investments in various types of competencies and knowledge affect the firm's profitability in the long run, and are there significant (positive or negative) interactions between these investments? In an earlier study, skills and competencies of the employees were found to have an impact on profits (Leiponen, 1999). Most interestingly, skills were observed to interact with one another. The positive effect of research skills on profits was conditioned by a high enough 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 on profitability of R&D collaboration and innovation, and 2) how competence investments complement these strategies.

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. 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 capability investments 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*.

Theoretical and empirical evidence suggest that organizational complementarities can be a source of increasing returns (see e.g., Athey and Schmutzler, 1995; Ichniowski, Shaw et al., 1997). As mentioned earlier, Teece (1986) argued that complementarities among a firm's capabilities are important determinants of profitability of innovation. More specifically, successful innovation may not always mean high returns from innovation. In order to profit from new products and technologies, the firm needs to have access to the requisite capabilities to realize and leverage the positive effects of innovation. Inspired by this idea, the existence of complementarities is explored here. I focus on the interactions among R&D collaboration with various types of partners, competence investments, and innovation in determining the profitability of Finnish manufacturing firms over a period of 7 years (1990-96). The basic proposition is that to benefit from investments aimed toward product and process innovation (internal, collaborative, and outsourced R&D) the firm needs sufficient internal competencies (see hypothesis 1 below). While available proxies of organizational knowledge accumulation – measures of educational levels and fields of the employees and the past innovation outputs – can be criticized, I argue that they are sufficiently correlated with the unobservable variable of interest.

H1: Innovation is complementary with internal competencies in their effects on profitability.

The second hypothesis concerns the profitability of R&D collaboration. Extant 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, Richards et al., 1996, among others). In contrast, the reasons for *not* collaborating – analysis of costs rather than benefits – have not been sufficiently examined. In thinking about this question, Pisano et al. (1988) suggest that collaborative ventures may be a strategy to minimize transaction costs. Appropriability hazards are then weighed against the benefits of sharing knowledge and risks of R&D. If the risk of spillover of strategic knowledge is high, the firm may choose not to engage in cooperation.

Here I propose another explanation for why some firms are able to benefit more from external R&D (collaborative or contract R&D) than others, and therefore are more likely to outsource innovation activities: the realized benefits depend on the existence and scope of complementary internal knowledge assets. Without sufficient internal capabilities, the firm will not be able to internalize and utilize effectively the new knowledge created through collaboration (hypothesis 2).

H2: The profitability effects of collaborative R&D interact positively with internal competencies, i.e., collaborative R&D is complementary with internal competencies.

Firms can collaborate with different kinds of partners to innovate. Von Hippel (1988) and others have examined the locus of innovation and noted that cooperation and communication between users and suppliers of technology are vital for successful innovation. Collaboration with universities is another important type of research cooperation, enabling firms to access new knowledge from institutions engaged in basic research. Finally, firms can collaborate horizontally with rival firms, even though there is evidence to suggest that firms are more likely to collaborate with customers, suppliers and universities than competitors (Cassiman and Veugelers, 1998; Leiponen, 2000).

3 Data

The analysis makes use of the two Finnish innovation surveys available (1991 and 1996), business and employment surveys for each of the years 1990 through 1996, and a complete record of domestic patent applications for the same period. The innovation survey datasets contain information about product and process innovations, R&D, and innovation collaboration during the periods 1989-1991 (first survey) and 1994-96 (second survey).

Table 1. Industries

Industry	SIC	N
Food	15-16	22
Textile	17-19	14
Wood	20	11
Paper	21	6
Printing, publishing	22	25
Oil, Chemical	23-24	10
Plastic, Rubber	25	8
Nonmetallic minerals	26	5
Primary metals	27	6
Metal products	28	4
Machines, equipment	29	26
Electronics	30-33	17
Cars, vehicles	34-35	3
Furniture	36	8
Total		165

A panel dataset of 165 manufacturing firms over the period 1990-1996 is used in the econometric analysis. The sample is constructed such that to be included, firms must have participated in both innovation surveys and all or all but one of the annual business and employment surveys for the period 1990-1996. This construction naturally creates some survivor bias. There is also the potential for a bias toward larger firms because large firms are slightly over-represented in the innovation surveys and larger firms are more likely to survive over the seven-year period. All manufacturing industries are included (see table 1 above for industry breakdown). Variables are listed and described in Table 2. Descriptive statistics are provided in table 3.

An average firm in the dataset had 495 employees in 1996 (table 3). Firms applied for 1.3 patents on average in 1996. In fact, there were only 33 firms that applied, but the average for these was 6.5 patents. This is a good example of the highly skewed distribution of patenting. 7.1 percent of the employees in an average firm have a higher "technical" degree and 0.2 percent have a "research" degree (post-graduate). 53% of firms indicate positive R&D expenditures in 1996.[1]

[1] 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 2. Variables (data available for 1990-1996 unless otherwise indicated)

Dependent Variable	PROF	Operating profit/sales
INNOVATION ACTIVITIES	PROD96	Dummy for successful product innovation (sales revenue from the commercialized new product >0) (1996)
	PROC96	Dummy for process innovation (survey question about whether the firm process innovated or not) (1996)
	OUTRD96	Dummy for R&D outsourcing (1996)
	RDINV	Internal Research and Development investments/sales
	RDDUM	Dummy for R&D investment > 0
	COLLAB91	Dummy for R&D collaboration (1991)
	OUTRD91	Dummy for R&D outsourcing (1991)
	COL_com	Dummy for R&D collaboration with competitors (1996)
	COL_cus	Dummy for R&D collaboration with customers (1996)
	COL_con	Dummy for R&D collaboration with consulting firms (1996)
	COL_sup	Dummy for R&D collaboration with suppliers (1996)
	COL_uni	Dummy for R&D collaboration with universities (1996)
	COL_res	Dummy for R&D collaboration with (non-profit) research institutes (1996)
COMPETENCIES	TECHNIC	Share of employees with a higher technical or natural scientific degree (e.g., university engineer, master of science in chemistry)
	RES	Share of employees with a post-graduate degree (doctoral or licentiate)
	RESDUM	Dummy for RES > 0
	PAT	Number of domestic patent applications
	PATDUM	Dummy for PAT > 0
	PROD91	Product innovation dummy: proxy for dynamic capability (1991)
	PROC91	Process innovation dummy: proxy for dynamic capability (1991)
FIRM	EMPL	Number of employees
	KINT	Capital intensity (fixed capital/sales)
	MS	Domestic market share in the 2-digit industry
Industry level control variables	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 for the patenting firms

According to the 1991 innovation survey data, 62 percent of firms introduced new products in the markets (with positive sales revenue), and 60 percent adopted new processes. Fifty five percent of firms engaged in collaborative R&D. The 1996 innovation questionnaire was updated to emphasize technological innovation, and partly for this reason the share of innovating firms has dropped to 38 percent. Another reason for the drop in innovation output may be an overall decrease in R&D spending during these recession years. However, there is consistency across the observations as firms innovating in 1989-91 were more likely to innovate in 1994-96 (Lehtoranta, 1998).

Table 3. Descriptive Statistics (N=163, Year=1996)

	Mean	Std. Dev.	Minimum	Maximum	Mean for the Innovation Survey sample (1996, N=1032)
SALES (Mmk)	663.5	2383.5	10.4	25677.7	232.8
EMPL	494.6	889.6	29	6615	183.8
KINT (%)	15.9	15.6	0.3	129.0	14.7
MS (%)	0.65	2.76	0.01	28.0	n.a.
PROF (%)	7.1	7.5	-16.7	28.2	6.5 (N=803)
PAT	1.32	7.20	0	84	0.62
PAT > 0 (N=33)	6.52	15.08	1	81	7.1 (N=90)
RES (%)	0.2	0.5	0	3.5	0.2
TECHNIC (%)	7.1	7.8	0	50.0	7.3
RDDUM	0.53	0.50	0	1	0.39
RDINV > 0 (N=88) (%)	1.81	2.21	0.001	13.0	2.42 (N=403)
PROD91	0.62	0.49	0	1	n.a.
PROC91	0.60	0.49	0	1	n.a.
COLLAB91	0.55	0.50	0	1	n.a.
OUTRD91	0.55	0.50	0	1	n.a.
PROD96	0.36	0.48	0	1	0.26
PROC96	0.39	0.49	0	1	0.26
COL_com	0.16	0.37	0	1	0.08
COL_cus	0.33	0.47	0	1	0.22
COL_con	0.17	0.38	0	1	0.12
COL_sup	0.33	0.47	0	1	0.22
COL_uni	0.34	0.48	0	1	0.21
COL_res	0.29	0.46	0	1	0.17
OUTRD96	0.45	0.50	0	1	0.28
INDKINT (%)	14.8	5.1	9.8	31.9	14.35
INDPAT	3.3	2.9	1.0	11.0	3.53
CONC3 (%)	28.6	12.1	8.2	53.3	n.a.

Notes: n.a. = not available. Two firms had a missing observation for 1996.

In the 1996 innovation survey, R&D collaboration was studied in greater detail and firms were asked about their collaboration partners. About one third of the firms in the sample collaborated with customers, suppliers or universities, but only 16% collaborated with competitors.

In comparison to the more or less representative innovation survey sample of 1996 (N=1032 unless otherwise indicated), as expected, the panel sample is 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 early 1990s. Also, firms in the panel sample are more likely to engage in R&D, but surprisingly, those that do R&D, invest less on average than firms in the larger sample.

Correlations between the first-differenced variables are displayed in Table 4. Most of the correlations are quite low. Capital intensity and profitability tend to move in somewhat opposite directions. Market share growth is negatively associated with most innovation activities. Research and technical skills correlate positively. For correlations among the original variables, see table A1 in the appendix.

Table 4. Correlations of the differenced variables (N=165), 1993-96 (T=4)

	dPROF	$dPROF_{-1}$	dEMPL	dKINT	DMS	dCONC3	dINDKINT	dINDPAT	$dPAT_{-2}$	$dRES_{-2}$
dPROF(-1)	-0.29	1								
dEMPL	0	-0.01	1							
dKINT	-0.16	0.01	-0.06	1						
dMS	0.1	0.05	0.1	-0.03	1					
dCONC3	0.02	-0.04	-0.01	-0.12	-0.06	1				
dINDKINT	-0.17	-0.03	0.01	0.21	-0.01	-0.28	1			
dINDPAT	-0.06	0.04	-0.01	-0.04	0.06	0.11	-0.05	1		
$dPAT_{-2}$	0.03	-0.02	-0.16	0.01	0.31	0.03	0.03	0.08	1	
$dRES_{-2}$	0.05	-0.01	0.04	-0.01	-0.01	-0.12	0.12	-0.07	-0.01	1
$dTECHNIC_{-2}$	-0.01	-0.04	0.05	-0.03	-0.01	0.01	0.06	0.07	-0.08	0.35

Notes: *d* indicates first-differenced variables. PAT, RES, and TECHNIC are lagged two periods.

To look at relationships among the categorical innovation variables and between the categorical and continuous variables, Table 5 provides means for different kinds of innovators and non-innovators. The table indicates that among firms reporting product innovation in 1996 (N=59), 73% also made process innovations. Of these, 71% collaborated with universities, 69% with suppliers, and 68% with customers. 83% of firms making product innovations in 1996 had also innovated in 1991, but only 49% of firms reporting product innovation in 1991 did so in 1996. This discrepancy arises from the change in the survey instrument. Among process innovators, the share of firms engaging in collaborative innovation and competence investments is slightly lower, but a similar clustering effect is still clear. The share of process innovators engaging in different kinds of collaborative arrangements is about double that for all firms.

Table 5. Innovator profiles (N=164)

	PROD96	PROC96	COL_ com	COL_ cus	COL_ con	COL_ sup	COL_ uni	COL_ res	RES-DUM	PAT-DUM	PROD91	PROC91	COLLAB 91	RDDUM	All firms
PROD96	1	0.67	0.77	0.73	0.75	0.76	0.74	0.79	0.60	0.69	0.49	0.45	0.51	0.43	0.36
PROC96	0.73	1	0.73	0.69	0.82	0.74	0.72	0.73	0.57	0.77	0.46	0.51	0.49	0.46	0.39
SALES (1995, Mmk)	1356	1267	2170	1288	2135	1459	1415	1531	1568	2104	963	980	1055	789	646
COL_com	0.34	0.30	1	0.42	0.54	0.37	0.39	0.40	0.28	0.40	0.24	0.22	0.22	0.20	0.16
COL_cus	0.68	0.59	0.88	1	0.86	0.72	0.79	0.77	0.53	0.63	0.41	0.44	0.46	0.40	0.34
COL_con	0.36	0.36	0.58	0.44	1	0.44	0.46	0.46	0.26	0.43	0.21	0.24	0.23	0.21	0.17
COL_sup	0.69	0.63	0.77	0.71	0.86	1	0.72	0.77	0.51	0.54	0.44	0.44	0.47	0.40	0.33
COL_uni	0.71	0.64	0.85	0.82	0.93	0.76	1	0.88	0.57	0.74	0.47	0.44	0.49	0.42	0.35
COL_res	0.64	0.55	0.73	0.67	0.79	0.69	0.74	1	0.43	0.54	0.41	0.40	0.45	0.37	0.29
RESDUM	0.54	0.47	0.58	0.51	0.50	0.50	0.53	0.48	1	0.57	0.38	0.39	0.45	0.35	0.32
TECHNIC	0.10	0.08	0.09	0.10	0.08	0.09	0.10	0.10	0.09	0.10	0.08	0.08	0.09	0.08	0.07
PATDUM	0.41	0.42	0.54	0.40	0.54	0.35	0.46	0.40	0.38	1	0.29	0.26	0.31	0.25	0.21
PROD91	0.83	0.72	0.92	0.75	0.75	0.81	0.82	0.85	0.72	0.83	1	0.76	0.84	0.75	0.61
PROC91	0.75	0.78	0.85	0.78	0.86	0.80	0.75	0.81	0.72	0.71	0.74	1	0.77	0.72	0.60
COLLAB91	0.78	0.70	0.77	0.76	0.75	0.80	0.79	0.85	0.77	0.80	0.76	0.71	1	0.68	0.55
RD DUM	0.95	0.94	1.00	0.95	0.96	0.96	0.95	1	0.87	0.94	0.97	0.96	0.98	1	0.79
Cases	59	64	26	55	28	54	57	48	53	35	100	98	91	130	164

Note: Each column presents mean statistics for firms, for which the respective innovation indicator is equal to 1.

Collaborations with different types of partners appear to form a kind of a hierarchy. Collaborations with customers, suppliers and universities are most prevalent, and those with competitors and consulting firms are least common. Interestingly, among firms collaborating with competitors, almost 90% also collaborate with customers and universities, and among firms collaborating with consulting firms, about 90% also collaborate with customers, suppliers or universities. It seems that collaborations with suppliers and customers are the "easiest," or require the least internal capabilities from the firm, while benefiting from joint R&D with competitors is the most difficult. Additionally, the average firm size increases when moving from collaboration with customers to collaboration with suppliers, universities, or research institutes and increases again for firms collaborating with competitors or consulting firms. The average sales turnover of firms engaged in collaboration with competitors is more than three times that of all firms.

Surprisingly, having RES-qualified employees is not so clearly associated with other innovation activities. RES-employees are likely to be found in larger firms. Patenting is also associated with size. In addition, there are clearly more patenting firms among those collaborating with competitors or consulting firms.

The period of study coincides with an economic recession and subsequent recovery in Finland. This turbulence in the environment is reflected in firm behavior and performance. Several outliers were removed from the data due to drastic changes in firm size, performance, or other variables. Still, the remaining data can hardly be 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 additional noise in the data.

4 Econometric model

The estimation method is GMM for panel data to account for the potential heterogeneity and simultaneous or predetermined variables (see Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998). The empirical model is the following:

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

Π_{it} denotes profits for firm i in period t, $\boldsymbol{X^E}_{it}$ are the strictly exogenous, time varying industry level control variables, $\boldsymbol{X^P}_{it}$ are 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. $\boldsymbol{Y_i}$ is a vector of the interactions of the X^P's to test for the presence of complementarities. Positive cross-partial derivatives of the relevant X_i's imply complementarity. This is equivalent to the γ parameters being positive (for discussion on the identification of complementarities, please see Appendix 2).

To control for fixed effects, with which the *X*'s may correlate, the model is estimated in first differences:

$$\Delta\Pi_{it} = \alpha'\Delta\Pi_{it-1} + \beta_E'\Delta X_{it}^E + \beta_P'\Delta X_{it}^P + \gamma'\Delta Y_{it} + \Delta\varepsilon_{it} + \Delta\delta_t \qquad (2)$$

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 among the explanatory variables may still remain. To correct for this, values of the explanatory variables lagged 2 periods or more are expected to be valid instruments, because the model is dynamic (AR1). The orthogonality conditions are

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

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

Or equivalently: E($\boldsymbol{Z_i'u_i}$) = 0, where $\boldsymbol{Z_i}$ is the (T-2) × *m* matrix of instruments (*m* being the number of orthogonality conditions available):

(4)

Second-order serial uncorrelation of the error terms is required for the consistency of this model. The Sargan test statistic of the overidentifying restrictions (stacked instrumental variables) is also reported with the results.

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \dots & \Pi_1 \dots \Pi_{T-2}\, X_1^P \dots X_{T-1}^P : \Delta X_T^{E}{}' \end{pmatrix}$$

Arellano and Bover (1995) argued that the first-differenced estimation loses information that could be particularly useful with short panels. They propose a system method that estimates the level equations together with the differenced equations using instruments in first differences for the levels equations and instruments in levels for the differenced equations. This increases precision in their simulations. This system estimator (SYS) is discussed also by Blundell and Bond, who find that the SYS-estimator can alleviate the problem of weak instruments in case α is close to one. The additional moment conditions are:

$$E(u_{it}\Delta y_{i,t-1}) = 0 \qquad \text{for } t = 3,4,\ldots,T \qquad (9)$$

The validity of these moment restrictions depends on certain stationarity assumptions concerning the data. The requirement is that

$$E(u_{i1}\mu_i) = E(u_{i1}v_{i3}) = 0 \qquad \text{for } i = 1,\ldots,N \qquad (10)$$

Basically, the condition is satisfied if the level of the fixed effect is not correlated with its deviation from the initial conditions. For example, this is true if the deviations from "equilibrium" in the initial period are randomly distributed across agents. In the data at hand, however, it is possible that this is not the case – shocks may have been industry-specific. In the estimation section we will examine the performance of the extra moment conditions. However, the system estimator preserves information from the levels equations, which enables the identification of time-invariant effects. This is essential in this study with respect to the innovation variables, and makes the system estimator the most preferred one here. For more information about the estimator, see Appendix 2.

5 Estimation results

The objective of the econometric analysis is to see whether complementarities exist among competencies, R&D, and the organization of R&D (external or internal governance). The results for the model without interaction effects are shown in Tables 7-9 to provide a base case. For comparison, the model is estimated both with the standard fixed effects method, 3-stage least squares (3SLS; instrumental variable method for simultaneous equations), first differenced GMM (one-step), and the system GMM (one-step and two-step, see Appendix 2.1). The first specification (Table 7) only includes the standard economic variables: lagged dependent variable, size proxied by number of employees, capital intensity, market share, 3-firm concentration ratio, capital intensity in the industry, and patenting intensity in the industry. Competence variables are lagged by two periods, because of the assumed lags in their effects on economic performance.

The different estimation methods yield results that are sometimes orthogonal. Fixed effects and 3SLS are not consistent for the dynamic model estimated here, and this is probably the reason for unexpected results on firm level control variables, especially capital intensity and lagged dependent variable. These methods do not seem to identify the dynamic structure and predetermined firm-level variables correctly. Instead, the exogenous industry-level variables are estimated more consistently across methods.

The different estimators agree on the positive impact of research competencies (RES, Tables 8-9), and patent applications (PAT). Instead, the results on technical competencies (TECHNIC, see Table 8) and dummy for R&D firms (RDDUM; Table 9) are mixed. Blundell and Bond's results (1998) suggested that the system estimator improves efficiency and precision, implied here by the larger and more significant coefficient on the lagged dependent variable ($PROF_{-1}$). Therefore, it seems reasonable to base the discussion that follows on the system estimator despite the possibility that the nonstationarities of the data create problems with consistency. Two-step Sargan and second-order serial correlation tests do not indicate problems with the instrumentation or specification in general.

Table 7. Baseline regressions 1: firm- and industry-level control variables (N_max=165, T=4, N*T=640)

	Fixed Effects		3SLS		DIF 1-step		SYS 1-step		SYS 2-step	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
CONST	**-1.79**	-3.71	-0.35	-0.67	1.04	1.70	**5.89**	3.62	**5.75**	17.40
PROF$_{-1}$	0.08	1.91	**-0.33**	-4.75	**0.18**	2.70	**0.37**	6.86	**0.38**	37.47
EMPL	**-0.002**	-2.62	0.00	-1.04	**-0.004**	-2.85	-0.001	-1.59	**-0.001**	-14.88
KINT	-0.06	-1.53	**-0.16**	-3.12	**-0.11**	-2.73	**0.06**	2.05	**0.06**	13.22
MS	**15.35**	2.24	18.71	1.89	14.40	1.94	13.93	1.58	**12.75**	11.28
CONC3	-0.02	-0.68	0.04	0.82	-0.02	-0.51	0.04	1.21	**0.04**	5.78
INDKINT	**-0.30**	-2.94	-0.21	-1.30	**-0.23**	-2.34	**-0.20**	-2.34	**-0.20**	-14.56
INDPAT	-0.28	-1.70	-0.12	-0.55	-0.27	-1.70	-0.23	-1.75	**-0.25**	-8.68
2nd order serial correlation (p)	-0.97	(0.34)			-0.76	(0.45)	-0.62	(0.54)	-0.58	(0.56)
2-step Sargan (p)					99.18	(0.56)			138.27	(0.23)

Notes: Estimations are carried out with the DPD98 for Gauss by Arellano and Bond (1998) except 3SLS with TSP 4.4. Dependent variable: operating profit margin (PROF), N= 165, NT=640 except in 3SLS N=145 because TSP requires balanced panel. All equations include time dummies.
Instruments for DIF- and SYS-estimators: Const, PROF(gmm), EMPL(gmm), KINT(gmm), MS(gmm), PAT(gmm), TECHNIC(gmm), RES(gmm), dCONC3, dINDKINT, dINDPAT, time dummies.
"gmm"-instruments are the stacked overidentifying moment restrictions as in matrix (4) above, cf. Arellano and Bond (1991). Due to the matrix limitations of GAUSS, maximum of 3 lags are used.
Coefficients in **bold** are significant at the 95% confidence level, those underlined are significant at the 90% level.

Table 8. Baseline regressions 2: competencies (N*T=640)

	Fixed Effects		3SLS		DIF 1-step		SYS 1-step		SYS 2-step	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
CONST	**-1.93**	-3.95	-0.47	-0.87	1.06	1.70	**6.23**	3.98	**6.02**	17.78
PROF$_{-1}$	0.08	1.87	**-0.31**	-4.47	**0.17**	2.64	**0.36**	6.50	**0.38**	37.92
EMPL	**-0.002**	-2.87	0.00	-0.96	**-0.004**	-2.37	-0.001	-1.91	**-0.001**	-22.51
KINT	-0.07	-1.57	**-0.15**	-3.03	**-0.12**	-2.88	**0.07**	2.09	**0.06**	13.60
MS	**14.89**	2.12	15.28	1.46	12.70	1.63	12.51	1.21	**11.49**	10.76
CONC3	-0.01	-0.45	0.05	1.21	-0.01	-0.43	0.03	0.94	**0.04**	5.05
INDKINT	**-0.32**	-3.05	-0.24	-1.49	**-0.25**	-2.50	**-0.22**	-2.86	**-0.23**	-17.26
INDPAT	-0.24	-1.44	-0.03	-0.14	-0.24	-1.48	**-0.33**	-2.45	**-0.36**	-9.91
PAT$_{-2}$	0.01	0.17	0.10	0.94	0.07	0.97	0.03	0.40	**0.03**	3.62
RES$_{-2}$	**4.34**	3.02	**3.90**	2.53	2.91	1.93	**1.93**	2.16	**2.06**	18.72
TECHNIC$_{-2}$	**-36.42**	-2.07	-28.52	-1.45	-21.29	-0.90	12.23	1.22	**12.85**	7.27
2nd order serial correlation (p)	-1.00	(0.32)			-0.78	(0.44)	-0.70	(0.49)	-0.64	(0.52)
2-step Sargan (p)					98.68	(0.49)			130.26	(0.33)

See notes for table 7.
The variable RES has been scaled up by 100.

Table 9. Baseline regressions 3: innovation dummies (N*T=640)

a) Innovation 1991 indicators

	3SLS Coeff.	t-stat	DIF Coeff.	1-step t-stat	SYS Coeff.	1-step t-stat	SYS Coeff.	2-step t-stat
CONST	0.48	0.55	1.34	1.93	5.54	1.55	**4.84**	4.72
PROF$_{-1}$	-0.33	-4.43	0.05	0.68	**0.30**	4.64	**0.32**	21.13
EMPL	0.00	-0.35	**-0.005**	-2.74	**-0.002**	-2.19	**-0.002**	-13.58
KINT	**-0.14**	-2.50	**-0.13**	-2.66	0.05	1.56	**0.03**	4.94
MS	17.90	1.45	8.18	0.64	13.66	1.10	**13.43**	12.76
INDKINT	-0.18	-1.04	**-0.24**	-2.43	**-0.21**	-2.50	**-0.20**	-10.87
CONC3	0.04	0.94	-0.01	-0.31	0.02	0.72	**0.02**	2.59
INDPAT	-0.18	-0.75	-0.26	-1.60	**-0.32**	-2.24	**-0.31**	-6.68
PAT$_{-2}$	0.12	1.06	-0.09	-0.75	0.03	0.43	0.02	1.41
RES$_{-2}$	2.37	1.37	**3.34**	2.02	**1.84**	1.99	**1.69**	8.19
TECHNIC$_{-2}$	-27.33	-1.25	-14.96	-0.59	7.16	0.66	**7.46**	2.90
RDDUM	**-3.61**	-3.04	2.34	1.66	2.77	0.46	2.16	1.34
PROD91	0.03	0.02	-1.78	-1.13	-4.30	-1.22	**-3.85**	-7.04
PROC91	-0.53	-0.39	-1.39	-0.94	-2.77	-0.81	**-2.11**	-2.13
COLLAB91	3.36	1.80	3.18	1.46	7.66	1.44	**8.48**	7.34
OUTRD91	0.27	0.19	-3.34	-1.77	-0.83	-0.18	-1.43	-1.08
2nd order serial correlation (p)			-0.30	(0.77)	-0.77	(0.44)	-0.71	(0.48)
2-step Sargan (p)							117.34	(0.37)

See notes for table 7 and 8.

b) Innovation 1996 indicators

	3SLS Coeff.	t-stat	DIF Coeff.	1-step t-stat	SYS Coeff.	1-step t-stat	SYS Coeff.	2-step t-stat
CONST	0.18	0.27	1.21	1.92	**5.23**	2.49	**5.69**	8.41
PROF$_{-1}$	**-0.32**	-4.51	**0.16**	2.55	**0.30**	4.53	**0.31**	19.48
EMPL	0.00	-0.81	**0.00**	-2.46	-0.001	-1.26	**-0.002**	-9.81
KINT	**-0.14**	-2.71	**-0.10**	-2.59	0.05	1.26	**0.05**	6.94
MS	12.58	1.05	11.53	1.23	12.44	1.14	**13.19**	12.89
INDKINT	-0.22	-1.33	**-0.27**	-2.53	**-0.19**	-2.23	**-0.19**	-8.20
CONC3	0.06	1.28	-0.01	-0.40	0.02	0.69	**0.02**	2.45
INDPAT	-0.05	-0.22	-0.19	-1.24	**-0.30**	-1.99	**-0.34**	-5.84
PAT$_{-2}$	0.11	1.00	-0.12	-1.13	0.03	0.34	**0.03**	2.54
RES$_{-2}$	**3.34**	2.02	**3.19**	2.03	2.14	1.85	**2.01**	10.78
TECHNIC$_{-2}$	-28.08	-1.31	-19.93	-0.87	8.16	0.60	**8.29**	3.37
PROD96	-0.02	-0.02	-0.06	-0.11	0.25	0.05	0.53	0.36
PROC96	-0.40	-0.33	-0.12	-0.27	4.93	1.06	**4.47**	4.20
COL_cus	-2.20	-1.34	0.42	0.74	**9.10**	2.16	**7.66**	7.55
COL_uni	2.13	1.04	-0.84	-1.26	2.05	0.40	**4.45**	4.32
COL_com	1.16	1.02	-0.23	-0.44	-7.66	-1.76	**-7.00**	-9.32
COL_sup	0.38	0.28	-0.56	-0.87	-3.87	-1.00	**-3.46**	-3.59
OUTRD96	-1.74	-1.00	0.59	0.95	-4.89	-0.70	**-6.52**	-4.15
2nd order serial correlation (p)			-0.78	(0.44)	-0.80	(0.43)	-0.78	(0.44)
2-step Sargan (p)			100.86	(0.54)			117.17	(0.45)

From Table 9 above it is clear that the 3SLS and DIF estimators cannot identify very well the impact of dummy variables on profitability, while the system estimator that includes the levels equations is more precise. With the one-step estimators, none of the competence or innovation variables are significantly associated with profitability alone except RES and collaboration with customers (COL_cus). With the efficient two-step estimator, instead, all the innovation collaboration variables become statistically significant. Magnitudes of the coefficients do not differ much between the two system estimators, but it seems clear that the two-step estimator biases the standard errors down, while the one-step estimator inflates them.[2]

There is really no way to assess which estimator is closer to the "truth" with respect to hypothesis testing. Coefficients that are significant with the one-step procedure are likely to be strongly statistically associated with the dependent variable, but this test may be too strict. Thus, in the remaining analysis I will present both the system one-step and two-step results, to strike a compromise between the two less than ideal estimators. Results which are "close" to being significant with the inefficient one-step estimator are probably significant in reality. From now on, the fixed effects or 3SLS results are not reported, because they are not consistent for dynamic models and cannot identify the innovation related and time-invariant dummy variables, both of which are of central interest here.

5.1 Testing for complementarities: innovation and competencies (H1)

The first hypothesis concerns the interactions between competencies and profitability effects of innovation (Table 10). The results on the interactions between innovation output and competence measures indicate a relation of complementarity between technical competencies and innovation for both product and process innovation and both time periods. These coefficients are not statistically significant with the one-step estimator, but are very much so with the two-step. It is also conceivable that the profitability effects of innovation in 1994-96 have not materialized completely yet by the end of the period. The coefficients on the interactions for the earlier innovation measures are larger.

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[2] The weighting matrix is arbitrary, which can have considerable effects in finite samples. Asymptotically the estimators are equivalent.

The coefficients on the interaction between RES and innovation outcomes are systematically negative. Research competencies may be necessary for making inventions in the first place, but technical and probably market capabilities are more important in bringing the product to market or adopting new processes. Nevertheless, a research-intensive strategy seems to have been useful in general in recovering from the recession.

Table 10. Interactions between competencies and innovation outcomes (N*T=640)

a) Product innovation 1991

SYS	1-step	t-stat	2-step	t-stat
CONST	6.07	1.51	**4.52**	4.51
$PROF_{-1}$	**0.29**	4.51	**0.32**	22.86
EMPL	**0.00**	-2.27	**0.00**	-14.33
KINT	0.04	1.35	**0.03**	3.74
MS	15.09	1.24	**14.13**	12.60
CONC3	0.02	0.61	**0.02**	2.37
INDKINT	**-0.21**	-2.53	**-0.19**	-10.19
INDPAT	**-0.36**	-2.39	**-0.31**	-6.02
PAT_{-2}	0.07	0.85	**0.06**	5.09
RES_{-2}	9.73	1.70	**9.81**	6.62
$TECHNIC_{-2}$	-61.07	-1.12	**-64.00**	-6.63
RDDUM	6.14	1.00	**7.25**	5.21
PROD91	-11.00	-0.82	-4.89	-0.85
PROD91*$TECHNIC_{-2}$	100.74	1.58	**103.75**	9.31
PROD91*RES_{-2}	-9.46	-1.51	**-9.67**	-5.86
PROD91*PAT_{-2}	-0.05	-0.44	**-0.04**	-2.65
PROD91*RDDUM	4.92	0.37	-1.21	-0.20
2nd order ser.corr. (p)	-0.48	(0.63)	-0.39	(0.70)
2-step Sargan (p)			115.84	(0.38)

See notes for table 7.

b) Process innovation 1991

SYS	1-step	t-stat	2-step	t-stat
CONST	**12.39**	2.40	**10.14**	6.94
PROF$_{-1}$	**0.27**	4.05	**0.30**	15.80
EMPL	**-0.003**	-2.45	**-0.003**	-16.08
KINT	0.05	1.39	**0.04**	7.17
MS	18.98	1.73	**17.96**	14.88
CONC3	0.02	0.59	**0.04**	3.50
INDKINT	**-0.22**	-2.46	**-0.22**	-12.49
INDPAT	-0.23	-1.41	**-0.35**	-5.83
PAT$_{-2}$	1.08	0.87	**1.22**	4.47
RES$_{-2}$	10.04	1.00	4.40	1.55
TECHNIC$_{-2}$	-55.12	-1.20	**-40.65**	-3.45
RDDUM	-8.20	-1.04	**-7.01**	-4.57
PROC91	-43.36	-1.80	**-27.34**	-2.82
PROC91*TECHNIC$_{-2}$	93.80	1.75	**80.48**	5.98
PROC91*RES$_{-2}$	-9.73	-0.94	-3.97	-1.34
PROC91*PAT$_{-2}$	-1.10	-0.85	**-1.23**	-4.47
PROC91*RDDUM	46.72	1.87	**31.53**	3.25
2nd order ser.corr. (p)	-0.74	(0.46)	-0.63	(0.53)
2-step Sargan (p)			107.29	(0.61)

c) Product innovation 1996

SYS	1-step	t-stat	2-step	t-stat
CONST	4.24	1.10	**3.30**	3.35
PROF$_{-1}$	**0.24**	3.72	**0.28**	17.54
EMPL	-0.002	-1.64	**-0.002**	-10.19
KINT	0.06	1.82	**0.05**	8.03
MS	17.93	1.51	**16.59**	10.60
CONC3	0.02	0.64	**0.03**	2.69
INDKINT	**-0.21**	-2.29	**-0.20**	-9.27
INDPAT	**-0.31**	-2.30	**-0.29**	-6.32
PAT$_{-2}$	0.05	0.65	**0.04**	3.09
RES$_{-2}$	**5.66**	2.33	**5.42**	11.44
TECHNIC$_{-2}$	-34.46	-1.13	**-31.82**	-5.67
RDDUM	4.25	0.71	**4.78**	4.00
PROD96	31.31	1.51	**28.23**	4.57
PROD96*TECHNIC$_{-2}$	74.19	1.85	**69.60**	9.24
PROD96*RES$_{-2}$	-6.00	-1.51	**-6.00**	-9.13
PROD96*PAT$_{-2}$	-0.03	-0.27	-0.02	-1.56
PROD96*RDDUM	-35.90	-1.69	**-32.30**	-5.16
2nd order ser.corr. (p)	-1.00	(0.32)	-0.92	(0.36)
2-step Sargan (p)			116.05	(0.38)

See notes for table 7.

d) Process innovation 1996

SYS	1-step	t-stat	2-step	t-stat
CONST	5.38	1.56	5.08	4.56
PROF$_{-1}$	**0.28**	4.49	0.31	18.45
EMPL	**-0.003**	-2.41	-0.003	-13.29
KINT	0.05	1.29	0.04	6.24
MS	16.37	1.65	16.28	12.33
CONC3	0.03	0.85	0.02	1.87
INDKINT	**-0.23**	-2.54	**-0.23**	-8.91
INDPAT	-0.28	-1.72	**-0.28**	-5.12
PAT$_{-2}$	0.19	0.17	**0.42**	2.15
RES$_{-2}$	**4.96**	2.84	**4.49**	11.23
TECHNIC$_{-2}$	3.42	0.17	4.18	0.77
RDDUM	-1.98	-0.42	-1.08	-1.01
PROC96	16.79	1.39	**12.79**	4.05
PROC96*TECHNIC$_{-2}$	14.87	0.45	**17.23**	2.10
PROC96*RES$_{-2}$	-5.84	-1.69	**-5.42**	-7.49
PROC96*PAT$_{-2}$	-0.20	-0.17	**-0.44**	-2.23
PROC96*RDDUM	-8.88	-0.72	-5.41	-1.57
2nd order ser.corr.(p)	-0.74	(0.46)	-0.63	(0.53)
2-step Sargan (p)			107.29	(0.61)

5.2 Collaborative R&D and competencies (H2)

The second hypothesis examines the interaction between R&D collaboration and internal competencies. Specifically, internal competencies were hypothesized to be prerequisite to benefiting from collaborative R&D. The estimation results for each type of collaboration are in Tables 11-12.

Again, not all of the results are statistically significant by the one-step estimator, but referring to the methodological discussion in the previous sections, they may nevertheless be indicative. There is some evidence of an interaction between technical competencies and collaboration in general in table 11a. Outsourcing instead interacts especially with internal R&D (Table 11b). This suggests that firms cannot benefit from contract R&D unless they have some internal R&D capability.

"Dynamic competencies" measured by past innovation output (PROD91 and PROC91) interact significantly with three types of collaboration, those with customers, suppliers, and universities in the 1996 survey (table 12 a-d). The actual interactions are perhaps somewhat surprising. For instance, one could expect collaboration with customers to be complementary with internal product innovation capabilities, but in fact, *process* innovators tend to benefit more from collaboration with customers here. Similarly, collaboration with suppliers is complemented by dynamic *product* innovation capabilities, contrary to expectations. Product innovating firms should hence let suppliers take care of process development, because own process innovation and collaboration with suppliers appear to be substitutes. Finally product innovation and collaboration with universities interact negatively, implying that product innovators are not so likely to benefit from collaboration with universities. Process innovation capabilities, in contrast, complement university collaboration.

Table 11. Interactions between external R&D and dynamic competencies (N*T=640), 1991

R&D collaboration				
SYS	**1-step**	**t-stat**	**2-step**	**t-stat**
CONST	**5.59**	2.05	**4.74**	8.20
PROF$_{-1}$	**0.28**	4.08	**0.30**	21.37
EMPL	**-0.002**	-2.77	**-0.002**	-18.53
KINT	0.05	1.47	**0.03**	5.93
MS	21.25	1.71	**20.55**	15.96
CONC3	0.03	0.91	**0.03**	3.01
INDKINT	**-0.17**	-2.05	**-0.16**	-8.78
INDPAT	**-0.36**	-2.71	**-0.33**	-6.39
PAT$_{-2}$	0.05	0.67	**0.03**	2.45
RES$_{-2}$	14.74	1.17	**11.01**	3.68
TECHNIC$_{-2}$	-30.40	-0.87	**-33.78**	-3.68
COLLAB91	0.79	0.22	1.31	1.86
COLLAB91*RES$_{-2}$	-14.37	-1.10	**-10.78**	-3.47
COLLAB91*TECHNIC$_{-2}$	62.33	1.40	**65.52**	6.15
COLLAB91*PAT$_{-2}$	-0.04	-0.39	**-0.03**	-2.37
2nd order ser.corr. (p)	-0.81	0.42	-0.76	0.45
2-step Sargan (p)			115.22	0.45

Outsourcing				
SYS	**1-step**	**t-stat**	**2-step**	**t-stat**
CONST	5.13	1.40	**3.90**	3.22
PROF$_{-1}$	**0.30**	4.50	**0.33**	22.04
EMPL	**-0.002**	-2.49	**-0.002**	-14.62
KINT	0.04	1.43	**0.03**	4.31
MS	20.22	1.72	**20.20**	14.52
CONC3	0.02	0.54	**0.02**	2.46
INDKINT	**-0.21**	-2.45	**-0.20**	-10.44
INDPAT	**-0.39**	-2.93	**-0.41**	-8.58
PAT$_{-2}$	0.08	1.06	**0.07**	6.09
RES$_{-2}$	18.82	1.76	**16.75**	5.75
TECHNIC$_{-2}$	35.44	0.85	**31.11**	2.57
RDDUM	-3.09	-0.62	-0.93	-0.76
OUTRD91	7.63	1.63	**6.27**	5.67
OUTRD91*RES$_{-2}$	-17.99	-1.68	**-16.02**	-5.46
OUTRD91*TECHNIC$_{-2}$	-29.12	-0.56	-22.00	-1.54
OUTRD91*PAT$_{-2}$	-0.08	-0.72	**-0.07**	-6.01
OUTRD91*RDDUM	7.63	1.63	**6.27**	5.67
2nd order ser.corr. (p)	-0.76	0.45	-0.68	0.50
2-step Sargan (p)			117.89	0.36

Table 12. Interactions between external R&D and dynamic competencies (N*T=640), 1996

a) Collaboration with competitors

SYS	1-step	t-stat	2-step	t-stat
CONST	**8.76**	3.10	**7.44**	10.86
$PROF_{-1}$	**0.32**	5.39	**0.32**	21.83
EMPL	0.000	-0.51	**-0.001**	-4.30
KINT	0.07	1.86	**0.05**	9.88
MS	6.48	0.50	**5.64**	4.51
CONC3	0.02	0.72	**0.03**	3.65
INDKINT	**-0.27**	-3.02	**-0.26**	-15.76
INDPAT	**-0.32**	-2.29	**-0.35**	-7.22
PAT_{-2}	-0.16	-1.00	**-0.16**	-7.88
RES_{-2}	**1.81**	2.00	**1.89**	10.07
TECHNIC	**29.69**	2.10	**26.02**	9.33
COL_com	-13.39	-0.49	-8.29	-1.36
PROD91	-1.37	-0.61	**-1.16**	-2.07
PROC91	-1.85	-0.60	-0.31	-0.49
COL_com* PROD91	-2.67	-0.11	-3.57	-0.66
COL_com*PROC91	20.64	1.39	**16.81**	6.81
COL_com*$TECHNIC_{-2}$	-80.03	-1.86	**-77.63**	-13.52
COL_com*PAT_{-2}	0.31	1.41	**0.31**	14.59
2nd order ser.corr. (p)	-0.84	(0.40)	-0.77	(0.44)
2-step Sargan (p)			121.02	(0.36)

See the notes for table 7.

b) Collaboration with customers

SYS	1-step	t-stat	2-step	t-stat
CONST	**9.45**	3.22	**8.43**	10.85
$PROF_{-1}$	**0.28**	4.12	**0.29**	18.28
EMPL	**-0.002**	-2.37	**-0.003**	-14.51
KINT	0.04	0.89	**0.02**	3.47
MS	8.74	0.74	**8.85**	8.14
CONC3	0.03	0.87	**0.03**	2.55
INDKINT	**-0.18**	-2.03	**-0.16**	-6.82
INDPAT	**-0.41**	-2.62	**-0.45**	-9.11
PAT_{-2}	0.16	0.79	**0.17**	6.78
RES_{-2}	**3.25**	2.01	**2.83**	10.27
$TECHNIC_{-2}$	10.52	0.46	**12.05**	2.24
COL_cus	-5.11	-0.94	**-4.11**	-3.29
PROD91	-4.03	-1.28	**-3.67**	-4.44
PROC91	-5.35	-1.10	**-4.38**	-4.23
COL_cus*PROD91	6.35	1.05	**6.18**	5.22
COL_cus*PROC91	15.23	1.90	**14.76**	10.50
COL_cus*TECHNIC	-24.82	-0.66	**-19.06**	-2.50
COL_cus*PAT_{-2}	-0.15	-0.64	**-0.17**	-6.32
2nd order ser.corr. (p)	-0.81	(0.42)	-0.77	(0.44)
2-step Sargan (p)			119.41	(0.47)

c) Collaboration with suppliers

SYS	1-step	t-stat	2-step	t-stat
CONST	**7.10**	3.20	**6.30**	8.96
$PROF_{-1}$	**0.34**	5.77	**0.35**	21.03
EMPL	-0.002	-1.91	**-0.002**	-11.43
KINT	0.04	1.19	**0.02**	3.30
MS	11.19	1.12	**11.17**	8.68
CONC3	0.03	0.87	**0.03**	2.96
INDKINT	**-0.22**	-2.56	**-0.22**	-9.42
INDPAT	**-0.33**	-2.24	**-0.38**	-7.43
PAT_{-2}	0.48	1.12	**0.65**	5.96
RES_{-2}	1.38	1.10	**1.07**	4.58
$TECHNIC_{-2}$	37.26	1.88	**33.47**	7.01
COL_sup	1.44	0.21	-1.85	-0.79
PROD91	**-7.27**	-2.10	**-5.73**	-6.49
PROC91	2.42	0.85	**2.65**	3.48
COL_sup * PROD91	10.72	1.50	**11.85**	6.13
COL_sup*PROC91	-2.32	-0.33	-0.10	-0.06
COL_sup*$TECHNIC_{-2}$	-47.45	-1.27	**-40.48**	-5.53
COL_sup*PAT_{-2}	-0.48	-0.99	**-0.68**	-5.73
2^{nd} order ser.corr. (p)	-0.58	0.56	-0.48	0.63
2-step Sargan (p)			115.54	0.50

See the notes for table 5.

d) Collaboration with universities

SYS	1-step	t-stat	2-step	t-stat
CONST	**7.79**	3.08	**6.96**	9.97
$PROF_{-1}$	**0.32**	5.28	**0.34**	24.13
EMPL	**-0.002**	-2.04	**-0.002**	-12.77
KINT	0.06	1.93	**0.06**	10.36
MS	2.35	0.18	**2.14**	2.10
CONC3	0.02	0.60	**0.02**	2.85
INDKINT	**-0.25**	-2.85	**-0.24**	-10.80
INDPAT	**-0.30**	-2.01	**-0.33**	-6.84
PAT_{-2}	-0.41	-0.49	**-0.50**	-2.77
RES_{-2}	**4.15**	2.26	**3.99**	7.05
$TECHNIC_{-2}$	4.83	0.20	5.99	0.92
COLL_univ	5.03	0.89	**6.13**	6.05
PROD91	1.46	0.43	0.97	1.10
PROC91	-3.78	-1.08	**-2.53**	-2.92
COL_uni*PROD91	-9.98	-1.36	**-9.48**	-7.87
COL_uni*PROC91	11.86	1.86	**10.77**	8.72
COL_uni*TECHNIC	-21.33	-0.62	**-20.07**	-2.37
COL_uni*RES_{-2}	-4.60	-1.34	**-4.55**	-4.63
COL_uni*PAT_{-2}	0.50	0.56	**0.58**	3.20
2^{nd} order ser.corr. (p)	-0.81	(0.42)	-0.77	(0.44)
2-step Sargan (p)			119.41	(0.47)

Patenting as a measure of dynamic competence does not perform very well here. However, it has a relatively significant interaction with collaboration with competitors. Collaborative arrangements with direct competitors are vulnerable to leakage of strategic information, and active patenting can mitigate those risks.

Research competencies are important for economic performance, but not through interactions with innovation activities. This is in line with the observation in section 3 that research skills are not closely associated with other innovation activities (see p.13). There may be a positive profitability effect of a "research-intensive" strategy, while the actual ability to benefit economically from innovations depends more on technical competencies and accumulated organizational knowledge. Also, the lags of the profitability effects of research competencies through successful innovation may be a lot longer than the data here allows.

6 Conclusions

I have argued that a firm's profitability is critically affected by the capabilities it possesses. These capabilities are accumulated by investing in various competencies, including internal and external R&D and employees' skills. In addition to examining the profitability effects of a range of competence building measures and activities, this study explicitly focuses on the complementarities between them. Identifying complementarities sheds new light on the impact of organization on firms' innovative and economic performance.

The results indicate that there are indeed complementarities between competencies and innovation activities. First, most innovation output variables alone are not significant explanatory factors of profitability, and some of them even have negative signs. Estimations suggest that both technical and accumulated "dynamic" competencies reinforce the profitability effects of innovation. Second, collaborative R&D has stronger positive economic effects when the firm has already accumulated innovative capabilities. Third, appropriability issues arising from collaboration with competitors seem to be an important vector through which patents affect profitability.

The analysis demonstrated that there are likely to be important interactions between a firm's knowledge assets, learning, and innovation. Even with the rather crude measures for competencies and innovation activities available, there is evidence that managers need to consider competence investments and organization of innovation in order to leverage the interaction effects and realize the potential complementarities among knowledge assets and learning activities.

The results obtained with the econometric analysis are intriguing but not conclusive. The approach suffers from both data-related and methodological problems. First, the dataset may be nonstationary, which would create problems with the system estimator. Second, it is not clear how to interpret the significance tests with the dynamic panel data GMM developed by Arellano *et al.* One-step estimator with the arbitrary weighting matrix is inefficient, while the optimal two-step weights are "too" efficient. Third, multicollinearity of the independent variables can sometimes blur the results as the innovation activity indicators are highly correlated.

Results suggest that firms need to carefully think about which competence investments may be complementary in their operations. Ignoring one aspect of the competence "portfolio" may jeopardize the full realization of the returns to the others. This has obviously implications for management, but also for technology policy. For example, subsidies for R&D or for collaborative arrangements may not be productive unless firms possess the requisite complementary capabilities, which enable them to transform the results of R&D into successful new products or processes.

Appendix 1

Table A1. Correlations among the original variables, 1996

	SALES	EMPL	KINT	MS	PROF	PAT	RES	TECHNIC
SALES	1							
EMPL	0.76	1						
KINT	-0.01	0.06	1					
MS	0.92	0.79	0.06	1				
PROF	-0.08	0.02	0.14	-0.03	1			
PAT	0.53	0.48	-0.07	0.31	-0.14	1		
RES	0.26	0.20	0.17	0.23	0.11	0.18	1	
TECHNIC	0.20	0.18	0.03	0.12	0.03	0.26	0.25	1
PROD91	0.03	0.17	0.08	0.01	0.01	0.09	0.10	0.24
PROC91	0.17	0.23	0.15	0.16	0.12	0.12	0.17	0.20
COLLAB91	0.20	0.28	0.21	0.17	0.12	0.15	0.26	0.31
PROD96	0.23	0.29	0.08	0.22	0.18	0.21	0.24	0.36
PROC96	0.22	0.29	0.19	0.21	0.13	0.19	0.12	0.10
COL_com	0.29	0.34	-0.01	0.30	0.02	0.24	0.14	0.13
COL_cus	0.20	0.25	0.16	0.21	0.08	0.17	0.15	0.33
COL_sup	0.24	0.30	0.17	0.24	0.01	0.19	0.20	0.26
COL_uni	0.24	0.33	0.05	0.23	0.06	0.25	0.21	0.39
RDDUM	0.18	0.24	0.13	0.17	0.10	0.17	0.18	0.31
INDKINT	0.08	-0.03	0.36	0.12	0.09	-0.05	0.09	-0.07
INDPAT	0.12	0.09	-0.13	0.03	-0.19	0.31	0.10	0.43
CONC3	0.24	0.19	0.09	0.24	-0.04	0.19	0.15	0.39

	PROD 91	PROC 91	COL-LAB91	PROD 96	PROC 96	COLL comp	COL cus	COL sup	COL uni	RD-DUM	IND-KINT	IND-PAT
PROD91	1											
PROC91	0.29	1										
COLLAB 91	0.51	0.38	1									
PROD96	0.33	0.22	0.34	1								
PROC 96	0.10	0.29	0.23	0.53	1							
COL_com	0.20	0.22	0.19	0.37	0.31	1						
COL_ cus	0.15	0.25	0.29	0.55	0.43	0.51	1					
COL_ sup	0.26	0.28	0.35	0.58	0.51	0.41	0.58	1				
COL_uni	0.27	0.22	0.34	0.58	0.49	0.46	0.70	0.62	1			
RDDUM	0.26	0.27	0.30	0.68	0.64	0.41	0.63	0.61	0.68	1		
INDKINT	-0.01	-0.03	-0.01	-0.01	0.07	-0.10	-0.07	0.02	-0.04	0.00	1	
INDPAT	0.26	0.15	0.22	0.36	0.07	0.18	0.23	0.18	0.31	0.31	-0.25	1
CONC3	0.14	0.18	0.19	0.28	0.13	0.08	0.19	0.15	0.26	0.32	0.24	0.61

Appendix 2

A2.1 Generalized Method of Moments for dynamic panel data

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

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

is used with respect to equation (2) in two stages, first utilizing an initial weights matrix

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

with (T-2)×(T-2) matrix

$$(7)$$

which is then replaced in the second step by the residuals:

$$\begin{pmatrix} 0 & 0 & 0 & -1 & 2 \end{pmatrix}$$

$$A_N = \left(N^{-1} \sum_{i=1} Z_i' u_i u_i' Z_i \right) \qquad (8)$$

where 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.

A2.2 Identification of complementarities

According to Arora (1996) there are two problems in identifying complementarities. 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. Arora considers estimation with cross-sectional data, but 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.

Athey and Stern (1998) also discuss testing for organizational complementarities. They suggest using a system of equations to estimate simultaneously the "adoption equations" – in this case the determination of innovation and its organization – and the main equation of interest – here the profitability equation (1). However, they do not come up with any practical alternatives for estimating the multivariate probability distributions related to the adoption equations. It is well known that this kind 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 more complicated and left for future work.

Another problem to consider is that when two variables are complementary, there are not likely to be many observations with one but not the other. For instance, if collaboration with customers and product innovation are complementary, there are probably not too many firms engaged in collaboration but not innovation. Such a situation is illustrated in Table A2: off-diagonal observations are clearly fewer, but fortunately for the estimation, there are still a number of observations suggesting that complementarity to the extent it exists is not very strict. If it were, identification of the interaction effect would not be possible.

Table A2. Contingency table of product innovation (1996) and collaboration with customers

	COL_cus=0	COL_cus=1	Total
PROD96=0	90	15	105
PROD96=1	19	40	59
Total	109	55	164

The approach here with respect to Arora's warnings is pragmatic. By including proxies for the competence factors that correlate with innovativeness, 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. As a result, the complementarity parameters (γ) are biased upward.[3] Unfortunately there is no means of controlling for 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. However, this means that the estimates are conservative: since the null here is that there are no complementarities, we are only likely to make

[3] The variables used here provided a reasonable prediction of innovation outcomes in Leiponen (2000).

type II errors. This increases the reliability of the possible statistically significant estimation results.

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