

# Tracing technological opportunities, patterns of innovation and competence requirements through micro data<sup>1</sup>

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## Abstract

A key issue within the economics of technological change concerns the trade-offs between the nature and organization of innovation and the broader context wherein firms innovate. In theoretical jargon this translates into a discussion of the relationships between technological regimes and opportunities, sectoral patterns of innovation and related competences. Nonetheless, the more precise contents of these relationships remain more or less unspecified both in theoretical and empirical work. One reason is the lack of micro data that would cater to the diversity of different types of opportunities and innovations. The purpose of this paper is to identify and trace the distribution of different types of technological opportunities across sectors and industries, as well as their interrelationships with different types of innovations. The novelty of the paper is to approach the issue through descriptive and multivariate analysis of a new and unique data on innovation outputs in the context of Finnish industries. The results suggest the prevalence of both distinct and diverse sectoral patterns. Moreover different types of opportunities are associated with different types of innovations. This is taken to reflect some more fundamental differences in the nature of absorptive capabilities to absorb and adapt external knowledge.

**Keywords:** technological opportunities, innovations, sectoral patterns, absorptive capabilities

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## 1 INTRODUCTION

One central finding within the economics of technological change is that the nature and differences of technological opportunities largely determine to what degree innovating firms can extend their knowledge base and turn creative ideas into different types of innovations (see Cohen 1995 for an review of the literature). The intermediating factor, turning opportunities into different types of innovations is often referred to as competences or capabilities broadly defined, or more precisely as the absorptive capabilities to absorb and adapt external knowledge (see Foss 1997 for a reader on the competence-based view of the firm, Cohen & Levinthal 1990).

The interrelationships between technological opportunities, patterns of innovations and related competence requirements can be approached through the concept of technological regime that seeks to relate certain key dimensions of industrial and technological change to the organization, nature and sectoral patterns of innovation (Nelson & Winter 1977, Dosi 1982, 1988, Malerba & Orsenigo 1993, 1997). Nonetheless, the more precise contents of these relationships remain more or less unspecified both in theoretical and empirical work. One reason is simply the lack of micro data that would capture the true diversity of different types of technological opportunities, innovations, and innovation processes.

A common finding of most previous empirical work is that levels of R&D-expenditures, or R&D-intensities, in combination with appropriability conditions reflect different levels of technological opportunity (Klevorick et al. 1995, Nelson & Wolff 1997). Accordingly, the high-tech industries are characterized as high opportunity sectors, while the low-tech industries are characterized as low opportunity sectors. Alternatively the literature identifies broader categories, such as entrepreneurial versus routinized regimes or Schumpeter Mark I versus Mark II, where the focus is on the interrelationships between innovation, firm entry, exit and diversification (see special issue in *Journal of Corporate and Industrial Change* 1996, see Pavitt 1984 or Ceseratto & Mangano 1993 for alternative approaches). Nonetheless, less attention is given to technological opportunities varying not only in terms of levels but also in terms of content. Thus the fact that firms tend to be multi-technology and -product and face a range of different types of technological opportunities simultaneously is ignored.

The aim of this paper is to trace sectoral trade off's between different types of technological opportunities, the organization of external collaboration and their joint association with patterns of innovation and related competences, or competence requirements. The novelty of the paper is to approach the issue through new and unique micro data anchored directly to the innovation outputs of firms in the context of industrial innovation in Finland (compare to Townsend et al. 1981, Kleinknecht & Bain 1993, Santarelli & Piergiovanni 1996, Coombs et al. 1996, Tidd et al. 1996). Thereby the true micro-diversity of different types of opportunities and innovations can be acknowledged. Moreover the paper moves beyond tracing mere levels of technological opportunities through also identifying the content of different types of opportunities.

The paper is organized as follows. Section 2 starts off with a conceptual discussion, which relates the concepts of technological regimes to the discussion of sectoral patterns of innovation and related competencies, or competence requirements. Section 3 discusses the data and methodologies, as well as the results of the statistical analysis. Section 4 concludes the paper with a summarizing discussion and some thoughts on possibilities to complement and deepen the analysis.

## **2 A CONCEPTUAL FRAMEWORK**

### **2.1 The concept of technological regime**

A discussion on why patterns of innovation differ in different industrial contexts has been at the center of much research within the economics of technological change. Typically empirical research has focused on the interrelationships between differences in R&D-intensity, as a proxy for innovativeness or technological opportunities more generally, and various indicators of firm size or market concentration. More interestingly, however, the studies have indicated that structural features of industries reflect differences in the characteristics of technological change and innovation rather than the other way around. In particular, certain key features of technologies, competition and markets have strong explanatory power in explaining the nature and distribution of innovations, the organization of innovation and related competence

requirements (Cohen 1995). Taken together, these key features have been defined through then concept of technological regimes.

Nelson & Winter (1977) defined a technological regime as "a frontier of achievable capabilities, defined in the relevant economic dimensions, limited by physical, biological, and other constraints, given a broadly defined way of doing things." Apart from the more cognitive underpinnings of this concept, a few fundamental economic dimensions have been put forward by, among others, Dosi (1982, 1988) and Malerba & Orsenigo (1993,1997) that seek to operationalise somewhat more precisely the content or constituting parts of technological regimes. These dimensions are commonly referred to as the technological opportunities, appropriability and market conditions.

In this setting, technological opportunities reflect the ease of innovation for any given amount spent on R&D. In a broader sense they will be determined by market stimuli and the role of customers or suppliers as providers of ideas, developments in the sciences, the advancement in equipment and instrumentation originating from other sectors, as well as the extent to which firms rely on knowledge inputs from the universities, research organizations or other 'bridging institutions' (Klevorick et al. 1995). Thus, technological opportunities are determined both by the sources of innovation and the nature of knowledge bases, although their ultimate micro-effects can be diverse. For example Malerba & Orsenigo (1997) also differentiate between different types of knowledge bases in terms their level, variety, and pervasiveness

The appropriability of innovation concerns the fraction of the returns to R&D that the innovator is able to retain and the possibilities of protecting innovations from imitation. The importance of patents is acknowledged, alongside secrecy, lead times, and continuous incremental innovation or product complexity. In a deeper sense, appropriability conditions refer to the degree to which knowledge is tacit or codified, and more easily replicated, or specific versus generic etc. (see Levin et al. 1987). These characterisations of appropriability conditions relate to more or less unobservable firm-specific phenomena and the broader contexts characterizing different industries and sectors.

Finally, the extent that technological opportunities can be appropriated through innovations depends on market conditions. These are some combinations of market size

and growth, the income elasticity of various products, as well as the levels and changes in relative prices, in particular on the market for labor and capital goods (Dosi 1982,1988). Nonetheless, while there is agreement that market conditions are important for explaining sectoral patterns of innovation, it is not always clear at what level they exercise their greatest impact. For example, there might exist rapidly expanding ‘pockets of demand’ in specific product niches even though the industry as a whole could be classified as a mature one with stagnating demand (Harrigan & Porter 1993).

## **2.2 Technological opportunities, patterns of innovation and competence requirements**

The focus of this paper of the interrelationships between technological opportunities, patterns of innovation and competence requirements assumes that the concept of technological regimes also carries normative implications to the level of firms and innovations. One problem in is that the concept of technological regime operates at a rather abstract and unspecified level of fields of technologies or industries. On the other hand, especially the characteristics of technological opportunities are derivable from micro-level phenomena. A relevant starting point for accommodating different levels of analysis seems to be to consider different levels of technological opportunities as proxies for different ‘learning environments’ that constrain or expand firm’s viable options and strategies during innovation (compare to Malerba & Orsenigo 1993).

For starters, in environments characterized by higher technological opportunities it could be assumed that technological opportunities are associated with generic knowledge bases and technologies that also imply a greater need for collaboration with a range of external partners. In R&D-intensive science-based sectors, for example, a large number of studies indicate the importance played by universities and research organizations, or interdisciplinarity more generally for the advancement of knowledge (see e.g. Pavitt 1984, Gambardella 1995, Reger & Scmoch 1996). Moreover, the opportunities for radical innovation are greater and thus competence requirements will also reflect the need to continuously integrate different sets of engineering and scientific principles through explicitly developing outward-looking absorptive capabilities (Cohen & Levinthal 1990). Eisenhardt & Martin (2000) suggest further, that the role of dynamic capabilities to simultaneously exploit existing competencies

and technologies through incremental innovation and explore new one's through radical innovation are especially important in these types of environments.

The customer or market interface is another frequently discussed source for technological opportunities. Among others Lundvall (1992), von Hippel (1988) and Eliasson (1995) stress the role that competent buyers and users play for the origin and development of innovations. The prime example is the medical instrument industry or machinery (von Hippel 1988). On the other hand, collaboration with users also create a need for higher receiver or absorptive capabilities that enables the incorporation of completely new engineering and scientific principles through radical innovation (Eliasson 1995). Taken together, these insights seem to suggest that technological opportunities related to customers might be associated with both incremental and radical innovation, depending on the nature of different products and industries.

While high technological opportunities relates to scientific breakthroughs, new technologies, or progressive customers, low technological opportunities are typically discussed in terms of the product or industry life cycle theory (Abernathy & Utterback 1978, Utterback 1994). In this context, lower R&D-intensities reflect some combination of depleted opportunities and weak appropriability conditions. Competition is mainly over price and incremental process innovation, learning by doing and using, dominates over radical innovation (compare to Malerba 1992). Firms are more focused on developing inward-looking absorptive capabilities, or transformative capabilities to maintain, continuously reactivate and synthesis available technologies and competencies (Garud & Nayyar 1994).

One problem with available proxies for levels of technological opportunities, such as R&D-intensities, is the fact that opportunities are not only confined to technological advances and R&D within the sector or industry in question. Apart from internally generated opportunities, firms frequently develop close ties to specialist knowledge sources and gatekeepers, universities and research institutes (Karnoe et al. 1999, Palmberg 2001). Alternatively, suppliers of machinery and equipment from other industries might provide major sources of opportunities in supplier-oriented industries (Pavitt 1984). Moreover, the content of technological opportunities and their interrelationships with competence requirements and growth will also depend on

institutional contexts in specific areas where regulations and standards, for example, largely will shape the direction and dynamics innovation.

A final viewpoint relates to a partial critique of simplifying distinctions between incremental and radical innovation, and the related competence requirements. More specifically, Henderson & Clark (1990) introduce the important distinction between innovations as a system and a set of interrelated core components or technologies. Hence they distinguish between modular innovations, which only change the core technologies, and architectural innovation that change the architecture of the system without changing the core technologies. These types of innovations are situated somewhere in between incremental and radical innovations in terms of competence requirements. They can be incremental to the firms but relatively radical to the markets, or the other way around.

### **3 SECTORAL PATTERNS BY INNOVATION OUTPUT**

#### **3.1 A note on the data and methodology**

Referring to the introduction, the novelty of this paper is to apply the concepts of technological opportunities to data anchored directly to innovation outputs. The database that is used consists of some 1600 innovations commercialized by Finnish firms during 1985-98. The definitional starting point for the identification of innovations was 'a technologically new or significantly enhanced product from the viewpoint of the firm'. The focus on innovations new to the firms during the identification of innovations was designed to capture some aspects of the creation or reconfiguration of firm's competencies.

The innovations in the database have been identified 'bottom-up' using a combination of reviews of trade and technical journals, and expert opinion as an elaboration on the object-approach to data collection (compare to Townsend 1981, Kleinknecht et al. 1993, Santarelli & Piergiovanni 1996, Coombs et al. 1996, Tidd et al. 1996). The literature reviews consisted of reviewing a careful selection of 18 relevant trade and technical journals, as well as the annual reports of the largest firms, with the ambition of covering as extensively as possible all major industries. This resulted in 2/3 of all the

innovations in the dataset. The remaining 1/3 was identified using the experts representing different industrial and technology fields, the Technical Research Centre (VTT), the National Technology Agency (Tekes) and the technical universities. Given the fact that the population of all innovations is practically unknown, it should be noted that these methodologies are not comparable to statistical sampling in a strict sense, even though the literature reviews entailed some elements of random sampling. Descriptive analysis nonetheless indicates that the structure of the database is more or less similar to the structure of patenting and innovating firms in Finland more generally (Leppälähti 2000, Palmberg et al. 2000).

An advantageous aspect of the data is that it is not stuck in pre-defined industrial classifications, as is the case with firm-level surveys such as the Community Innovation Survey (CIS). It will therefore better capture technological opportunities that transcend industrial borders and firm boundaries, as well as their interrelationships with different types of innovations. In this paper a related survey data is used that covers 569 innovations from the manufacturing industries. The survey was undertaken during the year 1999 and resulted in a response rate of 64 percent, or some 800 responses. In this paper I exclude 231 service sector innovations because I include variables that capture R&D-intensities of different industries that are unavailable and dubious in these sectors (Patel 2000). The survey is not hampered by significant item non-response.

### **3.2 The sources of innovation and collaborative patterns – univariate analysis**

For empirical analysis a reasonable starting point is to assume that differences in R&D intensities capture different levels of technological opportunity, although their interrelationships with appropriability conditions and market conditions are more difficult to operationalize (compare to Klevorick et al. 1995, Nelson & Wolff 1997). In this paper the OECD taxonomy of R&D-intensities is used to define different levels of technological opportunity (see appendix 1 for the OECD taxonomy).<sup>2</sup> In addition, a subset of the survey data is used to identify the content of different types of technological opportunities. The selected variables are presented in table 1.

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<sup>2</sup> More relevant firm-level data is not available due to data confidentiality.

Table 1. Variables selected to capture the content of different types of technological opportunities

Variable	Description
<i>Origin of new products</i>	<i>Likert scale 0-3 by degree of importance</i>
OPRICE	Intensification of price competition
ORIVAL	Threat posed by rival product
OCUST	Customer demand
OPTP	Public technology procurement
OSCIENCE	Scientific breakthrough
OTECH	New technologies
OPRES	Public research or technology program
OENV	Environmental factors
OREGLEG	Regulations, legislation, standards
OLIC	License
<i>Collaborative partners</i>	<i>Likert scale 0-3 by degree of importance</i>
CCONC	Firm in the same concern
CCUS	Customers
CCONS	Consultants
CSUB	Subcontractors
CUNI	Universities
CVTT	Technical research center of Finland
CREIN	Other research institutes
CCOMP	Competitors

The selected variables are assumed to reflect the content of different types of technological opportunities as follows. The first set of variables, OPRICE-OLIC, capture the importance assigned to different sources for the origin of innovation on an ordinal Likert scale from 0 to 3. More precisely, the variables OPRICE-ORIVAL reflect the sources of technological opportunities in terms of the nature of competition and imitability of innovations, while OCUST-OPTP capture the role of both private and public sector customers or demand more generally. Apart from these demand-related sources, the variables OSCIENCE-OPRES capture the reliance of innovations on scientific breakthroughs and new technologies, or collaborative public research programs that have been frequent in Finland especially during the 1990s. Finally, technological opportunities often depend on regulatory and legislative issues characterizing the sector or industry in question. These are captured by OENV and

OREGLEG that reflect the importance assigned to environmental issues respectively regulations legislations and standards as sources for innovation.

The second set of variables, CCUS-CCOMP, describe the importance assigned to different collaborative partners, likewise on an ordinal Likert scale from 0 to 3. They are taken to reflect both the sources of technological opportunities, as well as how internal competences are complemented with external one's. Thus they should correlate with OPRICE-OREGLEG and jointly highlight particular trade-offs between technological opportunities and collaboration underlying absorptive capabilities (Cohen & Levinthal 1990). The variables CCONC-CCUS capture the importance of collaboration within the firms and customers respectively, while CCONS-CREIN capture vertical collaboration with specialist knowledge sources such as consultancies, subcontractors, universities and research institutes. Finally, the variable CCOMP captures horizontal collaboration with competitors.

In the subsequent comparative analysis, the innovation outputs are anchored to aggregate sectors of R&D-intensities by the principal industry of the innovating firms. In table 2 mean values of the scores assigning different levels of importance to different sources of innovation outputs have been calculated. Since the scale is ordinal rather than interval, the absolute levels are less interesting and the setup is only relevant for comparisons across the industries.

Table 2. The origin of innovations by R&D-intensity

N=553	Sector				
	ALL Manu- facturing	High R&D	High- medium R&D	Low- medium R&D	Low R&D
Price competition	0.95	0.57	0.90	1.01	1.21
Rival product	0.86	0.77	0.86	0.76	0.95
Market niche	2.28	2.50	2.25	2.22	2.32
Customer demand	2.06	2.20	2.06	2.13	1.95
Public procurement	0.31	0.45	0.29	0.28	0.32
Scientific breakthrough	0.49	1.00	0.44	0.39	0.51
New technologies	0.97	1.11	1.01	0.85	0.88
Research program	0.54	0.50	0.52	0.63	0.51
Environmental factors	0.86	0.18	0.83	1.18	0.99
Regulations, legislation	0.74	0.82	0.70	0.87	0.70
License	0.18	0.50	0.14	0.16	0.17

Overall, different levels of opportunities, as defined above, seem to be quite important for distinguishing between the origins of innovations. According to the table, customer demand and the observation of market niche are dominating incentives to innovate overall. Nonetheless, customer demand is relatively more important in the high-opportunity sectors compared to the low-opportunity sectors. The more significant differences emerge in the case of scientific breakthroughs, new technologies, the intensification of price competition, and the threat posed by rival products.

The greater role played by scientific breakthroughs and new technologies in the high opportunity sectors is in line with the description of science-based industries (compare to Gambardella 1995, Reger & Schmoch 1996). In the low opportunity sectors the importance of price competition and rival products is probably reflects the maturity of industries and technologies, as well as the threat from imitation (compare to Abernathy & Utterback 1978, Utterback 1994). Similarly, environmental issues are more important in the low-opportunity sectors industries compared to the high-opportunity sectors.

Table 3. Collaborative partners during the development of innovations by R&D-intensity

N=479	Sector				
	ALL Manu- facturing	High R&D	High-medium R&D	Low-Medium R&D	Low R&D
Firms of same concern	0.62	0.54	0.52	0.73	0.84
Customers	1.52	1.55	1.63	1.54	1.19
Consultants	0.39	0.37	0.40	0.45	0.34
Subcontractors	0.82	0.76	0.85	0.80	0.81
Universities	0.65	1.12	0.61	0.66	0.53
VTT	0.71	0.31	0.78	0.89	0.53
Other research institutes	0.42	0.82	0.37	0.35	0.44
Competitors	0.26	0.32	0.27	0.19	0.26

When turning to the importance assigned to collaboration and different collaborative partners, less clear similarities and differences emerge. All-in-all collaboration is important across all industries irrespective of R&D-intensity (compare to Palmberg et al. 2000). Moreover, customers dominate in importance as collaborative partners across

the board, even though they appear as somewhat more important in the high-opportunity sectors. These results thus also reflect the importance that customers play for the origin of innovations. Similarly, the greater reliance on sciences for the origin of new products in the high-opportunity sectors is reflected in a high score for universities and research institutes as collaborative partners. The importance of collaboration with firms in the same concern is higher in the low-opportunity sectors.

### **3.3 Identifying technological opportunity regimes – multivariate analysis**

The comparison above gives some first indication of the prevalence of different types of technological opportunities by their different levels, approximated by R&D-intensities. As suggested at the outset an alternative and more relevant viewpoint progresses ‘bottom-up’ from shared characteristics of the origin and development of innovations to the content of different types of technological opportunities, thus abstracting from predefined R&D-intensities and industrial classifications. The setup for this kind of viewpoint is compatible with principal component analysis.

Principal component analysis is a multivariate technique used to identify a relatively small number of factors that can be used to represent relationships among sets of interrelated variables in a larger dataset. Principal component techniques compute a set of orthogonal components as a linear combination of those variables that minimize the variance for each component. Thus each component represents a unique combination of certain correlated variables with different component loadings (Hair et al. 1992). As a rule of thumb, component loadings below 0.3 are regarded as insignificant while those above 0.5 are regarded as highly significant. Generally speaking, component loadings around 0.3-0.5 are deemed as interesting and reflecting that a particular variable receives a strong loading on a component. (Aronsson 1999). Furthermore, each component explains a share of the total variance in the dataset up to a cumulative total. Table 4 presents the attained six principal components.<sup>3</sup>

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<sup>3</sup> The variables OPTP, OLIC and CONC were dropped from the analysis due to their low explanatory power.

Table 4. Six principal component loadings (only loadings over 0.1 are acknowledged, significant loadings in bold)(n=569)

Variables	'Science-based regime'	'Customized regime'	'Competitive regime'	'Regulatory regime'	'Generic regime'	'Technology oriented'
OPRICE	-0.104		<b>0.813</b>	0.106		0.108
ORIVAL		0.151	<b>0.811</b>			
OMNICHE		<b>0.636</b>	-0.172	0.103		0.268
OCUST		<b>0.790</b>	0.162			
OSCIENCE	<b>0.627</b>	0.129				<b>0.361</b>
OTECH	<b>0.331</b>					<b>0.737</b>
OPRES	<b>0.528</b>	-0.134	0.158	0.286		0.156
OENV				<b>0.862</b>		
OREGLEG		0.116		<b>0.794</b>	0.101	
CCUS	0.129	<b>0.656</b>	0.121		<b>0.361</b>	
CCONS	0.166		-0.116		<b>0.691</b>	
CSUB	-0.163		0.105		<b>0.489</b>	<b>0.625</b>
CUNI	<b>0.771</b>				0.136	-0.124
CREIN	<b>0.650</b>			0.137	<b>0.390</b>	
CCOMP		0.119	<b>0.300</b>		<b>0.610</b>	
Cum. %	13	23	33	43	53	61

Cumulatively the principle component analysis explains 61 percent of the total variance in the dataset with several significant variable loadings. The overall model scores satisfactorily on the Kaiser-Meyer-Olkin measure for sampling adequacy (0.652) testing whether the partial correlations among variables are sufficiently large. Moreover, the model scores significantly ( $p=0.000$ ) on Bartlett's test of sphericity, rejecting the null-hypothesis that the correlation matrix is a unity matrix. However, it should be noted that the analysis hinges on the assumption commonly made when using survey data, that the ordinal nature of the variables can be interpreted as interval-level data.

The aim of explorative principal component analysis is to give meaningful interpretations of the data-generated components, based on the variables that get high loadings under respective component. Thus the first component that explains the largest share of the variance in the dataset is labeled 'Science-based regime'. This type of regime has high loadings on the sciences and new technologies for the origin of innovations. Firms consequently assign great importance to collaboration with

universities and public research institute as a means to internalize these types of opportunities for innovation. (compare to science-based sector in Pavitt 1984).

The second component is labeled 'Customized regime' due the high loadings of the variables assigning importance to the role of market niche and customers for the origin of new products. This is coupled with an importance assigned to customers also as collaborative partners. In this case the typical mode of innovation involves customers as the sources of technological opportunities where new opportunities are customized through innovations to specific market niches or customer segments.

The third component differs quite markedly from the two previous one's in that competitive factors (price competition and rival products as sources) get high loadings. Hence, this component is labeled 'Competitive regime'. Innovation is organized horizontally in collaboration with competitors that receive a positive loading. Moreover, collaboration with competitors and the easy imitability of innovations suggests that knowledge-spillovers are frequent and appropriability conditions are relatively weak.

The fourth component is labeled 'Regulatory regime' since it receives high loading on the importance assigned to environmental issues, regulations and legislation for the origin of innovations. Public research and technology programs are important sources of innovation and collaboration with research institutes is relatively frequent. In this case it is less clear-cut how the results should be interpreted. Environmental issues, regulations and legislation might direct innovative activity in certain predefined directions, constraining technological opportunities. However, they might also be a source of opportunities through new market openings, paving the way for environmentally friendly innovations or standardization of technologies.

Turning to the fifth component labeled 'Generic regime'. This type of regime contains high component loadings for the majority of collaborative partners, suggesting that the knowledge base is relatively generic, knowledge spillovers are frequent and technological opportunities are relatively rich. The generic nature of the knowledge base entailed by this regime might nonetheless also suggest that appropriability conditions may be weaker due to spillovers, where firms will have problems to prevent knowledge leakages during innovation.

The final sixth component has the highest loading on the importance assigned to new technologies as sources for innovation, alongside collaboration with subcontractors. Accordingly, I label this component 'Technology-oriented regime' under the assumption that technological opportunities relate more to the diffusion of technologies rather than the science-base per se, and that the internationalization of these opportunities foremost occurs through the application of components and machinery from downstream suppliers (this component bears resemblance to Pavitt's 1984 supplier-oriented industries). On the other hand, the role of scientific breakthroughs is also noticeable through the high loadings for this variable.

An interesting extension of principal component analysis is to compute standardized component score coefficients for each observation with a mean of 0 and standard deviation of 1. The component score coefficients can then be averaged across sectors and industries, in this context to determine the distribution of different types of technological opportunity regimes by their levels. The distribution of technological opportunity regimes across sectors by R&D-intensity, as a proxy for their different levels, is presented in figure 1.

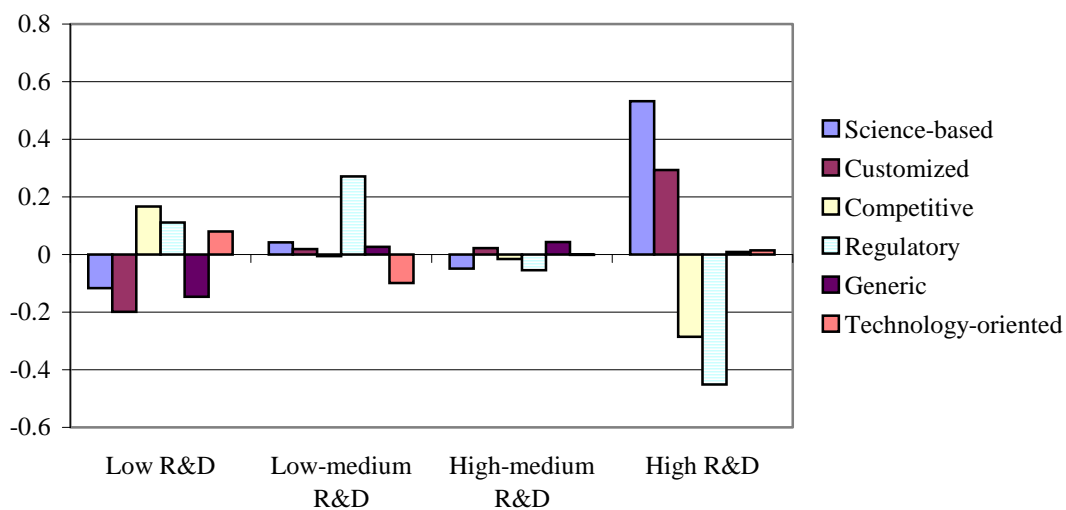


Figure 1. Average principal component scores across aggregate categories of R&D-intensity

The general impression from the figure is that the distribution of the different types of regimes follows some distinct sectoral patterns that are interpretable also in the light of

‘stylized facts’. In the high opportunity sector the dominance of science-based regimes is clear, while this principal component scores negatively in the low-opportunity sectors. This result is readily interpretable in terms of the tight linkage between scientific advances and the role of universities, research institutes and technology programs for the advancement of innovation in science-based sectors.

On the other hand, the competitive regime scores high in the low-opportunity sectors but high and negatively in the high-opportunity sectors. In this case the results can be related to the discussion on industry and technology life cycles, where low-opportunity sectors are characterized by maturing technologies and the prevalence price competition. The ease of imitation also induces horizontal collaboration with competitors.

Apart from the clear distinction between science-based and competitive regimes the high-opportunity sector is also characterized by the customized regime, where market-driven sources and collaboration with customers define technological opportunities. The interpretation of this is in line with the fact that innovations from many R&D-intensive industries tend to be more complex, requiring more specification and collaboration with lead customers (compare to von Hippel 1988, Lundvall 1992, Eliasson 1995).

The regulatory regime, where environmental issues, regulations, legislation and standards are the main sources for technological opportunities appears to be prevalent in the low-opportunity sectors, alongside the technology-oriented regime. The regulatory regime is more difficult to interpret. However, the prevalence of the technology-oriented regime in the low-opportunity sector supports the description of supplier-dominated industries where the lack of in-house R&D capabilities is compensated with opportunities originating from subcontractors, or suppliers (compare to Pavitt 1984). Finally, the generic regime does not seem to discriminate significantly between different levels of technological opportunities.

The distribution of average component score coefficients across aggregate sectors by R&D-intensities is of course a crude point of departure that suppresses some of the strengths of the micro-oriented data at hand. Thus, when moving beyond the aggregate sectors, it is expected that the distribution of different regimes is more diverse. Since

the dataset suffers from unit non-response in certain industries, and for the sake of clarity, only the industries with a reasonable number of observations are considered. The distribution of different regimes over these industries is presented in figure 2.

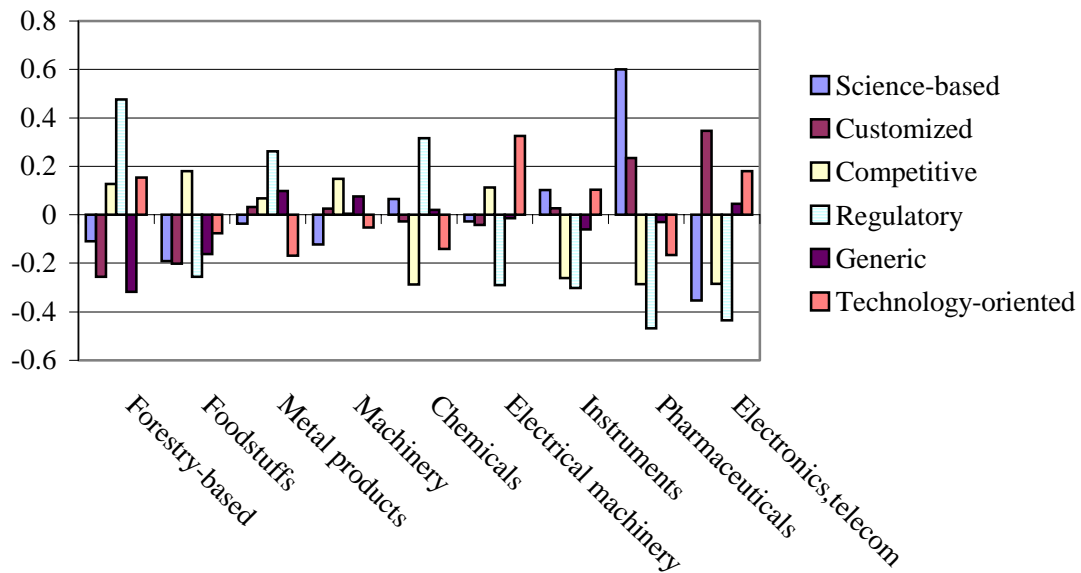


Figure 2. Average principal component scores across industries by R&D-intensity

In this set-up of the high-opportunity industries pharmaceuticals receives a very high score for the science-based regime as expected, confirming that especially the pharmaceuticals industry is characterized by a very specific pattern compared to the others (Gambardella 1995). Except for instruments and chemicals, in most other industries this regime scores negatively. More generally, the high-opportunity pharmaceuticals, electronics, telecom, and instruments industries all share a combination of the customized and the science-based regimes, or the technology-oriented regime. The technology-oriented regime is also prevalent in the electrical machinery and forestry-based industries that are described as supplier-dominated in Pavitt's (1984) taxonomy.

In the low-opportunity industries both forestry-based and foodstuffs industries are characterized by the competitive regime. This type of regime is much less prevalent in the other industries of higher R&D-intensity, with the exception of the machinery industries. In the forestry-based and the metal products industries the regulatory regime dominates, while the generic regime scores positively in the metal products and machinery industries, and significantly negatively in the forestry-based industries.

Similarly to the high-opportunity sectors, it is evident that different types of regimes coexist.

### **3.4 Technological opportunities, patterns of innovation and competence requirements**

One advantage of principal component analysis is the possibility to define surrogate variables that summarize the content of each principal component based on the underlying loadings for the different variables in the original dataset (Hair et al. 1992). The surrogate variables will sharpen the interpretations that otherwise would be blurred since average component scores consist of a linear combination of all variables in the original dataset, even those that score negatively.

In the following the principal component analysis is elaborated upon in direction that enables the examination of the interrelationships between different types of technological opportunities, patterns of innovation and related competence requirements. This is done through simple Spearman's rank correlations between the variable that receives the highest loadings under each component in the principal component analysis in table 4, as surrogate variables, and the set of binary and categorical variables in table 5.<sup>4</sup> The associated p-value is based on a non-parametric test of the null-hypothesis that the related Rho value equals to zero, or that no correlation is present.

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<sup>4</sup> The surrogate variables were also defined as the mean score of the three original variables with the highest loadings under each component. This resulted in less conclusive result, although broadly in line with those in table 5.

Table 5. Rank correlation of different types of technological opportunities, competence bases and expansion

Sources of opportunity	Significance level of Spearman rank correlation							
	Nature of competence base				Expansion			
	Radicalness	Focused	Diversified	Processes	Time to return of profit	Growth of turnover	Expected growth of turnover	Technological novelty
Science-based	+++	++	--	0	--	++	+++	+++
Customized	0	0	+	0	+	0	0	0
Competitive	--	--	0	+++	+++	+	+++	--
Regulatory	0	0	0	0	0	0	0	0
Generic	0	0	0	0	0	0	0	+++
Technology-oriented	+++	0	0	0	0	0	++	0
+++/-- Positive/negative correlation with p-value significant at the 0.01 level								
+/- Positive/negative correlation with p-value significant at the 0.05 level								
+/- Positive/negative correlation with p-value significant at the 0.10 level								

The first set of variables distinguishes between different types of innovations and competences bases underlying different types of innovations, assuming that the nature of innovation also reflects some features of competence requirements. The radicalness of the innovations distinguishes innovations that are incremental both to the firm and the markets at one extreme, and radical both to the firm and the markets at the other extreme on a scale from 0 to 3. (compare to the OECD Oslo Manual from 1997). A focused knowledge base implies that the development of distinct core technology characterizes the nature of innovation, while a diversified knowledge base describes innovations that draw on competencies to combine and integrate different components and modules in new ways (compare to the distinction between modular and architectural innovation in Henderson & Clark 1990). The final category of knowledge base captures innovations where the development of process technologies has been the most important type of competence, and thus where process and product innovations are tightly intertwined (Archibugi et al. 1994).

According to the results by different types of technological opportunities, the science-based, competitive and technology-oriented regimes correlate significantly with different types of competence bases. The science-based regime correlates positively

with the radicalness of innovations as well as focused competence bases. The correlation is negative in the case of diversified competence bases. These results are in line with the description of science-based sectors, where radical and modular innovation in core technologies dominates over incremental and architectural innovation. On the other hand, the competitive regime is negatively associated with the radicalness of innovation, as well as focused competence bases. In this case, the development of process technology stands out, suggesting that process and product innovations are intertwined in this type of regime that is characterized by price competition and the ease of imitation (compare to Abernathy & Utterback 1978, Utterback 1994).

In addition to competence bases, variables capturing what is termed ‘expansion’ are included. They reflect how fast the innovations expand in terms of growth and technological novelty. They are assumed to capture some crude feature of the ‘efficiency’ of different types of regimes at the level of innovations. The first variable captures innovations that have returned profits faster than the average (the average is 3 years). If profits are returned quicker than average, the innovation is characterized by rapid growth either due to its commercial success or market conditions more generally. However, the time to return profits will also depend on the size of R&D and other investments. Therefore expansion is also captured as the share of turnover of the innovating firm that the innovation has generated during the last three years after commercialisation, as well as the expected during the next three years (1 for innovations with growing share and 0 otherwise). Finally, the technological novelty of the innovations is included through a variable that distinguishes between innovations that are patented and those that are not.

In this case, the science-based regime correlates significantly positively with all variables except with the time required to return profits. Hence, innovations developed in science-based regimes generate profits with a lag, but are clearly associated with both higher realized and expected growth of turnover (pharmaceuticals is the obvious example). Moreover, the correlation with technological novelty by patents is in-line with the innovations being radical both to the firms and the markets. For the competitive regime the associations with the variables capturing expansion are similar, suggesting that incremental innovation that draws on existing competence bases and

process innovation also implies growth albeit through different mechanisms. In this case also the generic regime correlates with technological novelty of the innovations. Finally the technology-oriented regime inconclusively only correlates with the expected growth of turnover, while no correlations are present in the case of the regulatory regime.

#### **4 CONCLUDING DISCUSSION**

The purpose of this paper is to trace sectoral trade off's between different types of technological opportunities, the organization of external collaboration and their joint association with patterns of innovation and related competence requirements. The theoretical discussion draws on the literature on technological regimes and especially the interrelationships between technological opportunities and patterns of innovation. The point of departure is that different types of innovations also capture some features of related competence requirements. The data used is based on the identification of innovation outputs and a related new and unique survey.

The statistical analysis suggests that the data is useful for identifying the content of different types of technological opportunities and their distribution across sectors and industries. Using multivariate analysis six distinct types of technological opportunity regimes were identified, named the science-based, customized, competitive, regulatory, generic and technology-oriented regimes. When these were averaged across sectors some quite distinct pattern emerges. In the low-opportunity sectors the competitive and regulatory regimes dominate, suggesting that price competition, rivalry, collaboration with competitors, as well as environmental and regulatory issues, are important sources of opportunities.

In the high-opportunity sectors the role of science-based and customized regimes is paramount, indicating that higher opportunities are also associated with scientific breakthroughs, new technologies, market niche collaboration with and specialized knowledge producers. These results are broadly in line with what is suggested in the literature of industry or product life cycles, technological regimes and sectoral

taxonomies (compare to Abernathy & Utterback 1978, Pavitt 1984, Ceseratto & Mangano 1993, Klevorick et al. 1995, Malerba & Orsenigo 1997).

On the other hand, when the analysis is taken beyond aggregate sectors the picture is more varied with the coexistence of different types of regimes across different industries. In this case it becomes evident that broadly defined low-opportunity sectors also conceal 'pockets' of technology-oriented, science-based and generic opportunities, with the forestry-based, metal products and chemicals industries as the best examples. Similarly, only the pharmaceuticals industry stand-out clearly as a science-based industries, whereas most other high-opportunity industries are characterized by a greater mix of different types of opportunities. These results strongly question the relevance of using pre-defined industrial classifications for tracing and analyzing the nature and dynamics of innovation or as dummies in regression analysis. Moreover, they militate against defining technological opportunities merely by levels of R&D-intensities rather than their content. It might be precisely the interaction of different types technological opportunities that is crucial for the dynamics of innovation.

The multivariate analysis was elaborated upon through simple rank correlations between different types of technological opportunity regimes and the nature of different types of innovations in terms of the nature of the competence and their expansion, or growth and technological novelty. The results indicated that science-based regimes are associated with radical innovation, focused competence base, rapid growth and high technological novelty, even though profits are returned with a lag. The competitive regime is characterized by the opposite pattern, where innovations tend to be incremental, product and process innovations are tightly intertwined and the technological novelty of the innovations is low. On the other hand, growth of the innovation's share of turnover is rapid and profits are returned quickly. The technology-oriented regime is positively associated with radical innovations and expected high growth, while the results are less conclusive for the customized, regulatory and generic regimes (where the technological novelty of innovations is high).

Even though the nature of innovations only imprecisely capture underlying competence requirements, a synthesizing discussion concerning the interrelationships between different types of technological opportunities, patterns of innovation and related

competence requirements is appropriate. In the case of the science-based regime, the results are as expected. Opportunities arising from scientific breakthroughs and the diffusion of new technologies require collaboration with universities and research organizations. These are translated into radical or modular innovations that draw on focused competence bases and embody new scientific and engineering principles, and are technologically novel. This points towards the importance of developing outward-looking absorptive capabilities in high-opportunity sectors to absorb and adapt external knowledge. These types of capabilities, in turn, reflect the expansion in terms of the growth of the innovations share of turnover (Cohen & Levinthal 1990, Eisenhardt & Martin 2000, compare also to results in Becker & Peters 2000).

Innovations developed within the competitive regime likewise expand rapidly and also return profits quickly. The emphasis on horizontal collaboration with competitors, incremental innovation and the close linkages between product and process innovations nonetheless suggest that in-house activities are relatively more important than external collaboration. One interpretation could be that the role of inward-looking transformative capabilities overshadows outward-looking absorptive capabilities (Garud & Nayyar 1994). Instead of external collaboration, the competencies to maintain, continuously reactivate and synthesis available process technology is the key. Moreover, the close linkages between product and process innovations question the often used and somewhat artificial distinction between product and process innovations. In many traditional industries the competencies to integrate, adjust and run machinery and equipment is a core competence, as Laestadius (1998) suggests with the example of the Scandinavian pulp & paper industry.

The interpretations of the remaining types of regimes are trickier. The customized regime seems to return profits quickly, while the nature of innovation could be labeled architectural due to the weak association with diversified competence bases (Henderson & Clark 1990). The regulatory regime is inconclusive, while the generic regime captures a need to collaborate with a range of different partners. The significant association between the generic regime and the technological novelty, measured through patented innovations, suggests that spillovers associated with collaboration are mitigated through strong intellectual property rights.

This paper also raises some considerations for further research. One limitation is the static set-up of the analysis. It surely is the case that both the levels and contents of technological opportunities change over time and the life cycle of products and industries. An acknowledgement of this type of dynamics would be possible with regards to the innovation database but would require firm-level time series data on R&D-intensities. On the theoretical level, the synthesis of the concept of technological regimes and competence-based viewpoints of the firm need further considerations. The variables capturing competence bases underlying different types of innovations also need refinement if possible. Finally, the service sector should be incorporated in the analysis.

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## APPENDIX 1 – the OECD taxonomy of R&D-intensities

The OECD has established certain threshold levels, defining the technology intensity of 22 manufacturing industries, which account for some 95 percent of industrial R&D. The R&D data is then aggregated to the industrial level, whereby the share of these different industries of total manufacturing output, employment, value added and exports can be calculated. The threshold levels relate the R&D expenditures to total sales of the different industries as a weighted average across 11 OECD member countries (weighted by sector and country) in the following way: industries spending over 4 percent of total output/production on R&D are classified as high-tech, those spending between 1-3,9 percent are classified as high-medium- or low-medium-tech, and the remaining industries with R&D expenditures below 1 percent of total sales are classified as low-tech. The result is the ranking list presented in table 10 below:

Table 6. The ranking of industries according to R&D-intensity (OECD 1997)

High R&D-intensity	Medium-high R&D-intensity	Medium-low R&D-intensity	Low R&D-intensity
1. Aerospace 2. Computers, office machinery 3. Electronics-communications 4. Pharmaceuticals	5. Scientific instruments 6. Motor vehicles 7. Electrical machinery 8. Chemicals 9. Other transport equipment 10. Non-electrical machinery	11. Rubber and plastics 12. Shipbuilding 13. Other manufacturing 14. Non-ferrous metals 15. Non-metallic minerals 16. Fabricated metals 17. Petroleum refining 18. Ferrous metals	19. Paper and printing 20. Textiles and clothing 21. Foodstuffs 22. Wood and furniture