

EVOLUTIONARY PATTERNS OF TECHNOLOGICAL COMPETENCE  
ACCUMULATION: A MEASUREMENT PROPOSITION

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# **1. INTRODUCTION: COMPETENCIES, DYNAMICS AND FIRM BEHAVIOUR**

Lately the technological and organisational dimensions of performance creation in turbulent environments has been devoted more attention. One example is a special issue in Strategic Management Journal in 1997 (Henderson and Mitchell, 1997). The increased rate of technological change leads to both globalisation, but also turbulence at the industry level<sup>1</sup>. In sectors with rapid technological change clearly this effect on the technological and organisational competencies has implications for management of technology.

The resource-based theory argues that firm-specific resources that are specific and hard to imitate form the basis for a competitive advantage of the firm. But the resources alone are not enough to form an advantage in turbulent environments, now the focus is shifted towards the configuration of competencies and thus the relationships between the competencies become a key factor. For business economics the challenge is now to theorise on complex relations e.g. how can the firm handle turbulence to, not just stay in business, but actually create new businesses through competence accumulation<sup>2</sup>. Similarly, how do the changed competitive conditions influence the set-up of firm competencies. Obviously, this paper cannot deal with these issues in-depth, but will suggest a typology of competence accumulation, which combines the level of competence with the change in competence to obtain the type of competence accumulation that the firm has initiated in each field of technology.

Thus an underlying premise is the ability of the firm to act and react on the one hand but also the uncertainty caused by the rapid changes in the environment on the other. This premise is built into the empirical measure of competence through the use of the specialisation index (see section 3). The measure takes the activities of the firm (i.e. the decision to act) and the activities of the firms in the environment (i.e. the changes in the environment makes it more difficult for the firm to build new competencies) into account.

## ***1.1 Road Map***

The paper is divided into two analytical sections: The first develops the typology of competence accumulation and explores the competence configurations for a number of firms.

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<sup>1</sup> The term industrial dynamics is used interchangeably with the term environmental turbulence.

<sup>2</sup> As the focus is solely on technological competencies the term 'competence accumulation' and 'competence dynamics' are used interchangeably throughout the chapter.

The second part then continues by comparing the firm configurations of competence accumulation to each other and from these profiles deduces three behavioural strategies.

The chapter proceeds in the following way: Section 2 outlines the theoretical arguments for the relationship between firm-specific competencies, firm behaviour and industrial dynamics and deduces two research questions. Section 3 shortly presents the choice of method and the data set. Section 4 develops an analytical framework, in which competence dynamics can be measured along five dimensions each representing a different technological field. Section 5 presents the map of each firm and the findings for the single firm is discussed. Section 6 then moves to establish a relationship between competence accumulation and firm behaviour. The implications for management of technology are outlined and the competitive conditions under which the results apply are discussed further.

## **2. THEORETICAL ORIGIN AND OPERATIONALISATION**

The recognition that both internal organisational factors and the interaction with the competitive environment shape the evolution of firm competencies and performance will be explored and the research questions derived.

The relationship between the dynamics of competence activities and firm behaviour becomes vital in the special case<sup>3</sup> of turbulence in the environment as the need for faster reactions become apparent. The decision to build or leverage competencies is based on an assessment of the degree of uncertainty arising from the '*(a) uncertainty about the ability of the firm to sustain knowledge innovation or imitation and (b) uncertainty about the benefits to be derived if a firm tries to use such knowledge*' (Sanchez *et al.*, 1996: 25). But this decision also has an impact upon the environment: '*change in a competitive environment results from both competence building and competence leveraging activities of firms*' (Sanchez *et al.*, 1996: 24). The discussion of these effects is divided into two parts in this paper. First an in-depth treatment of the relationship between competence accumulation and industrial dynamics is discussed, which is then related to firm behaviour.

### ***2.1 Competence Accumulation and Industrial Dynamics***

#### **Theoretical Origin**

Processes of competence accumulation are co-evolutionary driven by strategic behaviour, competencies, and environmental change as suggested by Dosi and Malerba: '*In a situation of*

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<sup>3</sup> Increasingly the case of turbulence is less and less a special case as the rapid changes in technology and the move towards globalisation becomes normal.

*environmental complexity, [...] current capabilities affect current strategies, but also current strategies affect short-term performance as well as the long-term accumulation of capabilities'* (1996: 12). The introduction of dynamics into the competence notion implies that the temporary states of the competence base act as a platform for new developments and thus the changes that expand or diminish the platform becomes vital for firm behaviour. Furthermore, the investigation of competence dynamics and environmental complexity must take these changes and place them in a key role.

The interdependencies between the processes of competence accumulation and the external environment have mutual impacts upon each other: *'firms develop capabilities, either through choice or selection, that then shape the environment which, in turn, further shapes capabilities'* (Henderson and Mitchell, 1997: 12). The dynamics in the environment creates a need for the firms to explore the window of technological opportunities and turn them into an advantage: *'A firms true competitive advantage for coping with turbulence is not in its current distinctive competencies, but in those that it can grow tomorrow. A firm's organizational ability to leverage and strengthen existing competencies is important, but it must be equally adept at diversifying its competence base'* (Chakravarthy, 1997: 82). Furthermore, Lewis and Gregory gave a self-evident observation (1996: 146): *'[...] any analysis of competencies must include a time dimension'*. In combining these two statements it is given that any analysis of competence accumulation must include, not only the external environment, but also the dynamic interactions, which shape the competence patterns over time. Hence, the relationship between the external dynamics and the internal dynamics creates persistent differences across firms over time. *'The [...] perspective opens the conceptual lens of **strategy** to admit a more **dynamic** view of competition in which **differences in idiosyncratic firm capabilities** matter greatly and are the basis for much of the **competitive advantage** a firm may enjoy in its product markets in the long run'* ((Sanchez *et al.*, 1996: 3). Emphasis added by author).

### **Operationalisation**

From a theoretical point of view a relationship is established between competence accumulation and the industrial dynamics, but the degree to which these dynamics (internal as well as external) interplay and influence each other is still unclear. The first step is therefore to establish:

HOW CAN CHANGES IN THE PROFILE OF TECHNOLOGICAL COMPETENCIES, I.E. THE PROFILE OF COMPETENCE DYNAMICS, BE MEASURED FOR THE SINGLE COMPANY?

This question is solved through the development of a typology of competence accumulation to identify the type of competence accumulation and explore the differences across firms within telecommunications.

The fundamental idea underlying the typology is to identify the type of competence dynamics that the firm undertakes in each technological field. The first step is to calculate the cumulated level of specialisation in each period of time. Praest (1998: ch. 5) established empirically<sup>4</sup> that the same sample of firms engage in cumulated knowledge production and reproduction and therefore the level of competence must be regarded as cumulative. In each field the firm will pursue one of four types of competence accumulation, building, leveraging, erosion or no competence.

The data used to operationalise the typology, but also to develop the patterns of behaviour of firms are available in appendix A. For each firm the changes from observation to observation<sup>5</sup> and the sign of the change compared with the level of specialisation identify the type of competence dynamics. The actual criterion for each of the types of competence dynamics is presented in section 4 along with the theoretical definition.

## ***2.2 Firm Behaviour and Industrial Dynamics***

### **Theoretical Origin**

The previous section stated that competence accumulation, i.e. the internal dynamics and turbulence, i.e. the external dynamics act as drivers of performance creation. But none of these have been coupled with the overall behaviour of the firm to discuss how the competence dynamics in single well-defined areas of technology is related to firm behaviour given the above constraint.

The foundation of competence accumulation is the production of knowledge. To discuss this the terms exploration and exploitation are used to represent the diverse results of knowledge accumulation in terms of either production or reproduction of knowledge. Levinthal and Myatt (1994: 47) discussed the difference between these as: '*the returns to existing knowledge and capabilities tend to be more certain and immediate than the returns to the exploration of novel capabilities and opportunities*'. Therefore the outcome of the knowledge production process is based on search in the external environment and called 'exploration', whereas

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<sup>4</sup> 12 of the 16 firms change their knowledge base cumulatively, the remaining 4 firms were not significant and therefore no conclusions could be drawn based on the data.

<sup>5</sup> An observation is the change between two time intervals (e.g. the difference between (1980-82) and (1983-85) is one observation).

'exploitation' refers to reproduction of existing knowledge sources searched within the firm's own knowledge base.

According to March (1991: 7) exploitation captures refinement, choice, implementation, and selection, whereas exploration embraces variation, risk taking, experimentation, discovery, innovation, and search. Or as stated by Marengo (1993: 554): *'the trade-off between communality and diversity of knowledge is also strictly connected to the trade-off between exploitation and exploration.'*

These knowledge-creating processes can clarify how especially technological competencies can be created within the firm and how this can be analysed. Both competence building, leveraging, and erosion are analysed as arising out of a sequence of knowledge creating processes. These competence dynamics then led to the decision to rely on one of three strategies: to rely on exploration, exploitation or a mixture of those two. Each of these decisions leads to different behavioural patterns of the firms.

The exploration strategy creates flexibility but also fragility in the competence base, as the frequent changes through adaptation of new knowledge scatters the knowledge base and may endanger the continued existence of the firm. On the other hand the exploitation strategy creates stability and ensures that the competence base only develops in very small steps. Thus the exploration strategy gives instability and uncertainty but can give high economic payoffs, which can finance the future investments in new competencies. The exploitation strategy may in times of crisis and change be the anchor against erosion of the competence base and can take the firm into the next period, but the potential benefits are lower. Finally the mixed strategy, which balances exploitation and exploration, should give a sound foundation for the future if the management level can guide the shifts between the two strategies. If not the firm may end in a state of flux, in which the competence base cannot address the problems of the firm and therefore may lead to exclusion in the end.

Competence leveraging is then defined as reproduction of existing knowledge into new opportunities, with a fairly limited exchange in the market. The processes induce quantitative changes and lead to exploitation. As an alternative, competence building is the outcome of a sequence of searches for new knowledge through the external environment. These processes induce qualitative changes that enable the firm to explore new opportunities and lead to exploration in the long run. Finally, the firm may engage in a mixture: *'the basic problem confronting an organization is to engage in sufficient exploitation to ensure its current viability and, at the same time, to devote enough energy to exploration to ensure its future viability'* (Levinthal and March, 1993: 105). But this strategy may also be a result of

involuntary processes of adaptation to changes in the external environment. The differences between these strategies in terms of measurement are discussed in the following section.

### **Operationalisation**

The challenge is now to establish an empirical representation based on the profiles of competence accumulation to identify the changes in firm behaviour. To do this, the five pre-set technological dimensions that underlie the competence typology must be replaced by an operationalisable definition of the three strategy types.

It was argued that exploration is the outcome of repeated processes of competence building, which leads to high rates of change and fluctuations in the competence base, i.e. the result is a fragile structure. Exploration at the overall behavioural level implies that clear shifts in the single fields and across time must be undertaken. These create clear shifts in the environment in both the single fields and at the behavioural level, which are enabled by the broad search in new areas (search in areas with a low degree of relatedness).

Through measurements this is found by comparing the profiles in each period with the changes in competence accumulation that lead to the present state. A comparison from observation to observation shows that these firms have profiles, which changes often and mostly outwards in the space<sup>6</sup>. The reason being, that the behavioural long-term patterns reflect the overall changes in the profile (defined as the type of competence dynamics in each technological field) across the observations and thus only indirectly reflects the dynamics in each field.

#### HOW CAN FIRM BEHAVIOUR BE DEDUCED FROM THE COMPETENCE PATTERNS OF SINGLE FIRMS?

*Exploration* thereby combines the complete reconfiguration of the competence pattern and the active search to attempt catching-up on the leading frontrunners. It is expected that only a few firms rely on exploration, but that with increasing technological change the need for exploration will increase. *Exploitation* represents those patterns, which over time remains fairly stable and just keeps up with the pace of the environment. Those firms can build competencies in several fields as long as no changes are observed. An expected result is therefore that a majority of the firms should follow this behavioural strategy.

Finally, the *mixture* is illustrated as a sequence of shifts, which result in a fluctuating profile. Recall that the explorative pattern was argued to be similar to this, though in the mixture the

shifts move in both directions. In a case of good timing, the firm will develop a strong and flexible competence base in line with the suggestions from the theoretical section, whereas with lack of timing the result will be a very unstable competence base.

The firm can be 'clever' and then follows the theoretical proposition that a mixture of exploration and exploitation creates a sound basis for long term performance. This strategy leads to shifts inwards as well as outwards. The firm can also be mixing as a result of the dynamics in the environment, which forces the firm to rely on pure adaptation to the changes in the environment. The changes will again be very frequent and more in fluctuation than for the explorative patterns. Thus the profiles of change will be very alike no matter if the firm is a 'clever' firm with a deliberate pattern of mixture or if the firm stands under pressure from the environment.

### **3. CHOICE OF METHODS AND DATA**

The use of output data from the innovation process is important for measurement of competence accumulation. The number of available data sources is restricted because the data should reflect the knowledge underlying the competence base. A first type of data is the innovation survey<sup>7</sup> (e.g. the CIS as implemented by the EU). The innovation survey is based on questionnaires directed at the firm and not towards specific technologies. This type of data is less valuable than the patent data, which reflects the activities leading to new technologies. The advantages of using patents are three-fold: first the level of analysis can be the firm or the technology, second, the data point is objective and finally, the classification of technologies is very detailed (IPC). Furthermore, patents reflect, as a rough proxy, the knowledge generated within the firm. The association of patents to competencies is thus based on the knowledge content of the patent application, in which the firm implicitly states both the tacit and explicit knowledge embodied in the research team (which can be either a single inventor or a team of researchers).

The data covers 16 multinational companies' patent applications (at EPO and WIPO) within five technological sub-fields in telecommunications from 1980-94. These data are pooled in five intervals: (1980-82, 1983-85, 1986-88, 1989-91, and 1992-94)<sup>8</sup>.

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<sup>6</sup> Please observe that firms relying on competence building in all fields will not be seen as explorative as this is a stable behavioural strategy, i.e. exploitation.

<sup>7</sup> Archibugi and Pianta (1996) provide a comparison of patent data and innovation surveys in the analysis of industrial innovation.

<sup>8</sup> The application of intervals is required due to limitations in the data set. Only a small number of patents (especially in the first years) are available for the single firm in each year. To get statistical valid

The selection of data follows in five steps.

First, the technological field of telecommunications<sup>9</sup> is defined using the IPC classification, and secondly divided into five sub-fields: 'public and private switching', 'electrical transmission', 'optical transmission', 'radio transmission', and 'end products and terminals'. The boundaries of the technological fields are not unique, which means that a high degree of overlap is found, especially between 'public and private switching' and 'electrical transmission', and between 'public and private switching' and 'radio transmission'.

The implications of these overlaps are quite interesting. In the 'evolutionary' theory of the firm one of the characteristics assigned to competencies is cumulateness, which means that competencies are created based on existing knowledge. As new knowledge is generated it will rely on the knowledge that is closely related and thus increase the interdependency. Thereby the relationship becomes more intertwined through the creation of new knowledge over time. An example of this relationship is the technological development of mobile equipment, which from a technological viewpoint is based partly on the development of the wired telephone systems.

These interdependencies are reflected in the analysis through the use of intervals, in which the outcome in one period depends on the activity of the previous periods (the knowledge in one time interval is obtained in the next and so on). The time intervals in the empirical sections then become (1980-82), (1980-85), (1980-88), (1980-91) and (1980-94). The additional patent applications account for the creation of knowledge and therefore the accumulation of technological competencies.

The choice of patent data as indicator of technological competencies is rather new (e.g. Cantwell 1989 and 1993, Miyazaki 1994, Malerba and Marengo 1994, Patel and Pavitt 1995, Schmoch 1995). In this paper I argue that despite the problems associated with the use of patents, patent data still has a lot to say about competence accumulation and knowledge generation.

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calculations the data are pooled throughout the paper. The intervals are kept as small as possible to get more observations, which are defined as the **change** between two time intervals.

<sup>9</sup> The boundaries of the telecommunications industry follow the definition of the technological field of telecommunications. The two terms are therefore used interchangeably. The results on the industry dynamics are based on the activity of the 16 firms in the sample. These firm's possess 58.5% of the patent applications and I argue that this is a large enough portion to give insights into the overall industrial dynamics.

Then the 16 largest firms in terms of numbers of patent applications were identified, as well as the number of patent applications within each sub-field.

Specialisation indices  $RPA^{10}$  has been preferred as the most relevant indicator because it includes both the activities of the firm, the activity of all firms in the technological field and the whole industry. The RPA indicator enables analysis of the interdependencies between the single firm and the industry, and relatedly the accumulation of technological competencies and industrial dynamics.

The basis of the analysis is the specialisation index, which was first used on technical change by Soete and Wyatt (1983).

The index is calculated based on the revealed technological advantage (RTA):

$$RTA = \frac{\frac{P}{\sum_i P}}{\frac{P}{\sum_{i,t} P}}$$

In the RTA 'i' is the sum of the firms in the sample and 't' is the sum of the technological fields. This indicator has the neutral value of 1 and yields values between 0 and infinity. This is highly skewed, and therefore not suited for comparison of and interpretation as distances. In order to be able to make this direct comparison a mathematical transformation can be applied and the relative patent advantage defined.

The RPA gives value to the degree of specialisation of a firm within a specific technology area.

$$RPA = 100 \ln RTA$$

$$RPA = 100 * \tanh \frac{RPA}{100}$$

⇓

$$RPA = 100 * \frac{(RTA^2 - 1)}{(RTA^2 + 1)}$$

The indicator yields values in the interval [-100: 100] with a neutral value of 0. Thus the values can be compared to each other and interpreted as distances.

As the RPA includes the patenting activities of the competitors through the Pi the accumulation of technological competencies depend upon the growth in overall activities.

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<sup>10</sup> Due to space limitations we refer to some introductory texts for the definitions and methods of calculation. See e.g. Grupp (1998) for a general introduction into indicators, among others specialisation index and patent share; Soete and Wyatt (1983) on the definition of the specialisation measure, and finally Pavitt (1988) on the use and abuse of patent data.

Hence to maintain the level of specialisation demands a growth rate of the single firm within the technological field that is equal to the overall growth.

Thus, the indicator accounts for the dependence of the firm on the activities of the competitors and of all other activities in the industry.

Since the paper develops completely new methods only descriptive analyses are carried out, later more in-depth studies should follow.

## **4. A TYPOLOGY OF COMPETENCE ACCUMULATION**

The accumulation of technological competencies within the firm is focused on the process of activation of the firm's functional capabilities, knowledge, and organisational competencies while being constrained by an external environmental element and the path taken by the firm earlier. The environmental constraint grasps both the impacts from the external dynamics created by the competitor's accumulation of competencies and other exogenous factors.

The question to explore is accordingly:

HOW CAN CHANGES IN THE PROFILE OF TECHNOLOGICAL COMPETENCIES, I.E. THE PROFILE OF COMPETENCE DYNAMICS, BE MEASURED FOR THE SINGLE COMPANY?

The simultaneous activities of creation within every firm affect the competitors in the industry, as the new knowledge both redefines the technological opportunities and outdate existing knowledge and thereby decrease the value of the existing competence base of the firm. The dynamic impact upon the firm arises from the internal search for knowledge and the externally created technological competencies. A typology of competence dynamics should therefore address all these issues, creation of competencies, maintenance of the existing competencies, and also erosion of competencies either through changes in focus or by pure ignorance. Four types summarise these effects:

### ***4.1 Competence Building***

According to Sanchez, Heene, and Thomas (1996: 8), '*competence building creates new options for future action for the firm in pursuing its goals*'. Therefore competence building is not just a response to the pressure of the market, but is also a response to internal demand for new assets to operate in conjunction with the existing knowledge base. Competence building is pro-active in the search pattern involving high R&D costs and high uncertainty about the viability of the outcome.

From a measurement perspective, a firm builds competencies, if the **level of specialisation is neutral or negative<sup>11</sup> and an increase is noted, which indicates that relative to the competitors the firm increases the competence level** in the particular technological field.

The RPA reflects competence building when:

$$(-75 \leq RPA \leq 15) \wedge (\partial RPA > 10)$$

Or :

$$\partial RPA > 25$$

The last term becomes valid as the excessive change in specialisation outweighs the level of competence. These dramatic shifts in competence are especially seen for Nokia. Nokia is a firm that has restructured its competence profile through shifts in technological trajectories and thereby gained competence in new technological fields.

It is important to note that 'building' does not automatically imply that the firm is strong in the field. It is often the case, that the competence base is increased as part of a search process for new opportunities, but that the knowledge is not sufficient to leapfrog the competitors because of the external dynamics. Thus, temporary processes of competence building are likely to be seen, which do not result in a sustained position.

#### ***4.2 Competence Leveraging***

To leverage competencies requires continued reproduction of the existing competence base to address the perceived problems and to a smaller degree the changes in the environment. Thereby can existing competencies be applied to new markets in ways that do not require a change in quality but which initiates a quantitative change. Competence leveraging is, thus, a response to the changed conditions or the formulation of a problem and is, as such, more narrow in the search path; i.e. it is a reactive process.

In measurements, leveraging requires as a minimum that the firm's competency remains unchanged, compared to the growth of new knowledge in the environment. A firm leverages or maintains its competencies in the technological field, if the **level of specialisation in the first period is neutral or positive and the change compared to all other firms induces only a minor increase in the competence base**. Thus the firm leverages the competencies when:

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<sup>11</sup> In the extreme case the firm can build competencies upon a positive level of specialisation, but often the cumulative nature of knowledge creation will prevent large steps ahead through creation of new knowledge.

$$(-15 \leq RPA \leq 100) \wedge (-10 \leq \partial RPA \leq 10)$$

Or :

$$RPA < -40$$

### 4.3 Competence Erosion

In adding a perspective of divestment in competence accumulation the case of firms assigning less resources or simply leaving the special technological areas is included. The rationale behind such a decision can be either to reallocate resources to strengthen the focus on alternative opportunities, which is an unintentional choice of 'not acting' in other fields or the firm can simply forget the competencies by not using them. The speed with which the competitors change their competence base will immediately have a negative influence on the value of these leftover competencies. Once this process has started it may prove to be difficult for the firm to move back in and regain the lost. Competence erosion may therefore have both an intentional active element and an unintentional environmental driven aspect. These are not distinguishable from each other with this dataset.

The competence base is eroded if **the level of competence is decreased compared to the environment no matter the initial level of specialisation**<sup>12</sup>:

$$\Delta RPA < -10$$

As noted under competence building, the firm is not necessarily passively losing all the competencies, and therefore should erosion not be mixed with the often-stated case where major new innovations destroy whole sets of competencies (see e.g. (Tushman and Anderson, 1986) and (Kleivorick *et al.*, 1995)).

### 4.4 No Competencies

Small firms or highly specialised firms will often leave particular technological fields with no activity, i.e. competence or so little activity that the firm has no competence. Another case is the firm that despite activities in the field is left with a position with no competence (i.e. without any strategic value). The reasons for a poor position in one field can be found in a move into another direction by the firm itself or through creation of better competencies by the competitors in that field. The fourth element in the typology is thus interpreted as a position, which is defined by a low level of specialisation and not by a change in direction. If the firm has a **level of specialisation below -75 it has no competence.**

$$-100 \leq RPA < -75$$

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<sup>12</sup> An unchanged level of activity will most likely lead to competence erosion because of a general increase in the propensity to patent.

This level is set arbitrarily<sup>13</sup>, as it is certain that the company pay no or only limited attention to the technological field.

## 5. FIRM-SPECIFIC CONFIGURATIONS OF COMPETENCE ACCUMULATION

Based on the competence typology a graphical representation of the competence profile of each firm is given in this section and some results for a firm are discussed. A general point regarding the competence types has to do with the nature of the specialisation index. Although the index is symmetric, a high level of specialisation is difficult to maintain, as the requirement for an unchanged RPA is that the growth in patent applications must be equal to that of all firms taken together. A high level of specialisation thus requires continued growth to maintain the position of the firm. Remember that we are not looking for the competence *level* but the competence *dynamics* (a second-order connotation). This will for the profiles mean that even small set-backs in the competence accumulating activities results in slides from competence building towards competence erosion. But, it should also be clear that a position in competence erosion only indicates a slow-down and not necessarily a loss of position.

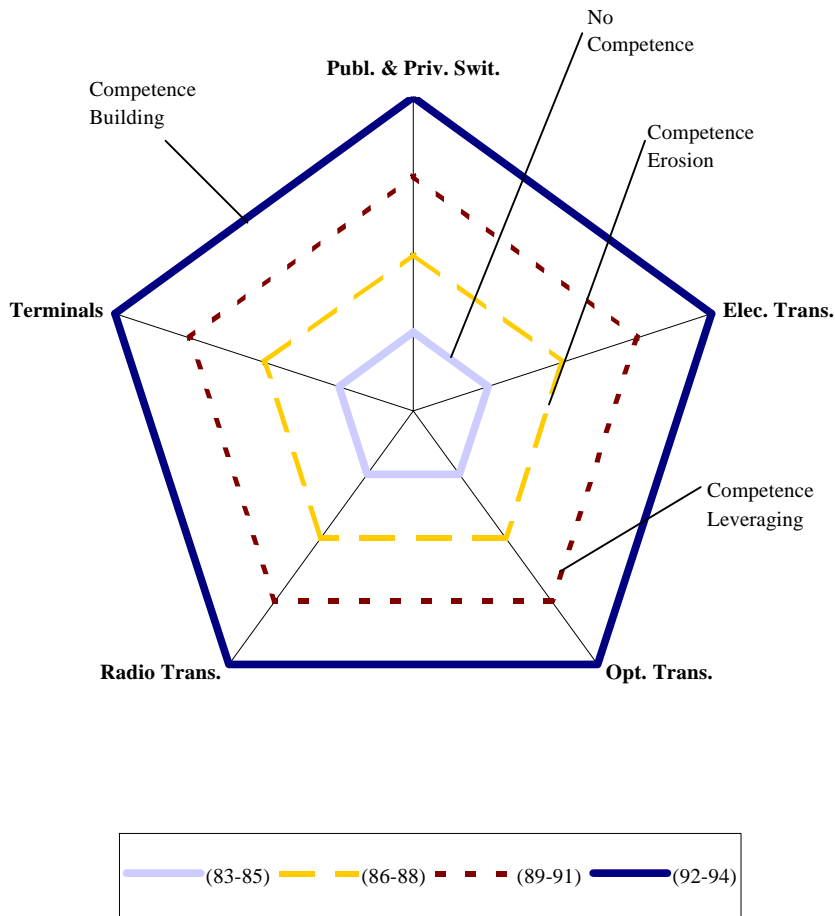
Figure 5.1 illustrates the different types of competence accumulation along the five technological dimensions (i.e. public and private switching, electrical transmission, optical transmission, radio communication and terminals). Accordingly, the profile in figure 5.1 represents a generalised competence configuration of a firm within telecommunications.

The central pentagon represents the 'no competence', and moving outwards the erosion, the leveraging, and the building competence categories. Thus, a profile based only on the outer ring of the pentagon reflects a firm, which is engaged in competence building in all fields in that period (cf. figure 5.1 in the period (92-94)). As the profiles typically contain a mixture of competence dynamics across the technological fields both the position in each period as well as the overall patterns over time can be interpreted as different behavioural strategies. In this section some firm-specific configuration are presented and the detailed dynamics as well as the overall behavioural strategy is discussed.

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<sup>13</sup> Appendix A contains a list of all calculations, which can be used to identify the type of dynamics. Moreover it can be seen that the level of competence is not very sensitive, i.e. the firms at this level and with no changes are seen in all periods and thus remains with no competence, or strong changes are induced and the firm moves into competence building.

**Figure 5.1:  
Patterns of Technological Competence Accumulation**



Over the considered time period, a number of behavioural strategies or actual behaviours result from the competence configurations and the competence dynamics. The combination of the competence level and the changes can lead to six different behavioural patterns. The first two situations are quite extraordinary, as well is the last one. The three remaining patterns are expected to be more general patterns of behaviour, which are followed by a larger share of the firms.

- I) **Complete reorganisation of the competence configuration.** This is one of the two extreme situations that can occur as a result of the competence-based activities. A firm in distress or with a need for radical changes can as a result of a changed strategy move out of existing core competence areas and engage itself in new activities. If the firm within these five technological areas form a new profile (i.e.

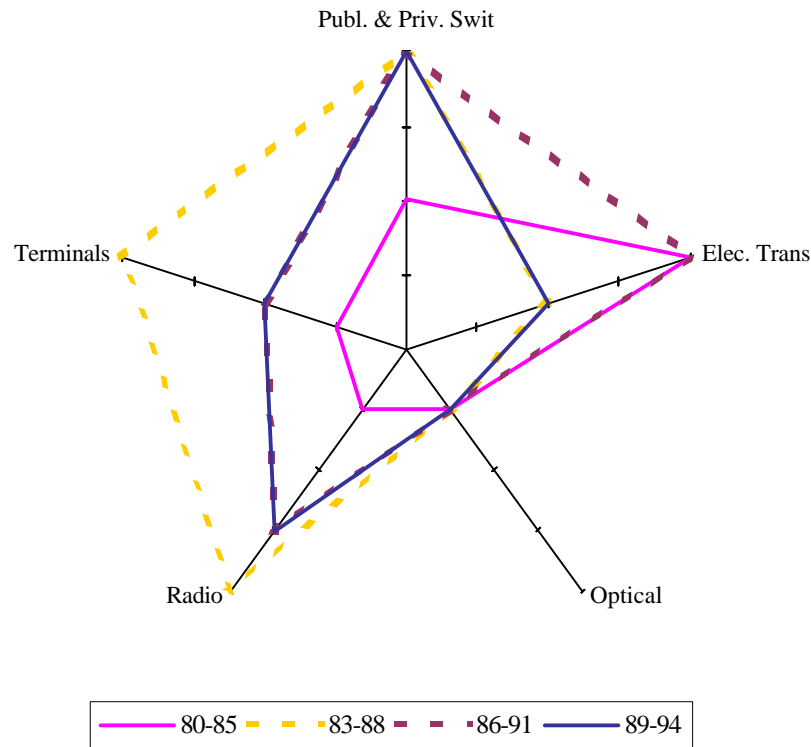
limited accordance between configuration in first and last period). See figure 5.2 for the configuration of Nokia.

- II) **Active search leads the firm towards a larger profile, i.e. increased dynamics and thus an attempt to catch-up with the leading firms.** To obtain this situation the firm must initiate more activities to secure a move from competence leveraging to competence building or a similar change in more than one field. One example of such a radical change can be seen in figure 5.3 for the competence profile of NEC.
- III) **Search leads to reconfiguration into new areas but the overall size remains unchanged.** This situation is expected to be quite normal and associated with incremental and path dependent accumulation of competencies. This is illustrated in figure 5.4 for Philips.
- IV) **Search outside the configuration but no visual result in terms of changed competence configuration.** A further option, which is potentially dangerous is to expand the search area and induce competence changes, but these are not implemented into the competence configuration. The potentially dangerous effect is based in the cost of trying to build new competencies but without an impact on the configuration. Over time this behaviour may lead to a lock-in situation, where the competence base is not adjusted to new external conditions. See figure 5.5 for Hitachi's search behaviour.
- V) **Search leads to smaller profile and therefore maintenance of existing core configuration.** The fifth situation illustrates how a period of search and renewal is followed by a period of consolidation. This is seen as the competence dynamics moves towards competence leveraging or even slow erosion. Despite this maintenance trend the firm may still be very strong in core competence areas and thus if this situation is followed by a new period of competence building it may prove to be the most viable situation. See figure 5.6 for the change in profile of Ericsson.
- VI) **Only limited search and no changes in competence profile.** As situation four could potentially dangerous so can this behaviour. A long period with no changes in the structure of the configuration can lead to lack of competence in new potentially interesting areas. One choice is of course to let new areas mature before involvement, but otherwise it can lead to lack of possibilities to move in. See figure 5.7 for the maintained profile of Fujitsu.

### ***5.1 Competence pattern I: The case of Nokia***

In figure 5.2 the case of Nokia's competence dynamics in the period 1980-94 is illustrated. In the period 1980-85 (i.e. the change from 1980-82 to 1983-85) it is seen that the firm has been

**Figure 5.2:  
Technological Competence Configuration of Nokia  
(1980-94)**



highly focused on electrical transmission through competence building, whereas in both optical transmission, radio transmission and terminals the firm had no competence.

Finally, the firm was active in public and private switching to a limited degree. Over time Nokia changed to increase its activities heavily into radio transmission and in public and private switching. Moreover in terminals for a short while in (1983-88) some competence building was initiated. The overall profile is accordingly characterised by large changes in competence dynamics.

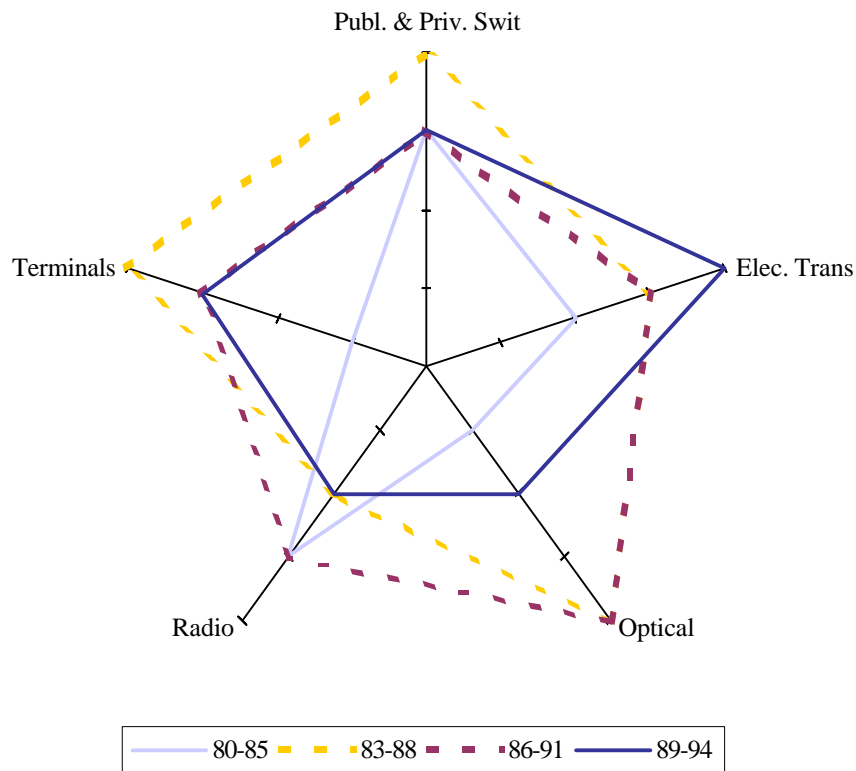
This theoretical picture is supported by the historical facts of Nokia. In the beginning of the 1980'ies Nokia was a company in financial trouble which was specialised in paper and rubber production among others. A change of CEO lead the firm to a complete reorganisation of its activities towards more high-tech areas and has during the last 20 years become one of the most important players on especially the mobile telephony market.

In sum, the above type of behaviour is quite radical and can lead the firm into a potentially vulnerable position without core competencies to lean on. On the other hand in success cases like the above the behavioural strategy has proven to be very successful and thus the choice to engage in such radical changes is very much a choice between risk and stability.

## 5.2 Competence pattern II: The case of NEC

In the following section those firms, which create a larger spectrum for competence creation are illustrated as a case of catch-up with the leading firms.

**Figure 5.3:**  
**Technological Competence Configuration of NEC**  
**(1980-94)**



NEC is used as example of increased competence dynamics<sup>14</sup> that has lead to a larger profile. In the first period from 1980-85 NEC was leveraging competencies in radio transmission and public and private switching. In electrical transmission the competencies were eroded and in the two last technological fields the firm had no competence. Although the competence dynamics have been more extensive than the actual profile in the last period 1989-94 the profile is enlarged as compared to the first period. This is a sign of aggressive competence changes that has to some degree lead to a new competence configuration. Especially in electrical transmission and in terminals are more drastic changes noted.

<sup>14</sup> Note that competence dynamics is distinguished from regular changes in that increased competence dynamics require not just growth but a growth rate, which is above that of the sample of firms, which are used as basis for comparison.

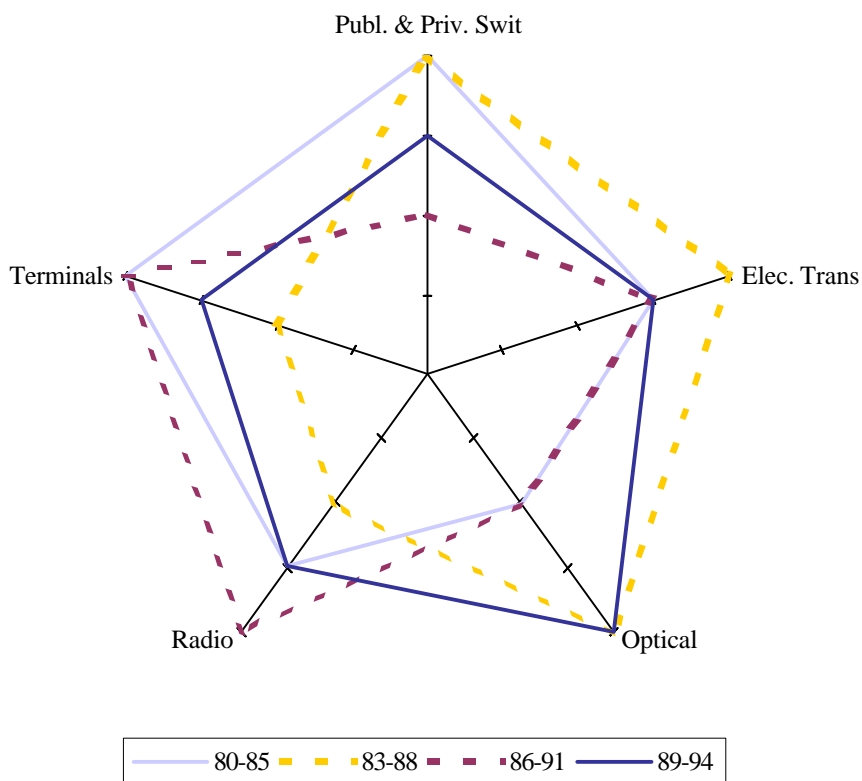
The theoretical changes correspond with the historical data for NEC in that the firm has attempted to create a position in radio communication but also in the traditional ‘japanese’ areas of competence such as terminals and electrical transmission.

Despite the strategy to gain a strong competence base in radio communication NEC has not quite succeeded. This is seen as a result of the drastic industrial changes, which have characterised the technological field – especially as high growth rates in patent applications. As discussed in section 3 high growth rates in the sample makes it more difficult to become competence building, as the growth rate of the firm must exceed that of the sample.

### 5.3 Competence pattern III: The case of Philips

The third strategy is based in a search for continued updating of the competence profile through exploration of new areas of competence as well as abandonment of existing competence areas either because of a lack of e.e. commercial interest or too high R&D cost.

**Figure 5.4**  
**Technological Competence Configuration of Philips**  
**(1980-94)**



For Philips a configuration is seen, which is characterised by extensive competence building activities that are changed through search activities into new areas. Thus the pattern shows a mixture of competence building in selected areas.

In the first period from 1980-85 the firm is engaged in competence building in public and private switching and terminals, whereas in electrical transmission and radio communication the firm is engaged in competence leveraging. Finally, in optical transmission a shift from competence erosion to competence building takes place from the first to the last period. Despite the extensive search activities the profile remains rather unchanged.

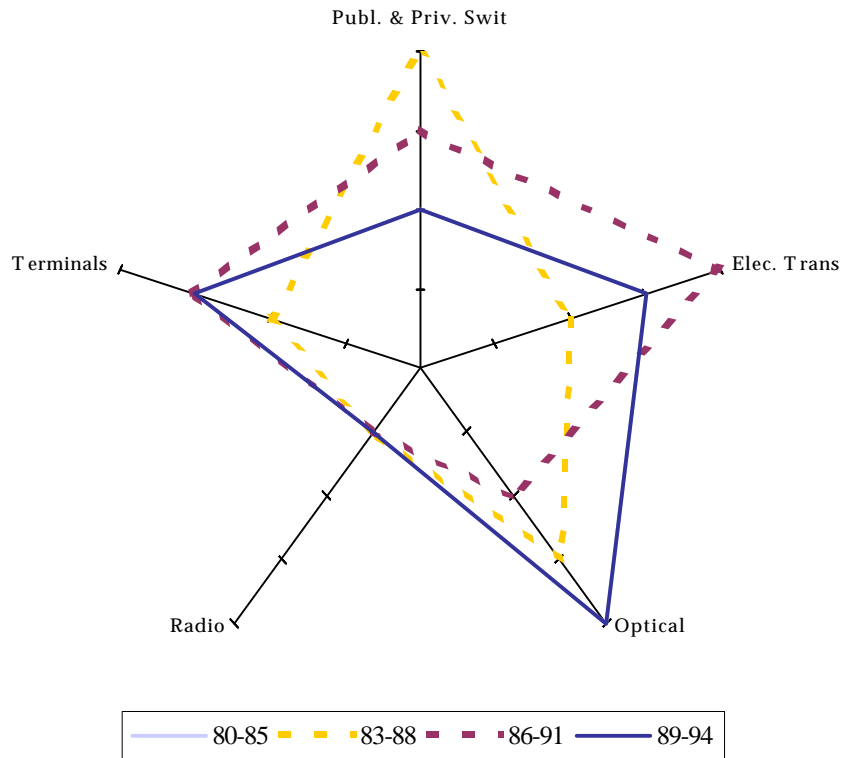
For Philips the period has proven to be very difficult. An attempt has been made to transfer the success of the general consumer electronics market to the mobile communications market. So far the commercial success has not been of importance but as seen in the above figure 5.4 the competence base has been developed throughout the period and thus the potential for commercial success through high-tech products seems high.

#### ***5.4 Competence pattern IV: The case of Hitachi***

The fourth strategy seems potentially dangerous to a firm with the aim of moving into the telecommunications market. The reason is that a firm with a weak competence base can face problems if the new competencies are not implemented into the competence configuration. On the other hand with a strong competence base the problems are much less interesting and the strategy may even seem viable. The reason being that with a strong competence base the firm can search outside the existing competence base and even choose not to engage in the areas that have been searched. This case reminds of strategy III. Through empirical data it may prove difficult to distinguish between the potentially dangerous situation and the search strategy, and to determine which one is the actually seen requires more data on the firm's competence base.

In figure 5.5 the profile of Hitachi illustrates how the configurations in the two periods (the first and the last) are overlapping and only the two intermediary years show changes from the profile. The overall picture is therefore a stable competence pattern, i.e. a stable mix of dynamics that the firm pursues. As will be noted later this strategy is easily assimilated to that of strategy VI. The difference between those two is mostly that in this strategy the firm is expected to test new areas more actively than is the case with the last strategy type.

**Figure 5.5**  
**Technological Competence Configuration of Hitachi**  
**(1980-94)**



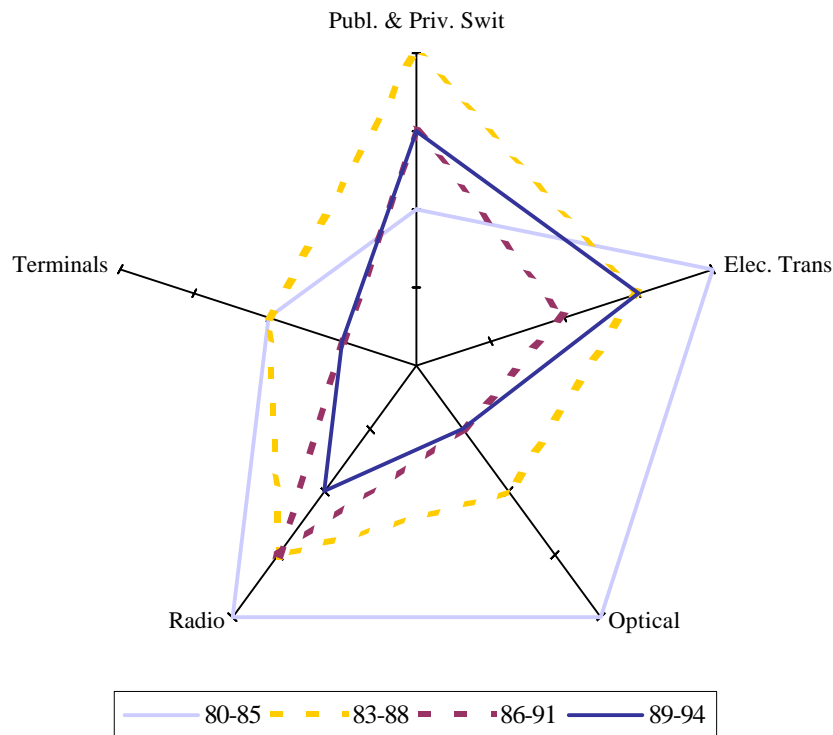
### ***5.5 Competence pattern V: The case of Ericsson***

The fifth strategy illustrates how a firm through a lower competence creating intensity can remain very strong and at the same time focused. The strategy therefore reflects those firms that are specialising in their competence base instead of increasing the activities (as e.g. in the first strategy). The strategy is seen in the figure as a smaller profile from the first to the last period. In the competence literature this strategy is seen as a period of renewal, which is followed by a period of consolidation (without actually implicating loss of strenght).

In figure 5.6 this is illustrated by the configuration of Ericsson. In the first period Ericsson is building competencies in radio communication, electrical transmission and optical transmission, whereas public and private switching is only characterised by competence erosion. The last period has traditionally been one of Ericsson's areas of strength especially after the introduction of the AXE switch. With a strong competence base it is natural to increase the attention in other areas and thereby increase or strengthen the competence base in related areas. For Ericsson this has lead to a strong competence base in radio communication,

where the degree of specialisation is very high (see appendix for the level). In optical transmission has Ericsson abandoned the activities over the considered periods.

**Figure 5.6**  
**Technological Competence Configuration of**  
**Ericsson (1980-94)**



Please note that if a comparison is made with the level of competence this will be very high for Ericsson although in radio communication a move from competence building to competence erosion is seen. This was the case that was mentioned in section 3.

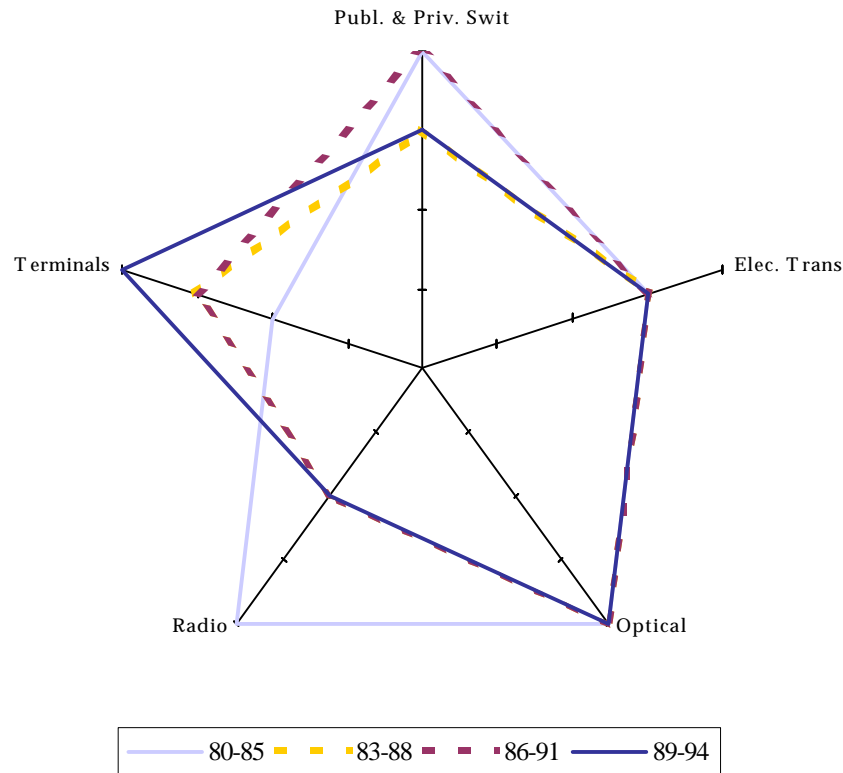
### **5.6 Competence pattern VI: The case of Fujitsu**

The strategy is characterised by only limited search towards changed competence dynamics and thus the competence profile will remain unchanged over the periods (or at least the first and the last period). The final strategy is therefore to be seen as a special case as the first strategy. The reason is that all firms will change the degree of knowledge production and thereby influence the competence configuration.

In figure 5.7 the differences between the profile representing the first period and the last period distinguish themselves from each other in public and private switching, terminals and

radio communication. The differences are only small, but also noteworthy is the very small changes in the other two periods.

**Figure 5.7:**  
**Technological Competence Configuration of Fujitsu**  
**(1980-94)**



## 6. FROM TECHNOLOGICAL COMPETENCIES TO FIRM BEHAVIOUR

Sections 2 and 4 argued from a theoretical viewpoint that competence dynamics do not reflect the overall firm behaviour directly, but represent the underlying moves and changes of the competence base in different technological fields. Section 5 then illustrated how the patterns of technological competence accumulation can be formed into profiles. The result was that six different situations were found in the time period 1980-94, which each illustrated a different way of changing the competence configuration. The aim of this section is to develop an empirical relationship between those competence-specific results and the long-term changes in the overall firm behaviour. These analyses are guided by research question 2:

HOW CAN FIRM BEHAVIOUR BE DEDUCED FROM THE COMPETENCE PATTERNS OF SINGLE FIRMS?

Underlying this question rests the assumption that firm behaviour is partly created by single technology-specific changes and that these can be identified. Moreover we assume that similarities across firms can be deduced from their technology base.

According to section 2.2, three types of general behavioural patterns are assumed to exist, which can be identified on the grounds of the type of competence dynamics and the frequency with which the firm will change the behaviour. Hence, these patterns do not refer to the single technological fields, but address the overall evolution of the behavioural patterns. We argue that these are aggregates of the competence patterns in section 5.

These 3 types of strategies are:

Firms relying mainly on *exploitation* develop and generate new competencies based on the existing knowledge base. The behavioural strategy guides the evolution through incremental and small changes, which lead to a competence base with a high degree of relatedness. Thus the overall behaviour is expected to remain stable and to keep the distribution across the fields unchanged, i.e. the type of competence dynamics is expected only to change very little.

Firms relying mainly on *exploration* of new technological opportunities in the creation of new competencies change their competence base through abrupt jumps induced by the continued experimental search in different areas. The aim is to gain an overall advantage and stay ahead of the competitors. These moves lead to changed strategies and thus a frequently changed distribution of activity i.e. the competence profile suffers from instability. The risk is high and the discrepancies between the firms with the same pattern are expected to be high.

Finally, a group of firms pursues a *mixture* of these two behaviours. Two reasons exist; learning, on the one hand, through a mixture of exploitation and exploration creates a sound basis for long-run performance through a mixture of established competencies enabling successful adaptation ('clever'). On the other hand, the external pressure from the industry may force the firm to change although the strategic intention was different, which leads to a highly fluctuating profile ('victim'). A similar competence pattern is expected for both the 'clever' and the 'victim' strategy.

### **6.1 Exploitation<sup>15</sup>**

A firm relies primarily on *exploitation* if the profile in the first period is similar to the profile in the last period. This does not mean that the firm only relies on leveraging on the competence base, but that in each technological field the type of competence dynamics only changes in small moves. Thus *exploitation* means that across all fields of competence the *distribution* remains *unchanged* or with minor incremental changes.

When we compare with the results of section 5 the firms that were characterised as either pattern III or VI (see figures 5.4 and 5.7) rely on exploitation.

To illustrate the stability in the profile and reliance on exploitation the profile of *Fujitsu* was presented in figure 5.7. In the period from 1980-94 Fujitsu has basically kept the distribution of the competence base stable. In the intermediary periods the firm only changed in three of the fields, whereas competencies were built in optical transmission, and the competencies related<sup>16</sup> to electrical transmission were leveraged. The dynamics in radio transmission shifted downwards from building to erosion indicating a move away from this field, whereas in terminals a shift from erosion to leveraging is seen. Hence the firm is rather stable in the development pattern of the competence base.

Another five companies pursue a strategy of maintaining the competence accumulating behaviours stable: Alcatel, AT&T, IBM, Philips and Siemens.

These findings indicate that as a response to the perceived environmental dynamics these companies keep their development patterns stable and thus pursues a type of organic competence accumulation.

### **6.2 Exploration**

If a firm relies on *exploration* the profile changes across the periods to show that the firm has relied heavily on search of external opportunities to expand the competence base. The profile in the first period will typically lie inside the profile in the last period, i.e. the firm increases its scope and thus attempts to devalue the competence base of the opponents. Thus, *exploration* means that the *distribution* across all fields is changed *frequently* across the periods, and mostly *outward* in the space as a sign of increased scope.

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<sup>15</sup> In explaining the following patterns of behaviour I first discuss the micro-changes in competence dynamics and then argue for the type of behaviour, i.e. the competence group that the firm should be positioned in.

<sup>16</sup> The illustration of the profile cannot take the synergetic use of competencies into account as the patents are only counted by their primary classification code. In many instances through a second classification (which is available) could reveal the degree of interdependency.

In section 5 these patterns of behaviour were noted especially in the complete reconfiguration of the competence base (cf. figure 5.2) and the attempt to catch-up (cf. figure 5.3).

The firms relying on exploration initiate experimental learning as a strong response to the external dynamics. These changes give abrupt moves as the adaptation of completely new knowledge lead the firm in different directions. The experimental search is enabled because of the weaker ties in the competence base than was seen for the exploitation strategy. The companies change the competence base in a radical manner through exploration of new and upcoming technological opportunities to leapfrog all other firms.

The case of *Nokia* is rather unique as the period of time in which Nokia has changed is very short and the success has been quite high. For the purpose of the more general patterns of behaviour the case of NEC is used.

Nokia<sup>17</sup> has in terms of business success been seen as one of the main actors within telecommunications and especially within mobile communications with growth rates above 50% (IDATE, 1996), but also as one of the most successful firms in corporate restructuring. For Nokia the comparison of the first and the fourth observation show a dramatic change in the profile, reflecting a very aggressive response especially in the first years. One reason for this is the fact that until the beginning of the 1980'ies Nokia was active in quite unrelated areas, but then made a drastic shift into telecom with an initial low level of specialisation. This then gave the platform for dramatic shifts that have proven to give a strong competence base. In the fourth observation, the firm focuses on building competencies in radio transmission and public and private switches, whereas in the first observation the firm's activities were directed towards electrical transmission. Hence not just in the overall changes outside telecom, but also within the telecom oriented area.

Two other companies are positioned in this group, NEC and Sony.

The advantage of exploration is clearly the ability to react swiftly upon changed environmental conditions through continuous production of new knowledge. But the behaviour involves high risk, as the outcome of the search processes is not only unknown but also costly to obtain. The abrupt jumps therefore increase the risk of failure, which is already high because of the industrial turbulence. Nevertheless, one argument for the adoption of such a

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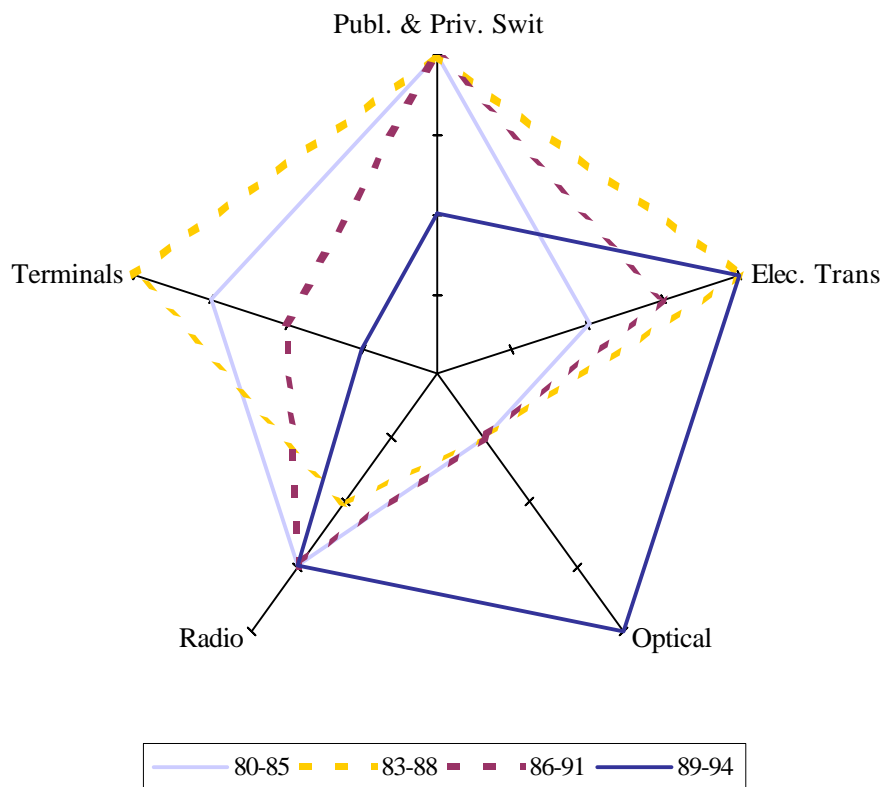
<sup>17</sup> The figure for Nokia is not included, but the impact is still discussed because of the power of this relatively new company in telecommunications.

strategy lies in the potential to gain high profits through the seemingly never-ending expansion of the industry.

### 6.3 Mixture of Behaviours

Finally, the *mixed* pattern of behaviour reflects *rapid changes* in the profile from one type of competence dynamics to another thereby creating rapid shifts in the profile both *inwards and outwards*, i.e. the profile will typically change in shape and in more than one direction. Recall that the mixed behaviour can be caused either as a result of a ‘clever’ strategy or as a response to changes in the environment. The clever strategy was in section 5 illustrated by the case of Ericsson, which actively engaged in shifting patterns of exploration and exploitation (cf. figure 5.6). On the other hand, the potentially dangerous situation was illustrated by the case of Hitachi (cf. figure 5.5).

**Figure 6.1:**  
**Technological Competence Configuration of Bosch**  
**(1980-94)**



In figure 6.1, *Bosch* acts aggressively and initiates competence building (at some point) in four out of the five fields, but the result in the fourth observation is that the firm has only managed to remain at a high level of knowledge generation in optical transmission and

electrical transmission. Hence, Bosch has not been able to initiate a sustained expansion in more than one technological field. This can be seen in the figure as rapid shifts inwards and outwards, moreover the changes are much more frequent than in the exploration case. This indicates that even though Bosch is strong and acted aggressively it was unable to adapt the new knowledge into the competence base. Thus, Bosch is a 'victim' of the environmental turbulence, where one possible explanation is the focus on high-growth fields, e.g. optical and radio transmission, which are more turbulent and therefore exposes the firm to harder pressure.

*Ericsson* has focused its activities through a rapid decrease in optical transmission and to a smaller degree in terminals and electrical transmission. But the firm stayed with its prime areas of specialisation, especially radio communication and private and public switching. The decrease in radio communication reflects the difficulty in aiming at competence building after successfully having established a strong competence base. The reason for positioning *Ericsson* in this group is the shift from a very strong competence base in radio transmission to refocus on public and private switching. This field has been a core area of focus should still be reinforced to maintain the strength. In general the changes lead to a fluctuating competence base and these rapid shifts must be incorporated in the competence base if the firm wishes to continue the type of behaviour.

GEC, Toshiba, Motorola, Matsushita and Hitachi, are the remaining five companies in this behavioural group. For the mixed group pattern IV faces a potential problem in the aim at approaching the high-growth technological fields, where they end up being pushed around through the activities of the competitors. On the other hand, the fifth competence patterns seems a sound way to go and thus the theoretical argument seems to be sustained in this section.

## **7. SUMMARY AND IMPLICATIONS FOR MANAGEMENT OF TECHNOLOGY**

Two research questions were analysed in this section; first, the measurement of competence dynamics along five technological dimensions, and second a relationship was established between competence dynamics and firm behaviour.

The first question was addressed by developing a typology of competence dynamics, which distinguished between competence building, leveraging, erosion and no competence. For each firm the type of competence accumulation was calculated and the positions of each firm were

compared in an illustration of three of the technological fields. In section 5 the calculations based on the typology were implemented and illustrated in radar figures. Based on these six different competence patterns were identified.

Through the third question a discussion of how the competence accumulating activities affect the actual behaviour of the firm was opened. Some may argue that these issues are the same, but actually competence accumulation is part of the actual strategy that the firm has carried out. The three behavioural strategies were identified using the change in profile defined by the summarised changes in each technological field as the criteria for demarcation. The groups were shown to change at different degrees, the exploitive group was expected to have the lowest degree of change, the explorative the highest degree of change, and finally the mixed group the most fluctuating shape.

The implications for management of technology has due to time constraints not been developed fully, but for the presentation at the meeting they will be presented!

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