Unfolding the Industry Dynamics

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UNFOLDING THE INDUSTRY DYNAMICS[1]

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Abstract:

Empirical research has made progress in developing indicators for the measurement of technological competences. A so far unmet challenge, however, is to trace the patterns of relationships among key variables at the firm level as they unfold in the context of the industry dynamics. The aim of the present paper is therefore to develop the methodology required to search for patterns of relationships among such key variables (R&D investments, technology and performance), to trace these patterns over time and thereby unfold the underlying industry dynamics. We are here referring to the possibility of using statistical methods such as Multidimensional Scaling (MDS) to trace similarities and dissimilarities among a set of variables - as opposed to testing simple linear and non-linear causal relations. We extend the previous use of MDS to further include what is known as "external unfolding." Using this proposed methodology, we derive an "industry space" that allows identification of the tendency to form groups, and to infer the stability of such groups of firms sharing similar conditions.

Keywords: technological competence, patents, MDS unfolding-analysis, external unfolding, industry-space, industry dynamics.

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1. UNFOLDING THE INDUSTRY DYNAMICS

Both the theoretical (Dierickx and Cool (1989), Nelson (1991), Dosi and Marengo (1993)) and the empirical relationship (Malerba and Marengo (1995), Schmoch (1995), Patel and Pavitt (1998)) between technology, R&D and performance have been at the centre of attention in numerous strategic management studies. Over time, the theoretical arguments have shifted in focus, from early arguments favouring a linear relationship between R&D and performance (e.g. Kamien & Schwartz (1975)) to recent efforts emphasising the cumulative effects of R&D investments on profitability (e.g. Nelson and Winter (1982)). According to the latter process-based perspective numerous firm-specific learning effects associated with competence accumulation complicate the relation between R&D and performance. Recent studies often view such complications as multiple history-dependent firm-specific processes that frustrate attempts of uncovering any simple empirical relation between R&D investment and financial performance (David (1994), Levinthal (1996), Dosi (1988)).

If we accept this recent process-based argument, both the indirect effect of competence accumulation, as well as the direct effect of R&D will influence performance. Empirical research has made progress in developing indicators for the measurement of technological competences but has not yet refined the statistical methods to match the level of sophistication of the recent process-based theoretical explanations, however.[2] In particular, a so far unmet challenge for empirical research is to trace the patterns of relationships among key variables such as firm-level R&D investments, technology and performance as they unfold in the context of the industry dynamics created by the mutual interaction of the industry members.

[2] Patents have almost exclusively been applied to the study of technological competences see e.g. Leiponen (1998), Patel and Pavitt (1998) and Miyazaki (1994). A second source of information is questionnaire-based measures of organisational and/ or technological competences see e.g. Bove, Harmsen and Grunert (2000), Malerba and Marengo (1995) and Lin (1997).

The aim of this paper is therefore to develop the methodology required to search for patterns of relationships between innovation measured by investment in R&D, technology measured by patents, and financial performance measured by turnover. It is further the aim to trace these patterns over time and thereby unfold the underlying industrial dynamics. Notice that the primary aim is to develop the methodology that is then applied to the case of telecommunications as one illustrative case.

The suggestion made here is to apply the statistical method of Multidimensional Scaling (henceforth MDS) and to extend it with what is known as external unfolding. The MDS-analysis enables us to trace similarities and dissimilarities among a set of variables – as opposed to testing simple linear and non-linear causal relations. The proposed methodology allows for the identification of groups of firms according to patterns of similarities in relationships among key variables, to infer the underlying evolving competence trajectories leading to the formation of groups, and to deduce the stability of such groups of firms.

These issues are important because the possible identification of stable patterns of similarities in the relation between superior performance and technological competence may have important implications for management of technology. This paper applies the newly introduced method to explore whether such patterns can actually be identified among sixteen multinational companies within the telecom industry, and discusses the associated implications for management of technology.

The paper proceeds as follows. Section 2 reviews the literature on technological competence in a process-based perspective, section 3 presents the data used in the present study, and section 4 describes the proposed use of MDS to unfold industry dynamics. Sections 5 and 6 present the results of the analyses and section 7 concludes and outlines implications for future research.

2. LITERATURE REVIEW

Common to various process-based perspectives (e.g. Dynamic Capabilities see Teece, Pisano and Shuen (1994) and (1997) and evolutionary economics Nelson and Winter (1982), Dosi and Marengo (1994), Levinthal and Myatt (1994)) on the organisational determinants of the firm's ability to search for, choose among and utilise emerging opportunities is that numerous firm-specific learning effects associated with competence accumulation are viewed as complications in the relation between R&D and performance.[3] One of these complications is that firms need to both allocate resources to further refinement of the existing production-set and to integrate new elements in this set (March 1991).[4] It is further commonly asserted that such complications involve multiple history-dependent organisational processes that frustrate attempts of uncovering any simple empirical relation between R&D investment and financial performance.

Learning is a painstaking process of trial and error in which the current state of the firm limits the set of possible future paths (path dependence) each of which lead to a distinct future state (Cohen and Levinthal (1990), David (1994), Levinthal and March (1993)). These processes of trial and error define a path-dependent dynamics according to which the development of the

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[3] The state of learning a firm has achieved at a particular time-step has variously been described by its "absorptive capacity" (Cohen and Levinthal 1990), "competences" (Nelson 1991) and "capabilities" (Teece and Pisano 1994).

[4] This tension is also known as the trade-off between exploration and exploitation (March 1991). Considering a distribution of learning draws, exploitation is associated with the *mean* of the learning process and exploration is associated with the *variance*. Exploration is therefore associated with the creation of new competences, high rates of employee turnover, as well as high levels of risk and innovation. By contrast, exploitation is associated with the refinement of existing competences and involves the reduction of risk. Both exploitation and exploration are associated with tendencies towards lock-in.

firm, e.g. the probability of expansion and contraction, in each time-step depends on its previous state. Such path-dependent dynamics is commonly associated with persistent firm level heterogeneity.[5]

In the face of path-dependent learning processes, it is further unlikely that uniquely determined outcomes are possible. In particular, this process-based view implies that we should not, in theory or practice, expect optimality in the mix of R&D expenditures, technological competence and economic performance. Instead, a variety of relationships may turn out to yield a comparable (high) level of economic performance. In the following, we will briefly review a sample of recent empirical studies that appear to support this view.

Using R&D expenditures and US patents of 500 global companies in 1990 and 1998 Bowonder et al. (2000: 55) applied a technology trajectory approach to show that the so-called global firms are increasing both the scope and depth of the dominant patent classes. Their results further indicate that the development of technological competences measured by patents is cumulative and depends on both the existing knowledge and the implementation of new knowledge. Bowonder et al. (2000) did not attempt to uncover whether any possible combined effects of R&D and patents influenced the performance of these firms, however. In a related study, Leiponen (1998) examined the contribution of different facets of competence (measured by patents and technical skills acquired through education) as determinants of profitability and reported a positive association between profitability and the different measures of competence. Dividing the sample into innovators and non-innovators further increased the strength of the effects. Unfortunately, Leiponen did not include measures of R&D expenditures that might untangle the possible mediating or moderating effect of

[5] Note here that firm-level heterogeneity does not necessarily imply path-dependence. For example, a simple

innovation. Malerba and Marengo (1995) used survey data to study how the technological competences of the Italian manufacturing industry influence firm performance. Based on a distinction between the competences needed for long-term versus short-term strategies, they found that '*in high technology sectors, technological competences are considered by firms as the most relevant ones for their long term strategies and competitiveness*' (Malerba and Marengo 1995 :475). The validity of this finding must be questioned, however, since the performance measure was based on the firms' subjective perception of own competitiveness. Finally, underlining the measurement problems inherent in empirical research on technological change, Lin (1997: 135) identified a number of elements of corporate technological capability but used crude measures to tap these constructs, constraining the empirical test to simple statistics that did not quite meet the study's sophisticated theoretical structure.

In summary, all the empirical studies referred to in the previous paragraph report that either technological competence, R&D expenditure or performance are pair wise related. None of these studies, however, aim to combine all three measures or to unfold the underlying industrial dynamics implied by the studies' different but rather sophisticated process-based theoretical models.

As mentioned above, a number of studies have recently emphasised that path-dependent processes lead to persistent firm level heterogeneity; a view that is consistent with arguments offered by the Resource Based View (RBV), the dominating strategy (content) paradigm over the last decade (Foss and Knudsen 2001, Foss 1998). Proponents of the Resource Based View (Peteraf (1993), Barney (1991)) have argued that firm-level heterogeneity is possible in

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stochastic process may be the source of persistent firm-level heterogeneity (Knudsen 2001).

equilibrium. This view seems to be supported by a large number of empirical studies reporting persistent firm-level differences in performance (e.g. Rumelt (1991), Geroski et. al. (1997), Jensen and McGuckin (1997), McGahan and Porter, (1997), Goddard and Wilson (1999), Eriksen and Knudsen (2001)). The findings reported in these studies are further consistent with a number of studies reporting persistent firm-level differences in technological competence (Patel and Pavitt (1995), Malerba et. al. (1997), Cefis (1999)).

The existence of persistent differences in performance and technological competence reported in the above empirical studies suggest that firm-level similarities in the unobservable relation between both of these variables are promising candidates for the identification of possible groups of firms sharing similar competitive conditions.[6] Consistent with this view, Jensen and McGuckin (1997: 28) argue that '*the majority of this variation [in performance] is not associated with traditional observables such as location, industry, size, age or capital; rather it is associated with unobserved firm- or business unit-specific factors, many of which appear to be long-loved attributes of the business unit.*' Along the same lines Eisenhardt and Martin (2000: 1106) observe that capabilities exhibit commonalities across firms, implying that they are more homogenous and substitutable than traditional RBV thinking implies[7]. Thus, the unobservable firm-level heterogeneity particularly in technological competence may be an important determinant of persistent firm-level differences in performance and may, combined with homogeneity in problem solving routines, allow for an identification of clusters of firms in an industry space.

As mentioned earlier, path dependence is a crucial characteristic of competence accumulation associated with firm level specialisation. In a study of the opto-electronics industry, Miyazaki

[6] Groupings of firms have been discussed in at least two settings. The first is the notion of 'Strategic Groups' by Porter (1980) applied by e.g. Peteraf and Shanley (1997); the second is 'Competence groups' as defined by Gorman, Thomas and Sanchez (1996) and applied by e.g. Knudsen (2000).

(1994) used bibliometric data, US patent data and interview data to show that firm-level path dependence in the accumulation of capabilities is in fact associated with technological specialisation. Increased specialisation tends to lock the firms in to a particular learning path associated with superior or inferior performance (March (1991), Ingram and Baum (1997), Dosi and Marengo (1993)).

Although the argument that firms experiencing consistent low performance only with great difficulty can adapt to improve performance is controversial (Levinthal and Myatt 1994), this viewpoint seems to be supported by a number of empirical studies. Miyazaki (op. cit.: 653) finds that '*firms search over broader horizon initially and are able gradually to narrow down their search through a painstaking learning process,*' which may happen to be fatal. In a study based on patent data, Fai (1999: 16) finds that large firms possess the required resources to diversify into new technological sectors, but may, due to the possibility of relatively lower costs in the short term, prefer to further the activities within their prior accumulated technological competences. Although the firm initially experiments with a broad set of competences, the effects of short-term positive feedback may lead to high levels of specialisation within an increasingly narrow range of competences (Levinthal and March 1993). Since specialisation in competence is usually associated with increasing rigidity, the firm may find that it is stuck in a competency trap, a situation in which the firm's narrowly specialised competences become obsolete as the world changes to favour alternative competences (Dosi and Malerba (1996), Levitt and March (1988), Tushman and Anderson (1986)). That is, firms will tend to restrict themselves to a limited set of technological

[7] Note that Eisenhardt and Martin's (2000) argument is based on a functional definition of capabilities.

competences and have difficulty in responding to developments outside this range of competence (Levinthal and Myatt 1994: 49).[8]

In summary, the above review indicates that path-dependence in accumulation of firm-specific competences, from a theoretical viewpoint, may be associated with persistent heterogeneity in performance at the firm level. A number of empirical studies support this view of persistent performance differentials and further indicate that the accumulation of (technological) competences and investments in R&D are promising candidates as antecedents to performance. Previous empirical studies have tested the degree to which performance differentials among firms in an industry are sustained over time and the relative importance of industry and firm-specific effects (including abstract unspecified effects as well as technological competence) as determinants of sustained differences in performance. Empirical research has also made progress in developing indicators for the measurement of technological competences. A so far unmet challenge, however, is to trace the patterns of relationships among key variables as they unfold in the context of the industry dynamics created by the mutual interaction of industry members. Interestingly, the interaction between the firm level and the industry level has moved out of focus after the success of Porter in addressing issues of competitive strategy and diversity across industries (Porter 1980).[9] Even though the substantial relation between the external environment and internal resources is prevalent in the literature (Levinthal (1994), Henderson and Mitchell (1997), Rumelt (1991)) the impact of the interaction among firms upon the industrial dynamics is by and large un-researched. In the following we address this issue by developing an MDS-based methodology that uses what is known as "external unfolding" to track the dynamics of the relations among

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[8] Levinthal (1994: 171) explains the effect of a competence trap as '*increasing skill at the current procedures makes experimentation with alternatives progressively less attractive*' thereby underlining the difficulty in actively escaping a competence trap even if it becomes fully recognized.

the key variables: R&D investments, technology and performance. We first present the data, a sample of the most influential telecom firms, and then the proposed methodology.

3. DATA AND OPERATIONALISATION

For two reasons, the present paper focuses on technological competences in the telecom industry. First, because of the cumulative and idiosyncratic nature of technological competence emphasised by Henderson (2000), such competences are likely to be a particularly important aspect of the competence profile of a firm in both the telecom industry and in other high-tech industries. Because technological competences are cumulative and idiosyncratic they are difficult to transfer across organisations and therefore likely determinants of persistent differences in firm-level performance.[10] Second, because the telecom industry is a very dynamic high-tech industry, continued updating of technological competences may be necessary for survival even in the short term (Praest 1998: chapter 7) and competence traps may be fatal. The study of the emerging relation between technological competence and firm-level performance among firms struggling for a favourable position within the telecom industry thus provides a rich context for the application of our proposed unfolding analysis.

As mentioned above, the purpose of the proposed MDS unfolding analysis is to trace the patterns of relationships among key variables (R&D, technological competence and performance) as they unfold in the context of the industry dynamics created by the mutual interaction of the industry members. This procedure is used because we view an industry as a dynamic environment in which the transfer of technological competence among co-operators

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[9] Porter was mainly concerned with the impact of the industrial conditions upon the firm, however.

as well as the attempts to imitate, outpace and outwit competitors will shape the development of the firm's technological competence (Henderson and Mitchell (1997: 8), Sutton (1998), Tirole (1988)). It is therefore important to focus on a single industry (because of sector differences), to include a measure of the competitors' activities (we use the specialisation index described below to do this) and to assess the stability of the industry dynamics (this is the purpose of the MDS unfolding analysis). In addition, the MDS analysis allows for individual assessments of the firms' relative positions in the industry space.

The sample used in the present study includes sixteen multinational companies within the telecom hardware manufacturing industry. For each company, the data includes a time series of three objective measures for the period 1986-1994: (1) innovation measured by investment in R&D, (2) technology measured by patent applications, and (3) financial performance measured by turnover.[11] The individual company profiles are adjusted on an annual basis to take all new acquisitions into account and to exclude all divestitures.

The patent applications used to measure a company's technology (a strategic attribute) cover the European Patent Office (EPO) and the World Patents during the period 1986-1994. The patent data were selected in a 3-step sequence. First, the technological field of telecommunications[12] was defined using the International Patent Classification (IPC). Second, the patent applications were identified in both EPO and the World Patent Index (WPIL) for the period 1986-94. These data were pooled in three intervals: 1: 1986-88, 2: 1986-91, and 3:

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[10] This claim that firm-specific effects dominate industry specific effects is consistently supported in empirical studies (Rumelt (1991), McGahan and Porter (1997), Eriksen and Knudsen 2001).

[11] However, some of the financial data have not been available and the firms have been excluded accordingly. The affected firms are from 1986-89 Matsushita, Philips, IBM and Alcatel and in both 1986-89 and 1986-94 are Sony and Toshiba.

[12] In this paper, we exclude technologies with a peripheral connection to telecom. The exact definition can be obtained from the authors.

1986-94.[13] The estimation of one period included all subsequent periods, i.e. the estimation of period 3 included both periods 1 and 2, whereas period 1 did not include other periods. Third, an index of technological specialisation (RPA) was calculated.[14] This technological specialisation index, calculated on the basis of the number of patent applications, is used as an indicator of a firm's technological competence.

Although patents do not capture all aspects of technological competence in a firm, patents remain the unique best objective measure of such competence.[15] Furthermore, because patent data are disaggregated measures they provide a useful basis for an objective assessment of the degree of technological specialisation in a population of firms. The IPC ensures that the patent attorney assigns each application accurately to the firm and to the appropriate technology class.

The economic data used in the present study include measures of R&D expenditures (a strategic attribute) and turnover (a performance measure).[16] The data are normalised in order

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[13] The use of intervals is required because some firms, in particular in the first year, only apply for a small number of patents.

[14] The RPA is defined as: $RTA = \frac{\frac{P_{i,j}}{\sum_i P_j}}{\frac{\sum_j P_i}{\sum_{i,j} P}} \Rightarrow RPA = 100 * \frac{(RTA^2 - 1)}{(RTA^2 + 1)}$;

Where P=number of patent applications in that period; i=company (ranges from 1 to 16) and j=technological field. RPA is symmetric in the interval [-100: 100] with a neutral value of 0. This measure is derived from the revealed trade advantage as defined by Soete and Wyatt (1983).

[15] An extensive debate has raged about the use and abuse of patent data to measure technological change and technological competences. However, as stated by Griliches (1991: 1702): '*patent statistics remain a unique resource for the analysis of the process of technical change. Nothing else even comes close in the quantity of available data, accessibility, and the potential industrial, organizational and technological detail*'. We shall not go further into the debate but merely comply with the above quote. For further references please see e.g. Pavitt (1988), Grupp (1998), Grupp and Schmoch (1999) or OECD (1994).

[16] We also conducted analyses including net income. The results of the two first periods are similar to the analyses using the turnover measure of performance reported in the present study. For the last period, however, exogenous factors (e.g. tax) are most likely the sources of deviation from the results reported here.

to establish compatibility across firms and across countries. We use the following two normalisation procedures. First, the number of employees is used as a weight to adjust for differences in firm size, and second, the purchasing power parity (PPP) converts all data into US $.[17] An alternative method to normalise currencies is to use exchange rates, but these tend to be easily influenced by general economic turbulence, like changes in oil prices. It must be noted that a problem with the use of the PPP is the bias in favour of the American firms relative to all other nationalities. Since this bias tends to be smaller than the bias associated with the use of exchange rates, we used the PPP to normalise currencies.

The goodness of the possible alternative indicators of performance has inspired ongoing debate and the issue does not appear to be settled.[18] Our rationale is not based on the logic of sustained competitive advantage, however.[19] Rather, we aim to trace regularities in the *patterns* of relationships among key variables (firm-level R&D investments, technology and performance) as they unfold in the context of the industry dynamics. Allowing for period-by-period variation, we wish to identify some possible common characteristic in the relationships among key variables. For this purpose the present paper uses a non-standard performance measure, namely specialisation in turnover.

The use of lag structures in estimating a relationship between input and output has been discussed, among others, by Grupp and Maital (1996: 12), who used a 4-year lag. In a turbulent industry like telecom characterised by short technology lifecycles, a lag structure of 2 years seems appropriate. In the present study, we therefore use a lag of 2 years, which

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[17] The purchasing power parities (PPP) were obtained from the OECD publication on ‘Main Science and Technology Indicators’ (1997).
[18] See for instance Venkatraman and Ramanujam (1986) and Chakravarthy (1986) for overviews of different approaches to measuring performance. For the relations among R&D, patents and performance see Tidd and Driver (2000)

implies that a comparison between technological specialisation and turnover is based on patent applications in the period 1986-88 and turnover in the year 1989. Accordingly the economic data were obtained for the years 1989 (matching the patent applications of 1986-88), 1992 and 1995 (matching patent applications of 1986-91 and 1986-94 respectively). Having presented the data, we next describe the proposed refinement of the MDS methodology that was used in previous studies.

4. DEVELOPING THE MDS-ANALYSIS

The purpose of Multidimensional Scaling (MDS) and related techniques, such as Correspondence Analysis, is to derive useful spatial representations of relationships among data. MDS generally attempts to represent certain types of data as relations on points in a multidimensional space (Green, Carmone et al. 1989). The MDS analysis derives the dimensions of the space as well as the relations among the data points. Often MDS is used to derive a space on the basis of subjective evaluations of a number of attributes, in which case the derived attribute space is referred to as a perceptual space (Bijmolt and Wedel 1999). Here we use objective data and refer to the derived attribute space as an "industry space".

In the present study, we use MDS to derive a spatial representation of the relations among the objective variables, firm-level R&D investments, firm level technology and firm level performance thereby inferring the industry space. The multidimensional attribute space we derive is therefore an industry-space representing the telecom industry. By using MDS, we obtain a map of the relations on points representing the firms of the telecom industry. That is, we obtain a map that shows the degree of overlap in the firms' strategic attributes. If the

[19] SCA is known from RBV (Peteraf 1993) and has been translated into long-term performance in empirical research.

points representing two firms happen to have similar coordinates in the derived map, we say that the two firms pursue similar strategies. More generally, we can use the derived map to assess whether there is a tendency to form strategic groups (a tendency for points to cluster) or not (no tendency for points to cluster).

Having derived the industry-space, we further proceed to include the performance measure. Adding the performance measure, the derived industry-space now portrays similarities in strategic attributes (R&D investments and technology) and the consequences of a particular choice of attributes in terms of performance. The derived industry-space is therefore a joint attribute and performance space and the coordinates of a particular point in this space represent the relative position of a firm in the telecom industry.

In order to further a more detailed assessment of the dynamics of the patterns of relations among firms in the derived industry-space, we applied what is known as external unfolding. That is, we used regression analysis to fit vectors representing both of the strategic attributes and the performance measure. In previous applications of MDS the axes of the attribute space have been less than easy to interpret. By fitting the regression vectors in the industry space the interpretation has become straightforward. The information gained thereby includes: (1) the relative position of the attribute vectors indicating whether strategies are *in*dependent or *inter*dependent, (2) the relative position of the performance vector and the strategic attributes, and (3) an assessment of each firm's strategy and its consequences. Note that the vectors are fitted in industry-space and represent industry-level properties derived on the basis of the relations among all individual firm level variables.

By next analysing how the points shift over time within this space, we can trace the industry dynamics as emerging patterns of relations among firms. By further applying the external unfolding analysis, we also gain information about the changing relative position of the industry level attribute and performance vectors. This information enables us to trace the patterns of relationships among firm level R&D investments, technology and performance as they unfold in the context of the industry dynamics created by the mutual interaction of the industry members.

The purpose of the proposed methodology is to provide a tool that can trace industry dynamics and strategic change without the need to impose strong and perhaps unreasonable fitting constraints (e.g. as in the usual regression analysis). The general idea of using MDS to analyse industry dynamics was originally proposed by Green and Carmone (1968) to assess the product life cycle in industrial markets. We believe Green and Carmone's (1968) idea is also a promising candidate for a meaningful and detailed portrayal of strategic change in industrial markets. By adding the possibility of assessing the relative change of industry-level strategic dimensions we have further refined Green and Carmone's (1968) outline of a methodology for the analysis of dynamic change. Moreover, this proposition allows for new ways of tracing dynamic patterns of technological change and thus to analyse the theoretical propositions of the process-based approach more directly. We next turn to demonstrating how our proposed methodology can be used to analyse the unfolding industry dynamics within the telecom industry.

5. RESULTS

Figures 5.1, 5.2 and 5.3 present the industry-space derived on the basis of the MDS-analysis for each of the three periods 1986-88, 1989-91, and 1992-94.[20] In each instance, the derived industry space is a joint attribute and performance space and the coordinates of the points in this space represent the relative position of a particular firm in the telecom industry for each of the three periods in question. The three arrows are the result of the unfolding analysis. These arrows were fitted to the map by regression analyses and are vectors representing both of the strategic attributes and the performance measure. As described in the following, the fit of each of the MDS-analyses as well as the fit of the unfolding analyses were excellent.

The fit of each MDS-analysis was assessed on the basis of the proportion of variance of the disparities accounted for in the MDS-model. Here we report the squared correlations (RSQ) computed on the basis of Young's S-stress formula. The RSQ estimates for the 1989- and the1995-model were in both instances 0.99998. For the 1992 model the RSQ was 0.99988. These values of fit are remarkably high indicating high validity of the three MDS models that were estimated. Here it is important to note that the recommended guideline to obtain a stable solution and to avoid inflated fit measures is to have more than four times as many objects as dimensions desired (Green, Carmone et al. 1989). Since we have two dimensions but only three objects for each analysis shown in Figure 5.1 to 5.3 this recommended guideline is clearly violated.

We therefore estimated a baseline model including all 9 objects (3 objects for each time period) in joint space.

[20] Based on the specialisation data in appendix A.

Figure 5.1: Industry space with attribute vectors 1989

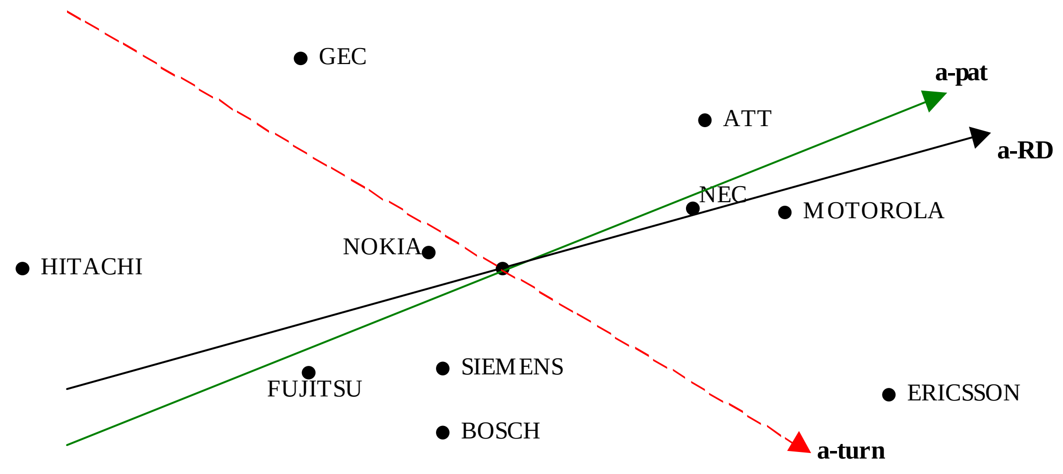


Figure 5.2: Industry space with attribute vectors 1992

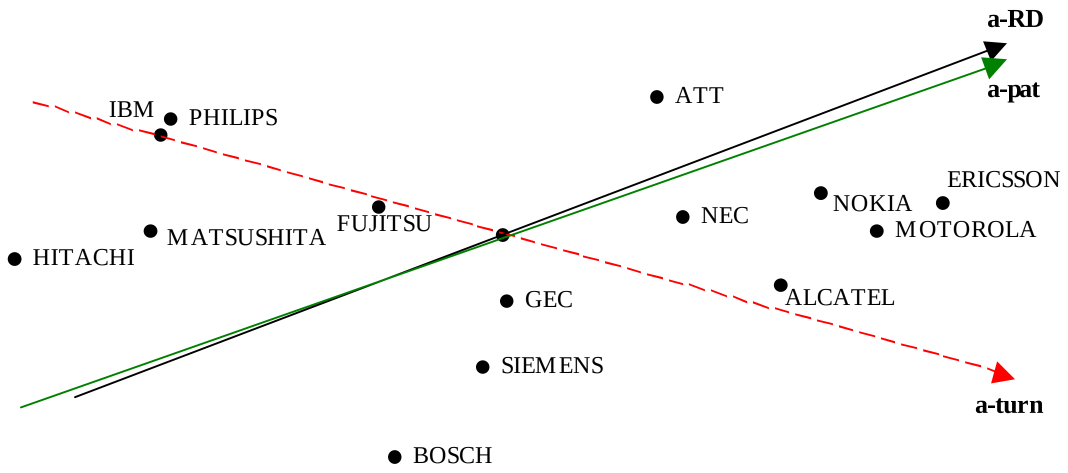
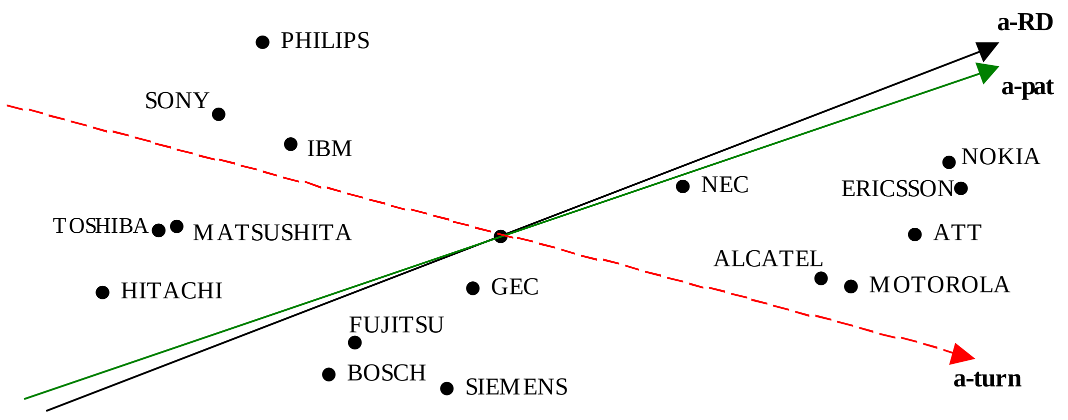


Figure 5.3: Industry space with attribute vectors 1995



Since this baseline model respects the recommended guideline and since it obtained an RSQ of 0.99980, a value very close to each of the three individual analyses, we conclude that the fit values of the individual analyses are not inflated and that a high degree of stability was obtained. This result supports that we obtained a high degree of validity also in each of the three MDS-analyses for 1989, 1992, and 1995.

In the external unfolding analysis the attribute and performance variables were regressed on the derived stimulus coordinates. In each of the regressions we obtained a very good fit (RSQ's in the order: patents, R&D and turnover, for 1989 are 0.999; 0.994; 1.0, for 1992 are 0.998; 0.984; 1.0 and for 1995 are 0.999; 0.991; 1.0) that demonstrates a high degree of validity of the unfolding analysis. We now proceed to a more detailed description of the industry dynamics on the basis of each of the three individual maps.

5.1 The relationship between technology and performance: A view of the industry

By inspection of Figures 5.1 to 5.3 below, note first that the industry-level vectors representing patents (a-pat) and R&D (a-RD) are located closely, almost overlapping, whereas the performance vector (a-turn) is crossing the two others. In the following we refer to the overlapping patent and R&D vectors as technology vectors and the performance vector as the "turnover vector." The directions of the vectors shown in Figures 5.1 to 5.3 indicate relative levels of attributes or performance. Higher levels are obtained in the direction each vector points to. The maps represent industry spaces and the individual points represent firms. A particular firm's relative position on a vector can be read directly of the map by drawing the perpendicular projection from the point representing the firm to the vector. In Figure 5.1, representing the period 1986-88, Ericsson, for example, has the highest level of performance (turnover), Motorola the second highest, and Hitachi the lowest.

A high position on the turnover vector (e.g. Ericsson) indicates that the firm, relative to other firms in the telecom industry, obtains a large share of its turnover from telecommunications. Therefore, a very high position on the turnover vector implies a potential risk associated with radical changes in the market. Moreover, a low level of turnover does not necessarily indicate low absolute levels of turnover, but only shows that the firm in question (e.g. Hitachi), relative to the other industry members, has a low level of specialisation.

Similarly, a high position on the technology vectors (e.g. Ericsson or Motorola) indicates a high level of technological specialisation relative to other firms in the industry. Note that a high level of technological specialisation without a corresponding high level of economic specialisation points to an inability to continue the required level of investments in the future. A low level of technological specialisation may for a different reason indicate the exit of the industry since this position implies a very high need for financing the continued updating of technological competences. Below, in Figure 6.1, we further consider the possible exit dynamics of the telecom industry.

By studying Figures 5.1 and 5.2 we observe a shift of the two technology vectors from 1989 to 1992 in which the patent vector moves closer to the turnover vector. To obtain a better estimate of this change, we computed the angles of the vectors. According to these estimates shown in Table 5.1, the angles between the patent vector and the R&D vector respectively to the turnover vector are fairly stable.[21] However, the angle between the patent and the R&D vectors diminish indicating slightly increased co-variation and thus higher interdependence

[21] Orthogonal vectors indicate that the dimensions are completely independent. By contrast, perfectly overlapping vectors indicate complete dependence. We further claim that a smaller angle between the technology vectors indicates a more stable configuration. The reason is that, in this instance, in order to gain an additional increment of turnover, an increasing share of the firm's resources must be allocated to the particular industry in question (e.g. telecommunications). That is, a firm must either exit or will tend to become increasingly

between the two dimensions of technology. The increased co-variation between R&D and patents is in line with the correlations reported in previous studies (see section 2 above).

Table 5.1: The angle[22] (in degrees) between the industry level vectors

	1989	1992	1995
Patent – R&D	16,6	11,0	12,8
Patent – turnover	59,2	62,0	58,7
R&D – turnover	57,1	63,5	59,9

5.2 Technological competence and performance: Firm level dynamics

In 1989, Motorola and Ericsson are positioned in the area of high specialisation in turnover and technology, with NEC lying on the boundary of that domain. Ericsson is a high tech company known for its success in the telecommunication product market. For all the three periods, Ericsson's product market success is reflected by its favourable position in the industry space derived in the present paper. In 1989 both Nokia and Hitachi contrast Ericsson in being positioned at relatively modest levels of turnover and technological specialisation. Subsequently, there is a dramatic shift in Nokia's position.

Until the beginning of the 1980es Nokia was only present to a very limited degree in the telecommunications market. This is reflected in Nokia's position in Figure 5.1 by low levels of technological specialisation and performance during 1986-1988. As shown in Figure 5.2, Nokia was subsequently during 1989-91 able to develop a more favourable position with high

specialised within an industry in which all technology vectors overlap. This dynamics tend to a stable configuration with a few large competitors.

[22] The following formula was used to calculate the angle between two vectors:

levels of technological as well as economic specialisation. As shown in Figure 5.3 Nokia then managed to further marginally strengthen this position during 1992-94.

Despite the dramatic shift in Nokia's position, the general observation is that there are few changes in the relative position among the firms in the telecom industry. By inspection of Figures 5.1 to 5.3, a total of only 6 moves (by 5 companies) are observed during the periods 1986-94. These moves are[23]:

1989 to 1992:	Fujitsu moves from I to IV
	GEC moves from II to I
	Nokia moves from IV to III
	NEC moves from boundary of I/III to III
1992 to 1995:	Fujitsu moves back from IV to I
	AT&T moves from II to III

Thus, a second result is the apparent stability in the configuration of the maps; only few firms change their position indicating that the relationship between R&D, patents and turnover is stable over time. This result is consistent with the arguments offered by proponents of the Resource Based View referred to in the above.[24]

In order to validate the findings of the present study, we compare with a study by Schmoch (1995) using a partly overlapping sample. Unfortunately, Schmoch's (1995) study ends at that

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$$\cos(\theta) = \frac{(a_1 * b_1 + a_2 * b_2)}{\sqrt{(a_1^2 + b_1^2)} * \sqrt{(a_2^2 + b_2^2)}}$$, where a_i and b_i refer to the coordinates of the MDS solution.

[23] The numbers refer to figure 6.1 in section 6 – see below.

[24] Praest's (1998: 141) study conducted on the sample of firms also used in the present study provides further evidence on the observed persistency in the accumulation of technological competences at the firm level.

point in time where we pick up (in 1989). So the comparison is limited to matching our results for 1989 with the final period of Schmoch's (1995) study. Using MDS-analysis on technological specialisation profiles, Schmoch (1995) identified three groups of firms in the telecom industry. The first group comprised the large well-established firms (Siemens, Alcatel and Ericsson) at the core of the telecom industry. The two other groups identified by Schmoch (1995) were located at the periphery of the telecom industry. These two peripheral groups consisted in 1989 of IBM, Fujitsu, NEC and Sony, Philips, Bosch, respectively. Furthermore, Schmoch identified a group of newcomers, including Nokia, Sony, Matsushita, Bosch and Toshiba, which entered the industry from other related areas of information technology (Schmoch 1995: 436). The positions of the newcomers in Schmoch's (1995) study were cutting across the three established groups of firms.

The comparison shows that Nokia's as well as Bosch's position are similar in both Schmoch's (1995) and our analyses. In a further analysis, Schmoch included the R&D expenditure per turnover in the maps (however not as an independent dimension as we do). Consistent with the findings of the present study, Schmoch (1995: 437-438) observed that the highly specialised firms in telecom had high shares of R&D to turnover, whereas the group of newcomers had much lower shares of R&D to turnover. This result supports our finding that there is a high degree of co-variation between R&D and technological specialisation. As Schmoch (1995: 438) observed, '*the question is open in how far this relatively low R&D share can be maintained in the future*'. This question is a further issue to be addressed in the following section.

In summary, the results of the present study support previous studies arguing that persistent firm-level attributes are sources of persistent differences of performance among firms within an industry. The results obtained in the present study applied a specialisation measure on two technological dimensions (strategic attributes) and one performance dimension (specialisation in turnover). The MDS-analysis further used an external unfolding procedure in which the positions of the individual firm over time are derived, not just from the moves of the firm itself, but also from the changes in the environment brought about by the interaction among the firms in the telecom industry. Therefore, a stable and persistent pattern requires a continued strategic pursuit of a particular economic and technological combination for all firms in the industry. The present study has therefore demonstrated, albeit on a small sample, that the stability in performance differentials found in previous studies e.g. Rumelt (1991), McGahan and Porter (1997) and Eriksen and Knudsen (2001) reflects persistence at the level of firm-specific strategic attributes. This result is consistent with the general claims of the Resource Based View. It would therefore be important to apply the methodology proposed in the present study to a large-scale empirical study. We will leave this question for future research and now turn to Schmoch's (1995) open question regarding the possibility that a firm may, for some reason, sustain a relatively low R&D share for a longer period of time.

6. IMPLICATIONS FOR INDUSTRIAL DYNAMICS

According to the results presented above, the firm-level strategic attributes as well as the economic performance of most firms of the telecom industry were persistent during the entire period spanned by the analysis. Consistent with this finding, there were very few moves (a total of 6 out of 24 possible) in the industry-space over time. It was observed that the two technology vectors are becoming increasingly interdependent over time. These observations motivate the definition of four domains shown below in Figure 6.1, to be interpreted as four groups with similar characteristics (labelled I to IV). On the basis of Figure 6.1, we now provide a description of the unfolding industry dynamics of the telecom industry.

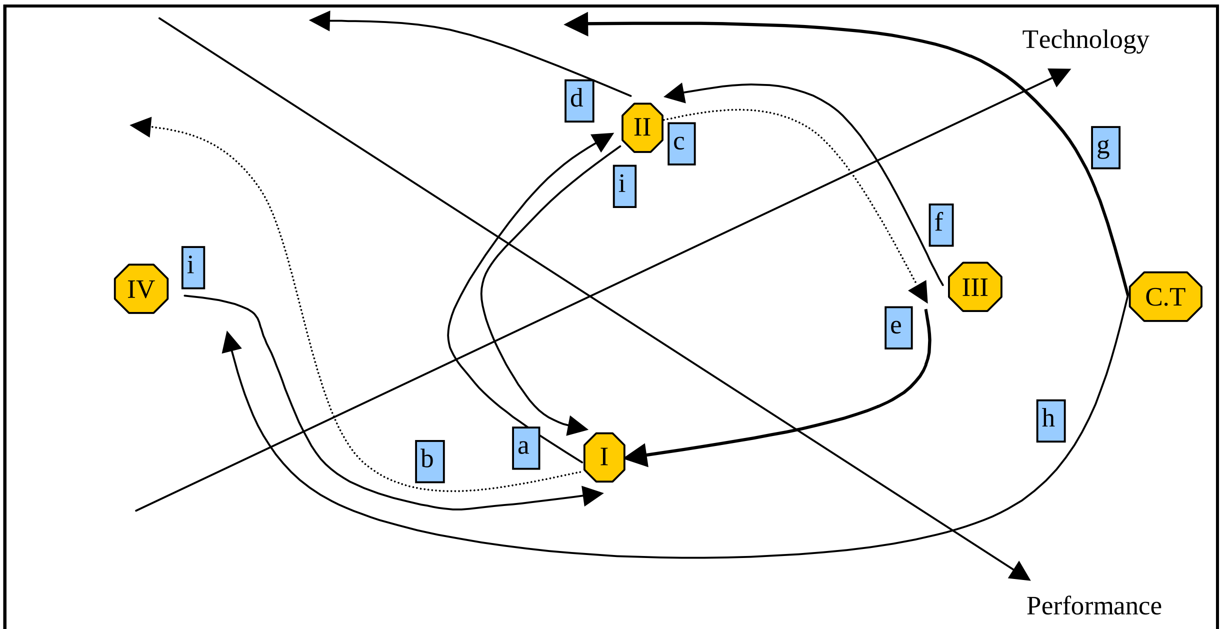

Figure 6.1: Industry Dynamics

Domain I: High economic and low technological specialisation

At first glance, domain I (see Figure 6.1 below) is very attractive since the firm is performing well in economic terms, and the technological specialisation is low, i.e. performance is achieved without extensive investments in new technological competences. Companies positioned in this group are Siemens and Bosch during all three periods, whereas GEC in 1992 and Fujitsu in 1995 enter this domain.

If competences are re-created (path a in Figure 6.1), there is no problem and the firm will move from domain I to domain II. In the absence of a re-creation of the firm's competences, the technological basis of the firm's economic specialisation may gradually erode. Eventually this scenario would lead towards the firm's exit of the industry (path b in Figure 6.1).

Domain II: High technological and low economic specialisation

Domain II is not very attractive. It is characterised by firms possessing a relatively high degree of technological specialisation but little ability to convert this strong position into economic performance. Unless the firm acquires such ability, the firm's economic performance is gradually eroded and it will sooner or later have to exit the industry (path d). However, in one particular instance a high technological specialisation may be used to create fall back positions as a safe guarding routine (Eisenhardt and Martin 2000). Domain II appears to be an unstable position that may be used as a stepping-stone towards future opportunities, e.g. a movement from domain II to III (along path c). This is not very likely because the maintenance of the competence base that is required is very high and will demand enough financial resources to prevent such a move. Considering the other alternative paths leading from II, the most likely movement appears to be along the technological vector to domain I (marked by i). This movement from II to I implies that the firm slowly erodes its competence base, either because it is unable to finance the required high level of technological competences necessary to move to III or because it decides to reap any possible surplus and divest. In summary, domain II is an unattractive and unstable location that does not provide a secure basis for long-term survival. Consistent with this viewpoint, no single telecom firm is located in this area during all of the three periods included in the present study. Philips and AT&T, however, temporarily locate in domain II.

Domain III: High technological and economic specialisation

At first sight, domain III seems very attractive because a high degree of specialisation in technological competence is accompanied by the necessary specialisation in turnover (a specialised customer base). As argued in the literature, however, the risk of obsolescence of existing competences through more attractive alternatives increases as the degree of specialisation increases. That is, domain III is characterised by a possible competence trap (marked by C.T in Figure 6.1) associated with a continued increasing refinement of the firm's specialised competences. As mentioned in section 3 a competence trap associated with likely failure (exit-paths g and h) becomes even more probable as the environmental dynamics increase. Because the loss of competences is the first effect of the competence trap, we believe path h is more likely than path g.

A timely strategic re-organisation of the competence base to avoid a competence trap is associated with a movement from domain III towards domain I (path e in Figure 6.1). This path is associated with the erosion of competences as a short-term solution to remain a high performer. Nevertheless a move to domain I by way of path e may lead to the accomplishment of a new and successful accumulation of competences and a move towards domain II by way of path a. Path f (move from III to II) is associated with the obsolescence of a particular technological competence in terms of decreasing economic return.

Domain III is therefore a relatively unstable domain, because it may either lead to a competence trap or to a strategic reorientation. Companies like Ericsson and Motorola are the only firms included in the present study to be located in domain III during all three periods. It is therefore interesting to examine whether these two companies have avoided the possible competence trap. For Ericsson[25], the answer is apparently *no*. During recent years, Ericsson has: (1) outsourced a number of vital functions including production, (2) in its critical activities (associated with core competence) depended to a higher degree on external partners, and (3) experienced increasing R&D cost per sold unit. For Motorola the case is different, as it initiated a strategic reorientation through the Iridium project (that failed however) (Finkelstein and Sanford 2000). Both events are consistent with the suggested characterisation of domain III.

Domain IV: Low economic and technological specialisation

Although apparently very unattractive, domain IV may be viewed in two ways: (1) as a position for entry or exit, or (2) as a low-commitment "listening post" where highly diversified companies may gain experience-based intelligence. Because the specialisation index measures specialisation as a share of the firm's own activities relative to the activities of the market, a highly diversified firm may be characterised by a relatively low degree of technological specialisation and yet perform reasonably well. Such a firm may thus remain in domain IV over longer periods of time. Examples of such firms are Hitachi and Matsushita. Schmoch's (1995) study did not include Hitachi, but listed Matsushita as a newcomer in 1989. The sustained position of Matsushita in domain IV reflects a highly diversified profile (see also appendix A). By contrast, Nokia represents the case of a firm entering the telecom market through domain IV (in 1989), and then proceeding to establish itself in domain III. This result is consistent with Schmoch's (1995) findings. Whether Toshiba belongs to the first or the second group remains to be seen on more recent data. In Figure 6.1 we have only indicated one possible entry path from domain IV namely via domain I (path j). It is rather unsure how entry will proceed and remains for further research to be clarified.

In summary, the external unfolding analysis provided an endogenously derived industry-space that allowed a descriptive assessment of the dynamics of the telecom industry. Based on the data of the sixteen companies it was possible to deduct a rather general picture of this dynamics. It was argued that domain II is inherently unstable and domain III becomes unstable as the basis of competition is altered (e.g. due to changes in customer preferences)[26].

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[25] For more detailed accounts of the Ericsson story see e.g. McKelvey and Texier (1997), Bernier (1996), Graetz (1996).

[26] The more likely paths are visualized by arrows marked in bold, whereas less likely paths are marked with a dotted line. These different likelihood's lead us to the deduction of more vs. less stable domains.

By contrast, domain I is a very stable area as the tendency to move from both domain II and III towards domain I seems to dominate the alternative paths.

For the telecom industry, it thus appears that domain I is rather stable and attractive. The problem with this conclusion is that the tendency to move towards domain I implies that competition among firms occupying this domain may drive profits towards zero. The firms in domain I may therefore use alternative strategies than technological specialisation in order to raise the costs of location. A possible alternative strategy is to pursue a high degree of technological specialisation in order to occupy domain III. The above assessment of the industry dynamics of the telecom industry further points to a number of dynamic drivers that may disrupt any possible equilibrium.

More generally, we have shown how our proposed methodology can be used to derive an "industry space" that allows for identification of the determinants of the tendency to form groups, and to infer the stability of such groups of firms sharing similar conditions. Note here that the proposed methodology is generally applicable across industries. The derived industry-space is specific to a particular industry, however. It must further be emphasised that the determinants of the tendency for firms to group in the industry-pace, the attribute- and performance-vectors, are endogenously derived and will therefore vary across industries.

In the telecom industry, we have seen that the two attribute-vectors, R&D and patent-specialisation overlapped to a degree that indicated that they could be treated as a single dimension of technology. This result must be expected to vary across industries. We further observed a rather high degree of interdependence (complementarity) between the technology-vector and the performance-vector. Again, this result may differ across industries. The point is that the proposed methodology unfolds the dynamics of a particular industry on the basis of the interactions among firms as they are expressed in the time-series used as input for the analysis. It is therefore important to select data that represent the key strategic attributes of the industry well. For the telecom industry we have used R&D and patent-data as well as a measure of performance. For different industries, different variables will better capture the key strategic attributes. We see this as a strength of the proposed unfolding methodology.

7. CONCLUSION

The aim of the present paper was to search for patterns of relationships among key variables (such as R&D investments, technology and performance), to trace these patterns over time and thereby unfold the underlying industry dynamics. In order to pursue this aim, we extended previous uses of MDS to derive and assess a meaningful representation of an industry. We refer to such a representation of the industry as an “industry-space.”

In order to further a more detailed assessment of the industry dynamics offered by previous studies, we applied what is known as external unfolding analysis. That is, we used regression analysis to fit vectors representing firm-level strategic attributes and performance measures in the industry-space derived by MDS. By applying this procedure we obtained information on each firm’s strategy and its consequences. Note that the vectors as they were fitted in the industry space represent endogenously derived industry-level properties.

By analysing how a firm’s position changes over time within this space, we were able to trace the industry dynamics as emerging patterns of relations among firms. By further applying the external unfolding analysis, we gained information about the changing relative position of the industry level attributes and performance vectors. As shown above, this information enabled a detailed assessment of the industry dynamics created by the mutual interaction of the telecom firms. More generally, we see it as strength of the proposed unfolding methodology that even if it is generally applicable across industries, the derived industry-space reflects the dynamics of a particular industry.

Our proposed methodology extends the approach originally introduced by Green and Carmone (1968) as well as the more recent use of MDS to assess possible groupings of firms. By adding the possibility of assessing the relative change of industry-level strategic dimensions we have further refined Green and Carmone's (1968) outline of a methodology for the analysis of dynamic change. In particular we have used the telecom industry to illustrate how our proposed methodology can be used to analyse the unfolding industry dynamics within the telecom industry. We view our proposed methodology as a first step in providing the refined methods necessary to conduct empirical analyses, also of very dynamic industries. The next development of our proposed methodology would obviously depend on a larger scale empirical test.

For the individual large firm, the present method can be applied without much difficulty as a strategic management tool. It allows the firm to trace its own potential strategies for the future as well as to identify and track the competitors of the industry closely. Thus, not only can the method improve the quality of existing management of technology but also provide a more thorough basis for identifying the competitors strategic moves. Through the concept of an industry space and the derived dynamic attributes the present study adds to previous conceptualisations of the R&D process.

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Appendix A: The level of specialisation

	1989			1992			1995		
	Patent	**R&D**	**Turnover**	**Patent**	**R&D**	**Turnover**	**Patent**	**R&D**	**Turnover**
Ericsson	82.7	52.9	91.4	84.0	54.6	93.8	71.9	46.9	90.4
NEC	61.8	28.7	27.7	40.3	21.1	39.9	23.4	17.3	24.1
Nokia	3.2	-14.3	-18.9	67.9	39.3	64.9	72.9	47.7	83.8
AT&T	72.7	34.9	18.5	61.2	34.3	7.7	58.1	36.9	86.0
Fujitsu	-38.4	-27.6	-27.2	-10.3	-5.0	-28.9	-57.9	-26.8	-31.5
GEC	-10.3	-14.8	-71.1	-8.7	-4.3	19.9	-29.6	-9.6	-10.8
Siemens	-8.4	-10.3	-0.8	-27.9	-14.1	29.6	-48.2	-20.4	-3.3
Bosch	-13.0	-17.2	7.9	-61.4	-34.2	30.1	-66.1	-32.9	-33.1
Hitachi	-88.9	-64.7	-98.2	-80.8	-50.8	-97.4	-89.3	-58.0	-98.3
Motorola	79.9	43.1	46.5	69.0	40.1	85.8	39.7	26.0	78.1
Alcatel				49.2	10.5	76.2	39.6	16.8	69.7
IBM				-32.4	-16.5	-92.6	-41.6	-16.4	-74.2
Philips		**Not available**		-27.4	-13.9	-94.2	-32.3	-11.2	-94.9
Matsushita				-54.9	-29.8	-73.5	-71.7	-37.5	-89.7
Sony					**Not available**		-50.0	-21.6	-95.4
Toshiba							-74.9	-40.5	-43.6