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Holger Ernst

Abstract

The availability of patent data from on-line databases or CD-ROM facilities has greatly enhanced the possibilities for the systematic evaluation of patenting activities. Hence, there is an intensive call for the use of patent data for strategic business planning in a variety of fields. Here, we will focus on patent portfolios which have been developed in order to support the strategic management of R&D in companies. Patent portfolios are used to evaluate a company's technological strengths and weaknesses in comparison to the competition. Since technologies vary according to their competitive impact, a company's position in patent portfolios yield important information for its strategic R&D investment decisions. Patent portfolios prove to be most valuable if static considerations are replaced by dynamic analyses. Sequences of patent portfolios show variations of companies' patent positions over time which allow to analyse dynamic changes of technological core competencies, technology attractiveness and R&D strategies.

1. Introduction

Technological change has been identified to be the major driving force for economic development (Solow 1957). Technological change is mainly determined by public and particularly by private research and development (R&D). Industrial R&D is the most important source for product or process innovations which allows companies to gain competitive advantages leading to sustained economic growth (Brockhoff 1994; Hauschildt 1997). This finding is supported by empirical studies at the firm level which found a positive relationship between R&D expenditures and various measures of commercial success, e.g. measures of productivity, growth and profitability (Mairesse, Sassenou 1991; Morbey, Reithner 1990; Capon et al. 1990).

In the academic literature and the consulting business it is stressed that companies are not well advised, if they react to the increasing technological competition only by increasing their total level of R&D expenditures. It is argued that the effective use of scarce R&D resources in those R&D projects, which yield the most profound and sustainable advantages over the competition becomes increasingly important (Brockhoff 1994; Sommerlatte 1995). Thus, various planning instruments have been suggested to support the effective allocation of R&D resources. Among them, different types of technology-portfolios have been put forward (Brockhoff 1994; Pfeiffer et al. 1986).

Traditional technology-portfolios are mainly based on subjective evaluations of technological positions. However, it has been observed that these evaluations can differ substantially depending on the interviewed experts (Möhrle, Voigt 1993). In addition, this type of portfolio does not take dynamic changes of positions in the portfolio matrix into account. Traditional portfolios only allow for static comparisons at certain points of time. It will be shown in this article that technology-portfolios based on patent data - patent-portfolios - offer an interesting way to overcome both shortcomings of traditional technology-portfolios. They are based on objective measures and further allow to incorporate dynamic changes of portfolio positions into the strategic R&D decision process.

The use of patent data mainly rests on the assumption that they sufficiently reflect the technological activities of firms. Major support for the use of patents as a measure for R&D outcome comes from quantitative empirical research, where the relationship between R&D and patents at the company level was examined (Bound et al. 1984; Hall et al. 1986; Pakes, Griliches 1984; Scherer 1983). Griliches et al. (1986) summarize this stream of research: "Not only do firms that spend more on R&D receive more patents, but also when a firm changes its R&D expenditures, parallel changes occur in its level of patenting" (Griliches et al. 1986, p. 7). Furthermore, a positive relationship between patent applications and lagged sales growth was found (Ernst 1996). This result proves to be very valuable, since it goes beyond the input-oriented measure of the level of R&D spending and supports the use of patent data even as an output measure of R&D, since patents indicate those technological activities which lead to subsequent market changes (Griliches 1990). The output impact of R&D is best mirrored by those patents, which are of higher technological and commercial quality than an average patent application. Patents granted, valid patents, international patent applications and patent citations have frequently been identified as quality signs of patents (Albert et al. 1991; Basberg 1987; Ernst 1995; Harhoff et al. 1997; Narin et al. 1987). Including these indicators of patenting quality in patent-portfolios enhances its meaningfulness.

This paper is organized as follows. In section two, we will first briefly discuss the structure of traditional technology-portfolios and will then, more extensively, describe the structure of patent-portfolios. In section three we will illustrate the use of patent-portfolios by applying this method to a group of international companies from the chemical industry. Here, we will analyze dynamic variations of portfolio positions and their implications. We conclude this paper with a brief summary and suggestions for further research in section four.

2. The portfolio method for strategic R&D planning

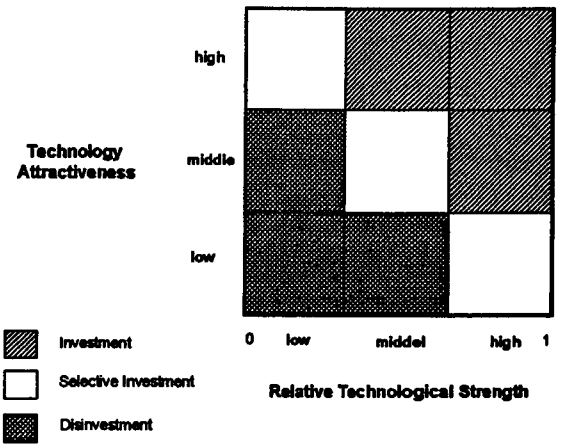
2.1 Traditional technology-portfolios

A variety of portfolio matrices has been developed to support the effective allocation of scarce R&D resources to specific technological fields. Brockhoff distinguishes between marketing- or technology-dominated approaches and attempts to integrate both views in one portfolio matrix (Brockhoff 1994). In marketing-dominated portfolios, strategic R&D investment decisions are directly derived from the product positions shown in the market-portfolio. Different technologies which lie or could lie behind these products are not explicitly considered. Thus, the attractiveness of single technologies cannot be evaluated. This approach is problematic because new emerging technologies which lead to the obsolescence of former highly attractive products may be overlooked (Pfeiffer et al. 1986). Furthermore, it is argued that the predominant market-orientation of R&D may lead to marginal improvements only and substantial innovations are not realized (Brockhoff 1985).

In contrast, technology-dominated portfolios allow the direct evaluation of product or process technologies. The general structure of technology-portfolios is illustrated by using the portfolio matrix suggested by Pfeiffer et al. (1986, 1991, 1995).[1]

The technology-portfolio shows the typical characteristics of two-dimensional portfolio matrices. On the abscissa, an indicator of a company's capabilities or strengths in a specific technological field is displayed. This value is predominately determined by the behavior of the firm under consideration. Pfeiffer et al. suggest to measure resource strength per technological field as a multidimensional construct which basically consists of two elements: a company's know-how and its financial strengths in order to build new know-how. These two elements are further broken down to separate items which are subjectively measured on a five point rating scale (Pfeiffer et al. 1991).

[1] An overview of other technology-portfolios is given in the work by Brockhoff (1994).



Source: Pfeiffer et al., 1986, p. 122.

Figure 1: Structure of technology portfolios

On the ordinate, an indicator of a technology's attractiveness is displayed. This value is predominately determined by the behavior of all other firms being active in the respective technological field. Technology attractiveness is also measured as a multidimensional construct which mainly measures a technology's development potential and its market potential. Again, corresponding single items are to be assessed by experts on the same five point scale (Pfeiffer et al. 1991). Based on the position of technologies in the portfolio matrix, the pursuit of general R&D investment strategies is recommended. Basically, a company should invest in technologies positioned in the upper right part of figure 1 as these technologies are attractive and the company holds strong positions. Contrary, the company should refrain from investments in those technologies positioned in the lower left part of figure 1. For the diagonal, selective R&D investment decisions are recommended.

Technology-portfolios are subject to critique known from other portfolio matrices (Brockhoff 1993; 1994). Here, we would like to point out two aspects which are of relevance to this paper.

First, traditional technology-portfolios are based on subjective personal judgments. It can be assumed that the assessment of both portfolio dimensions vary according to the interviewed person. It is known from organizational and marketing research that even knowledgeable informants may disagree because they hold different organizational positions and, thus, different perspectives on the same organizational phenomena. Here, a so-called informant bias is present which taints respondents' reports (Kumar et al. 1993). In particular, the assessment of a technology's attractiveness to a company requires the integration of the major functional departments (Marketing, R&D, Production). However, it was shown that interface problems between Marketing and R&D occur especially in the screening phase for new products (technologies) which leads to an informant bias (Ernst, Teichert 1998). Thus, the assessment of a technology's development and market potential may not be agreed upon by respondents from Marketing and R&D. Consequently, positions in technology-portfolios differ with respect to the interviewed person. Systematic research on respondent effects on the validity of technology-portfolio positions is not (yet) available. However, observations made during a practical application of a similar technology-portfolio method give further hints. Experts did not always have the knowledge to assess all the technological items they were asked and they substantially disagreed in their individual assessments (Möhrle, Voigt 1993).[2] In sum, technology-portfolios have to rely on personal judgments which lead to substantial measurement problems. They can partially be avoided by using multiple and knowledgeable respondents. However, aggregating different answers to one single construct for both portfolio dimensions continues to be problematic.

Second, technology-portfolios mirror technological positions at a certain point of time. However, they fail to show dynamic changes of portfolio positions. These dynamic developments could have an impact on the formulation of present R&D strategies. If a company decides to use a technology-portfolio to support its present R&D investment decisions, it will get a static picture of today's technological positions. However, it might be of importance to get further in-

[2] E.g., a median value of three could be observed for the deviating answers on a ten point scale. Furthermore, 17% of the answers deviated more than five points.

formation on the evolvement of these positions over the preceding years. Questions to be answered include for example: How has the attractiveness of a particular technological field changed in recent years?; In what phase of the technological life cycle is a technology?; Is a technology about to be rejuvenated?; Has the technological emphasis of competitors changed over the years?, Have our capabilities in specific technologies increased or decreased? Answers to these questions can only be given, if the history of portfolio positions is incorporated in technology-portfolio illustrations. However, traditional technology-portfolios do not provide this information.

We will argue in the following that technology-portfolios based on less but objective patent data may offer an interesting solution to both problems of subjectivity and missing dynamism inherent in traditional technology-portfolios.

2.2 A technology-portfolio based on patent data

The patent-portfolio has the same basic structure as it is known from traditional technology-portfolios described above. A measure of technological strength is used for the abscissa and a measure of technology attractiveness is used for the ordinate. However, both basic dimensions of technology-portfolios are now assessed by means of patent data. The basic concept of a patent-portfolio was first introduced by Brockhoff (1992). Since then, the contents of patent-portfolios have been expanded and practically applied on a large scale (Ernst 1998). Figure 2 illustrates the basic structure of a patent-portfolio.

On the abscissa, we measure a company's patent position in a specific technological field relative to its competitors. The relative patent position per company and technological field (RPP_{if}) is defined as follows:

(1) $$RPP_{if} = PP_{if} / PP_{i^*f}$$

(1a) $$PP_{if} = PA_{if} \circ PQ_{if}$$

(1b) $$PQ_{if} = \sum_{k=1}^{K} RPQ_{ifk}$$

(1c) $$RPQ_{ifk} = QI_{ifk} / \left[\left(\sum_{i=1}^{I} QI_{ifk} \right) / I \right]$$

with the following parameters:

PA = Number of Patent Applications; PP = Patent Position; PQ = Patenting Quality; QI = Indicator of Patenting Quality; i = Company (i = 1,..,I); i* = Company with strongest Patent Position (Benchmark); k = Indicator of Patenting Quality (k = 1,..,K); f = Technological Field.

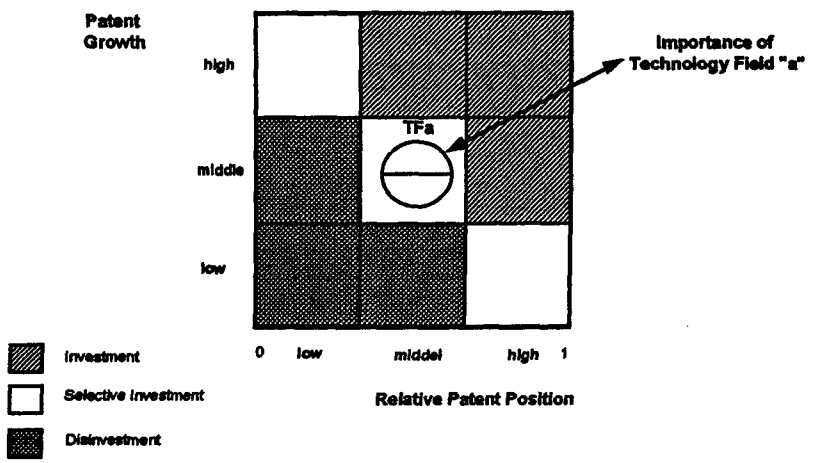


Figure 2: Structure of patent-portfolios

The number of patent applications (PA) reflects the patenting activity of companies. It shows the extent of R&D activities carried out in specific technological fields and further demonstrates the patentee's intention to use the invention economically in the market. However, by using patent applications only, one cannot distinguish between diverging qualities of inventions. Several indicators for patenting quality (QI) can be used:

1. **Rate of Patents Granted**: A patent will only be granted, if the invention consists of new technological elements (e.g., § 1(1) German Patent Law). Therefore, a patent granted is believed to be of higher technological value than the mere patent application (Basberg 1987). The rate of patents granted can differ substantially between companies and thus possibly deflates a high number of patent applications (Brockhoff 1992). The rate of patents granted

is measured as the number of patents granted over patent applications minus patent applications under examination.[3] The rate of patents granted is considered as an indicator of technological patenting quality (Ernst 1996).

2. **Rate of Valid Patents**: Patents are valid, if they have been previously granted and the protection fee is still paid for by the patentee. Assuming rational decision behavior it can be reasoned that valid patents are still economically valuable for the company, i.e. the economic benefit is larger than the cost to maintain the patent. It can further be assumed that the share of valid patents correlates with the renewal time of a patent, which is widely believed to be an indicator of high quality patents (Schankerman 1991; Schankerman, Pakes 1986). The rate of valid patents is measured as the number of valid patents over patents granted (Ernst 1995).
3. **Share of International Patent Applications**: International patent applications are considered to be more valuable, since the cost of obtaining an international patent is substantially higher than that of a national patent application (Basberg 1987; Griliches 1990; Schmoch 1990). In the literature, patent applications in the US have been frequently used to measure patenting quality (Basberg 1983; Glismann, Horn 1988; Soete 1987). For example, a company's share of US patents could be measured as the quotient of its US patents and the total number of its patent applications. In general, the selection of an appropriate foreign country to be used depends on the country of origin of the companies under investigation. It was shown for German companies that their share of US patents correlates with commercial success (Ernst 1996). If international comparisons are made, different indicators of international patent applications are to be used, e.g., if German companies are to be evaluated against competitors from the US, the use of US patents as an indicator of patenting quality is misleading. In these cases, it is advisable to either use patent applications at a foreign neutral third patent office (Pavitt 1988) as, e.g., the European Patent Office (EPO) or to define a new indicator of international patenting activity tailor-made to the requirements of the respective investigation.

[3] Patent applications under examination are subtracted from the total number of patent applications since they can still be granted in the future (Ernst 1995).

4. **Patent Citation Ratio**: Patents are used by patent inspectors at the patent office to document the state of technology when they check if a patent application contains new features which go beyond what has been known so far. This procedure leads to patent citations. The number of citations received by a patent in subsequent patent documents is often interpreted as a sign of an economically important invention (Albert et al. 1991; Carpenter et al. 1981; Harhoff et al. 1997). The average citation ratio can be computed by dividing the number of citations by the total number of patent applications (Narin 1987).

The last three indicators are of special importance for determining a patent's quality. Several empirical studies prove that these quality indicators positively correlate with measures of commercial success on the company level (Ernst 1995; Narin 1987). Thus, they are also referred to as indicators of the economical patenting quality (Ernst 1996). The same correlation could not be proven true for the share of patents granted as a measure of technological patenting quality (Ernst 1995). Thus, as it is known from market-portfolios, where a company's relative market share as the major driver of company performance (Schoeffler et al. 1974) is displayed on the abscissa, the inclusion of success-related quality measures of patents does enhance the meaningfulness of technological positions displayed in patent-portfolios.

It has been argued that the reliance on only one measure of patenting quality may be subject to significant evaluation failures caused by varying values for different quality indicators. Therefore, we aggregate the indicators of patenting quality described above to a construct of overall patenting quality, which is believed to provide a more stable assessment of companies' patenting quality (Ernst 1996):

5. **Total Patenting Quality**: A construct of patenting quality per technological field (PQ_{if}) is used which consists of the sum of relative measures for each individual indicator of patenting quality (RPQ_{ifk}). Relative values are calculated by relating the respective indicator of patenting quality for each company to its mean value over all companies under consideration (Ernst 1996; see formula (1c)). It should be pointed out that the number or content of the various indicators of patenting quality to be included in the construct of patenting quality can be subject to variations in accordance with the specific objectives of patent-portfolio illustrations.

Finally, the relative patent position of each company per technological field (RPP_{if}) is measured as the quotient of its patent position in a technological field (PP_{if}) and the strongest patent position of any of the relevant competitors in the respective technological field (PP_{i*f}). Thus, the maximum value for RPP_{i*f} is one. Using the strongest patent position per technological field as a benchmark allows the direct identification of leading and following companies in specific technological fields and illustrates immediately the distances between the respective companies (Ernst 1998).

On the ordinate, we measure the attractiveness of each technological field by using growth rates of patent applications. Brockhoff, e.g., suggests to measure the growth of patent applications in a specific technological field during the past four years relative to the growth in the preceding 16 years, which covers the 20 year patenting period (Brockhoff 1992). In the literature, numerous other growth measures can be found (Ernst 1998; Faust 1989; Marmor et al. 1979). Most of these measures of patent growth stress recent changes in patent growth, i.e., high growth rates in recent years relative to patent growth in preceding years are interpreted as an indicator of high technology attractiveness. Furthermore, it has been suggested to measure relative growth rates (Ernst 1998), e.g., by dividing the growth rate of patents in a technological field by the average growth rate of all other technological fields under investigation in the patent-portfolios. Both, the respective reference measure to calculate relative rates of patent growth and the aforementioned definition of time intervals can vary between different portfolios. It was shown that different measures of patent growth lead to diverging portfolio positions which has an impact on the conclusions drawn from the portfolios (Ernst 1998). In principle, relative patent growth in technological field f (RPG_f) can be measured as follows:[4]

$$(2) \quad RPG_f = PG_f / PG_R$$

$$(2a) \quad PG_f = PG_{ft-\tau} / PG_{ft-\theta}$$

$$(2b) \quad PG_R = PG_{Rt-\tau} / PG_{Rt-\theta}$$

[4] The natural logarithm is used to measure yearly growth rates correctly. The arithmetical mean is used for averaging growth rates. The validity of this procedure to calculate growth rates was proved (Wetzel 1964).

with the following parameters:

PG = Patent Growth; t = Reference Point for Time Interval; τ = Time Lag for Numerator (Recent Patent Growth); θ = Time Lag for Denominator (Preceding Patent Growth); f = Technological Field; R = Reference to Measure Relative Growth Rates.

The underlying assumption of using patent growth rates as a measure of technology attractiveness is that high patenting activity, either caused by a higher number of patent applications per company and/or by an increasing number of patentees entering a specific technological field, reflects the attractiveness of technologies and beyond that, even the attractiveness of market opportunities. The following reasons support this assumption. It can first be argued that a patent application shows a patentee's willingness to market the invention which in turn shows that the respective company assumes a commercial opportunity for its invention (Griliches 1990). Second, empirical research on the company level shows that patent positions are related to commercial performance for a cross-section of firms (Ernst 1995) and, even beyond, for cross-section time-series data, that patent applications lead to subsequent sales increases, thus, indicating a causal relationship between patenting activity and market changes (Ernst 1996). Third, a substantial number of studies on the level of technological fields exist that found an almost parallel development of patenting activity and market growth of products based on the underlying technologies (Achilladelis 1993; Ernst 1997).[5]

The circle size of the technological fields displayed in patent-portfolios reflects the distribution of total company's patents among technological fields. This indicates the importance of each technology within the company's R&D portfolio. Technology importance given to technological field f by company i (TI_{if}) is calculated by the number of patent applications in a technological field (PA_{if}) relative to the total number of patent applications of the company (PA_i) in question:

$$(3) \qquad TI_{if} = PA_{if} / PA_i$$

[5] Patent statistics published by the German Patent Office (GPO) show the increasing number of patent applications in the technological or product field airbag in the 1980s (GPO 1994). During this time, airbags have become a standard offering in almost every, even mid-sized and small cars. Similar developments can be observed for anti-blocking-systems in the automobile and mobile phones in the telecommunication industry.

with the following parameters:

TI = Technology Importance; PA = Patent Applications; i = Company (i,..,I); f = Technological Field.

In general, the patent-portfolio can be used to evaluate technological strengths and weaknesses of competing companies with respect to different technological fields. This information supports strategic R&D investment decisions. As we know from traditional technology-portfolios, companies should invest in growing technological fields where they hold strong patent positions, whereas they should disinvest in low growing (declining) technologies where they hold rather weak patent positions (see figure 2).

At the beginning of section 2.1, it was explained that traditional technology-portfolios and patent-portfolios are technology-oriented tools for strategic R&D planning. Both need to be aligned with other strategic planning instruments in order to avoid one-sided, technology-dominated misconceptions. Here, various methods to integrate traditional technology-portfolios (Benkenstein 1989; Brockhoff 1994) and patent-portfolios with market-portfolios have been suggested (Ernst 1996).

In the following, we will illustrate for a group of international companies from the chemical industry dynamic position changes in patent-portfolios and their impact on strategic R&D decision making. Other than traditional technology-portfolios, the patent-portfolio method allows to analyze dynamic aspects of portfolio positions. In other words, the emerging of today's positions in patent-portfolios over preceding years can be made visible because patent data can easily be assigned to their time of origin. Knowing the dynamic evolvement of patent positions over time adds valuable information to the interpretation of portfolio positions.

3. Application of the dynamic patent-portfolio method in the chemical industry

3.1 Preliminary work

We applied the patent-portfolio for a group of seven major international companies operating in a specific segment of the chemical industry. The companies came from Germany, Japan, and the US. For reasons of confidentiality we cannot report any information which could lead to the identification of the companies under investigation. During this case study we closely co-operated with senior R&D managers from the German companies. During an initial workshop, five technological fields were identified to be included in the patent-portfolio analyses.

It was decided to take patent applications that assure legal protection for an invention on German territory as the basis for our analyses. These patent applications can either be direct patent applications at the German Patent Office (GPO), or patent applications via the Patent Cooperation Treaty (PCT) mechanism or via the EPO. The major reason for this approach was our intention to measure the quality of patents, e.g., by means of patents granted and valid patents. Since patents are territorial rights, these indicators of legal status can only be compared at the same patent office. Here, the German companies were mainly interested in considering the patent situation on their local market. Furthermore, Germany can be considered as the most important market in Europe, especially for the chemical products under consideration. In general, 90% of patent applications at the EPO claim Germany as a designated state (Schmoch et al. 1988). Thus, patent applications at the GPO provide an almost complete picture of German and European patenting activities. In addition, we found for our sample that all European patent applications were also filed at the GPO. Senior R&D managers were convinced that their competitors would file all relevant patents at the GPO, also. However, it has to be maintained that patenting activity of German companies may be overestimated due to their home-country advantage, whereas patenting quality for their foreign com-

petitors may be exaggerated because international patent applications are filed more selectively (Ernst 1998).

Patent data was derived from the patent databases PATDPA, WPI and ESPACE-Bulletin from 1978 to date. Since this analysis was carried out at the end of 1997, patents applied for until the beginning of 1996 could be considered due to the 18 months time lag between priority date and publication of the patent application. These patents had to be allocated to the five technological fields. This can either be done manually or automatically (Brockhoff 1992). It was of interest to us to examine the deviation between both procedures (Ernst 1998). Thus, in one of the companies patents were allocated to the defined technological fields by their own R&D staff. Patents were automatically allocated by using a combination of relevant IPC-classes and keywords to define each technological field (Schmoch 1990). In total, 239 patents had to be allocated. 201 patents were assigned to the same technological field; eight of the remaining 28 patents were only assigned to a technological field automatically because they remained unclassified during the manual allocation procedure. The rather small deviation of 8% of the patents supports the use of automatic allocation procedures, after a technological field is properly defined by a combination of IPC-classes and precise technical expressions. Here, the alignment of those who perform the patent search and experts from R&D is crucial (Ernst 1996). Senior R&D managers argued that the manual inspection of single patent documents had always been very burdensome, especially when large amounts of patent data had to be evaluated and continuously updated. Thus, automatic allocation schemes would greatly enhance the usefulness of patent-portfolios.[6]

[6] The manual allocation of patents to technological fields is subject to a bias, if different persons are involved. Thus, criteria need to be specified which make the systematic and comparable assignment of patents possible. These criteria can be used as keywords for automatic allocation.

3.2 Drawing of patent-portfolios

The patent-portfolios followed the basic structure outlined in section 2.2. However, two remarks concerning the measurement of the two portfolio dimensions need to be made.

1. The relative patent position was measured according to formula (1). The share of patents granted, the share of valid patents, the citation ratio and the share of international patents were used as quality indicators (k) of the patent applications. The share of international patents was measured by dividing a so-called "triad patent" by the total number of patent applications. A "triad patent" is simultaneously filed in Germany, Japan and the US. This was viewed to be an appropriate measure because all of the considered companies operate on a global scale and the use of "triad patents" allows for a comparison between companies of different national origin.
2. The total time period was divided into three subperiods in order to analyze dynamic developments of positions in the patent-portfolios. Thus, patent-portfolios covering the years 1978 to 1985, 1978 to 1990 and 1978 to 1995/6 (date of data retrieval) were constructed which display the technological positions which we would have found if we had drawn single patent-portfolios for the years 1985, 1990 and 1995/6. Rates of relative patent growth as an indicator of technology attractiveness were measured according to the basic formula (2) outlined in section 2.2, i.e., recent patent growth for a technological field was divided by recent patent growth in all five technological fields.[7]

[7] E.g., patent growth in technological field 1 (TF1) in patent-portfolio II (1978-1990) is calculated as follows: a) Patent growth (TF1, 1985-1990) / Patent growth (TF1, 1978-1984); b) Patent growth (all five technological fields, 1985-1990) / Patent growth (all five technological fields, 1978-1984); c) Relative Patent growth for TF1 in patent-portfolio II (1978-1990) = a/b.

3.3 Analyzing patent-portfolio positions

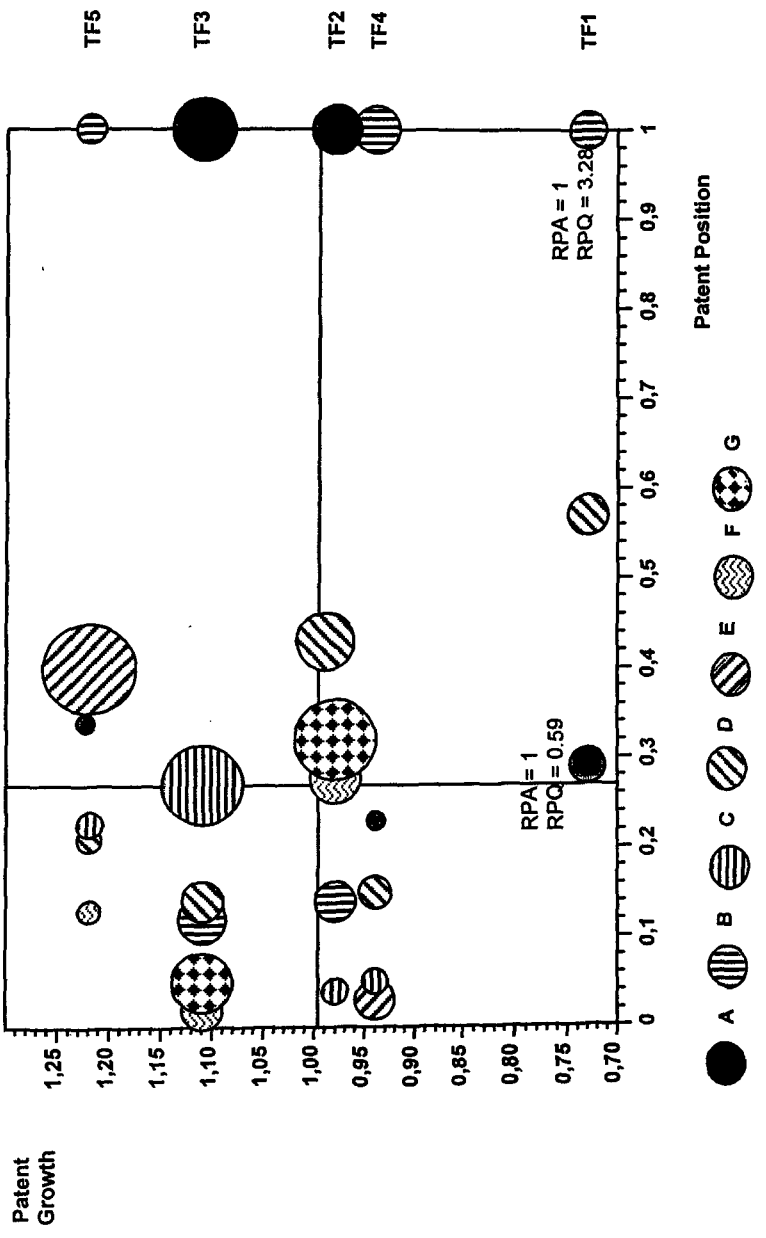


Figure 3: Patent-portfolio (1978-1985)

Figure 3 displays the first patent-portfolio for the year 1985 covering the time period from 1978 to 1985. TF5 and TF3 are the fastest growing technological fields; TF1 is the slowest growing technological field. All technological fields are either dominated by company A or B. Company A has strong patent positions in TF3 and TF2; it has weak patent positions in the technological fields TF5 and TF4. It seems that company A did neglect these two technological fields at that time. In contrast, company B shows an almost opposite pattern: strong patent positions in TF4 and TF5 and weak patent positions in TF2 and TF3. Interestingly, company B has the highest patenting quality in both technological fields four and five. Obviously, company B had an early major focus on these two technologies. Company B further holds the strongest patent position in TF1. Company A filed the same number of patents in that period (RPA = 1)[8], however, the quality of its patents (RPQ = 0.59) is much lower compared to company B (RPQ = 3.28). Hence, the inclusion of quality indicators for patents can substantially change the relative patent position in patent-portfolios (see section 2.2).

Figure 4 displays the second patent-portfolio for the year 1990 covering the time period from 1978 to 1990. Patent growth in TF4 and TF5 has further increased and is fastest among all technological fields. TF1 and TF2 are least attractive. All technological fields are further dominated by either company A or B. Only company D in TF1 and company C in TF5 come close in particular technological fields. It is striking that company A has dramatically improved its patent position in TF5 and TF4. Company A is the most active patentee in both technological fields in that period; however, patenting quality is lower compared to patents of company B which is still leading in these technological fields. Company A remains the dominant company in the attractive technological field TF3. Company B has the strongest patent positions in TF4 and TF5. In addition, it puts more emphasis on TF4 than company A and the quality of patents in TF4 and TF5 remains very high. In contrast, company B does not focus on TF2 and lies far behind company A in TF3. Finally, company B lost its dominant patent position in TF1. In that period, com-

[8] RPA is measured as described in formula (1). However, patenting quality is not taken into account.

pany A had closed the gap and even passed company B to gain the strongest patent position in TF1.

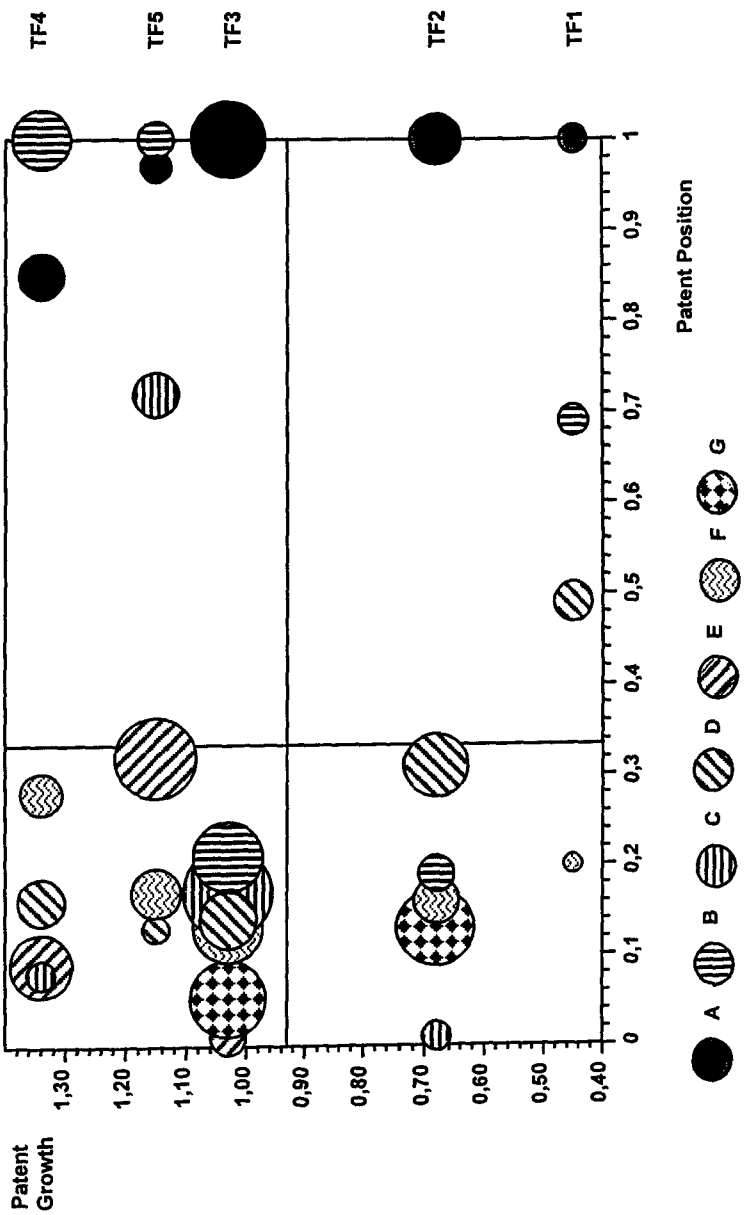


Figure 4: Patent-portfolio (1978-1990)

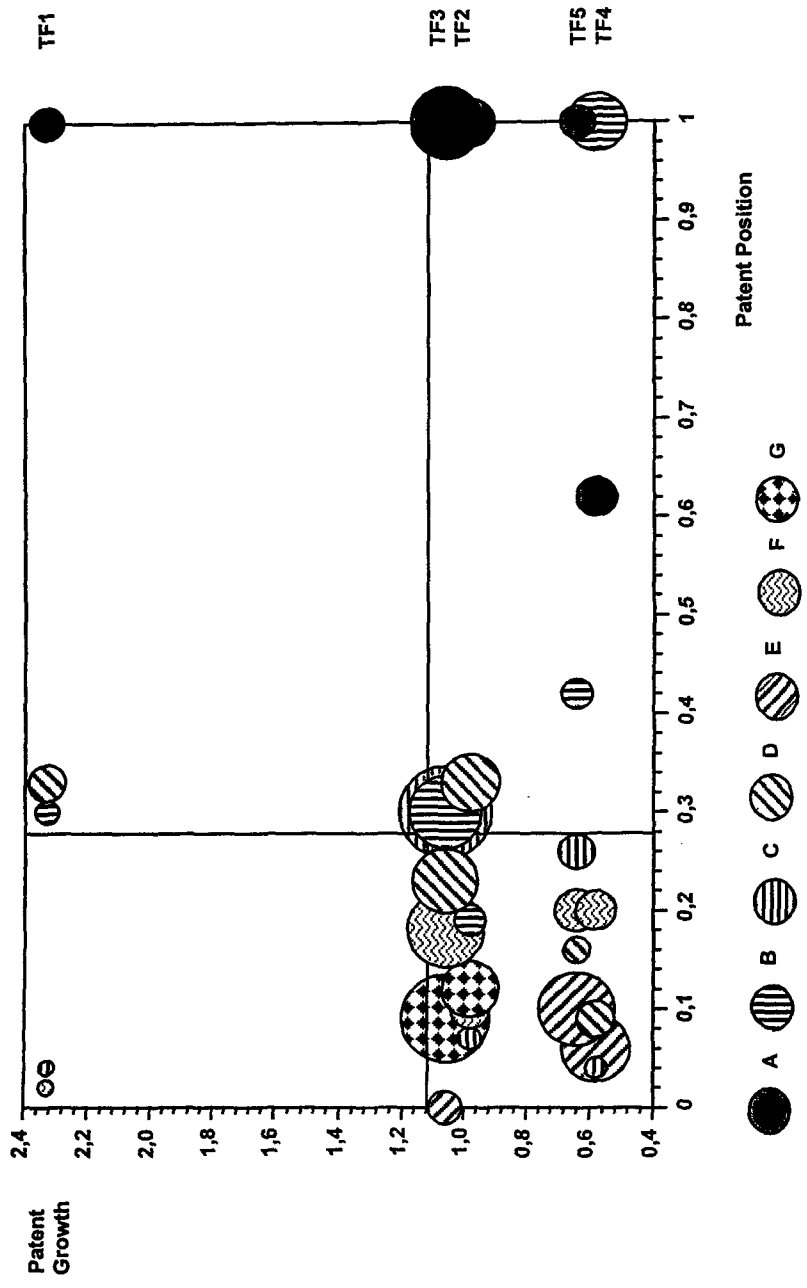


Figure 5: Patent-portfolio (1978-1995/6)

Figure 5 displays the third patent-portfolio for the year 1995/6 covering the time period from 1978 to 1995/6. Surprisingly, patent growth is fastest in those technological fields TF1 and TF2 which had experienced prior low growth rates. In contrast, patent growth is lowest in the former fast growing technological fields four and five. Patent growth has been high for TF3 during the entire time period. This seems to be a key-technology in the industry under consideration. All technological fields are still dominated by either company A or B.

The patent-portfolio illustration in figure 5 can further be improved, if those patents are excluded from the analysis which had not been renewed during the considered time interval. Thus, we use the patent stock to measure the relative patent position. The patent stock consists of valid (granted and in force) patents and recent patent applications which are still under examination by the patent office (Ernst 1998). In this case, the quality of the patent stock is measured by the remaining two indicators of patenting quality, i.e., the share of international patents and the citation ratio (see section 3.2). The resulting patent-portfolio is displayed in figure 6.

A few differences compared to figure 5 are apparent. First, companies D and B get closer to the still leading company A in TF1. Second, company D emerges as the second strongest competitor of company A in TF2. Third, company C and particularly company B close the gap to company A in TF5. Fourth, the leading position of company B in TF4 becomes even more evident. In sum, it should be stressed that this type of portfolio matrix proves to be most valuable if present patent positions of companies are to be assessed. The inclusion of former patent applications which have not been renewed would delude the portfolio illustrations. However, they prove to be very helpful in order to illustrate the evolvement of present portfolio positions and should, therefore, not be neglected.

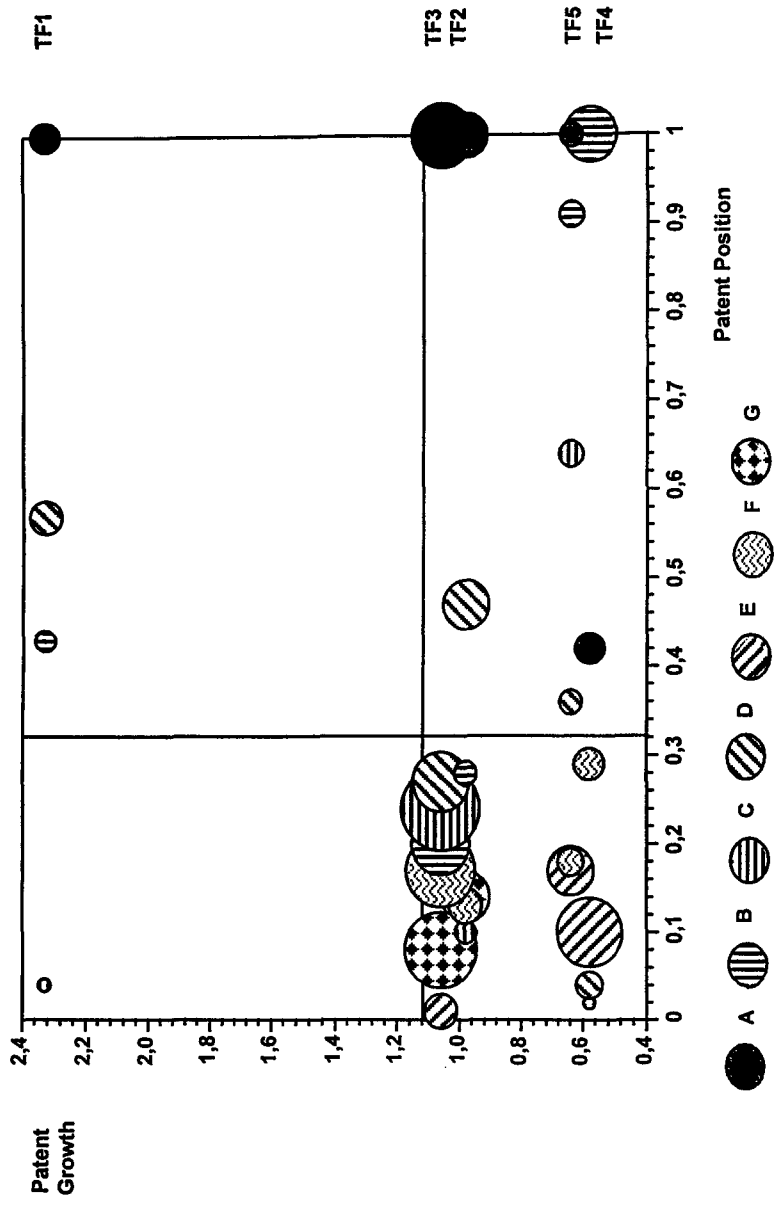


Figure 6: Patent-portfolio (patent stock, 1978-1995/6

3.4 Overall implications of patent-portfolios

Recent patent growth is fastest in technological fields one, two and three; recent patent growth is lowest in technological fields four and five. Future R&D effort should be directed towards these technologies which may promise more sustained competitive advantages than improving other technologies. Company A has early focused its R&D activities on TF2 and TF3, where it has had a dominant patent position (core technological competencies) from 1978 to 1995/6. Furthermore, company A has the strongest patent position in TF1, which was gained after the year 1985. Thus, company A appears to be well positioned, today, in the most attractive technological fields.

Company A shows an overall strong patenting performance. Across all technological fields, it has been the most active patentee and the quality of its patents is high. Company A takes the strongest patent position in four out of five technological fields and the second strongest patent position in the remaining technological field four. However, the distance to the leading company B is large in TF4. It became obvious from the early patent-portfolios that company A did not pay much attention to TF4 and TF5. Here, it followed other companies, especially company B.

Company B has a clear focus on TF4 and TF5. It was among the first companies to recognize the importance of these technological fields and it has maintained a leading position from 1978 to 1995/6. It appears that company B has gained a strong competitive position in this area. In particular, TF4 is given much emphasis, which contrasts to the activities of company A. It is, furthermore, opposite to company A because it has weaker patent positions in TF3, TF2 and TF1. However, the quality of company B's patents is high in the last two technological fields mentioned. In sum, the patent-portfolios show a distinct strategic difference of R&D activities between companies A and B from 1978 to 1995/6.

Companies C and D appear as the most serious competitors of companies A and B. Their patents are of high quality and cover all technological fields. Company D's particular strengths can be found in TF1 and TF2, where it has the second strongest patent position behind company A. Company C has a strong patent position (high quality of patents) in TF5 and has a particular R&D-emphasis on TF3.

4. Discussion

We successfully applied the patent-portfolio method for seven international competitors from the chemical industry. Final discussions with our partners in industry about the results of the study revealed that this instrument was viewed to add valuable information to the strategic R&D planning process and that, under benefit-cost considerations, it appeared very appealing to practitioners. The cost of patent data retrieval amounted to approximately $ 6,000 and it took a one-day-workshop with senior R&D managers to define the technological fields. However, it has to be added that the costs of patent data analysis cannot be generalized, since they depend on the extent of patent searches performed and the search expertise of the analyst. However, patent data retrieval costs are relatively low compared to other forms of technological information sources (Ashton et al. 1991) and more important, they have to be judged according to their benefits for strategic R&D planning. Moreover, all managers from the companies involved stressed the advantages of getting an objective picture of technological positions which could further be used to better communicate technological strengths to either senior management and/or outside stakeholders like investors or potential partners.

The positive experiences made during this study lead to the insight that the continuous and strategic analysis of patent information should become an essential part of strategic planning activities within each company (Ashton, Sen 1988). This could help to improve the insufficient level of information about competitors' R&D strategies. As the experiences from this study further show, the effective use of patent information in strategic planning can only be achieved by the inclusion of company expertise in the patent retrieval and analysis process. Thus, the outsourcing of strategic patent data analyses to external information brokers does not seem to be advisable (Reiche, Selzer 1995). Hence, companies need to establish a particular unit within the organization, which is responsible for the continuous and systematic evaluation of patent information (Ernst 1996).

The study further revealed that, in contrast to traditional technology-portfolios, patent-portfolios can be used to analyse dynamic technological developments. The emerging of today's positions in patent-portfolios over preceding years can be made visible ex-post

because patent data can easily be assigned to their time of origin. Knowing the dynamic evolvement of patent positions over time adds valuable information to the interpretation of portfolio positions. In our study, we were able to analyze dynamic changes with respect to the attractiveness of technological fields, the relative patent position of companies in these technological fields and the importance given to each technological field by each company. Here, we would like to illustrate this point by giving some examples.

TF3 shows high rates of patent growth over the total time period. It can thus be regarded as a core technology in the respective industry. Companies may not be well advised to neglect this technology. Furthermore, TF5 and TF4 were the fastest growing technological fields until 1990. Since then, TF2 and TF1 have been the fastest growing technological fields which yields important implications for future R&D investment decisions. To one of the German companies this result came as a surprise because senior management had been convinced that TF4 and especially TF5 would play an important role in the future. It was not perceived before that patent growth had already been high in these technological fields almost ten years ago. In this context, a major difference between companies A and B over time became obvious. Company B was among the first to realize the importance of TF4 and TF5, whereas company A caught up to company B only some years later. In this context, the patent position of company E is of interest. Company E holds patents only in TF4 and TF5. It was also among the first to file patents in these two technological fields (see figure 3). The latest portfolios (see figures 5 and 6) show that company E still holds these patents. Hence, these patents must be of substantial importance to company E. Company E may not be considered as a direct competitor of the other six companies since it does not operate along the entire value chain which is typical for this segment of the chemical industry. It rather focuses on the application of certain technologies to develop specific products. Looking at the portfolio may thus reveal that company E is fast in recognizing newly evolving application trends. It may thus be a candidate for the other chemical companies to be regarded as a lead user (von Hippel 1986). In sum, these examples and the detailed analyses in sections 3.2 and 3.3 show that dynamic changes in patent-portfolio positions over time add valuable information to strategic R&D decision making which would not have been available, if a traditional technology-portfolio had been drawn in that industry in 1995/6.

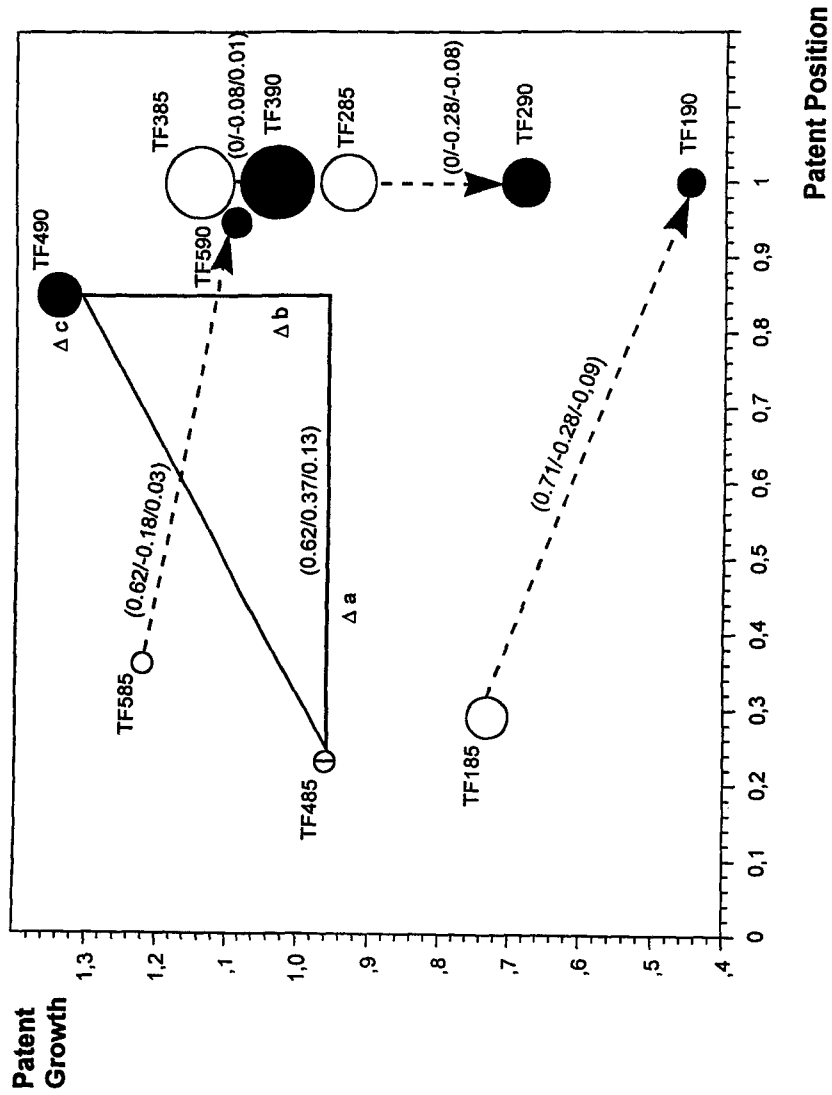


Figure 7: Dynamic development of patent-portfolio positions

Dynamic changes in patent-portfolios can be made more explicit. Figure 7 illustrates a different approach to analyze dynamic developments of patent-portfolio positions. Here, e.g., we consider changes of portfolio positions of company A between 1985 and 1990. Dynamic changes are captured by a vector showing the degree of deviation of the three portfolio variables between both years. Company A had a weak patent position in technological field four in 1985, where it was 0.8 away from the leading company. By the year 1990, however, company A had reduced its deficit by 0.62 and almost caught up to the most strongest patentee in technological field four. Figure 7 further shows that patent growth in technological field four had risen by 0.37, thus indicating the increased importance of this technological field. Finally, company A put a larger emphasis on technological field four in 1990 compared to 1985 (Δ c = 0.13). This development indicates that company A must have realized the attractiveness of technological field four and, therefore, substantially increased its R&D efforts in this field which resulted in a much stronger patent position. All other vectors in figure 7 can be interpreted accordingly. Overall, company A remained the strongest patentee in technological fields two and three and substantially improved its patent position in technological fields one, four and five during this time period.

This paper also yields some implications for further research. Here, one major aspect ought to be outlined. Since a positive relationship between quality indicators of patents and company performance has been found in empirical studies, we included these measures in the patent-portfolios in order to enhance the meaningfulness of portfolio positions. Thus, we indirectly assume a relationship between portfolio positions and company performance. It seems, however, worthwhile to directly test the relationship between a company's position in the patent-portfolios and various measures of economic performance. The hypothesis to be tested is that companies holding strong patent positions in highly attractive technological fields are more successful than those competitors holding weak patent positions in unattractive technological fields. This hypothesis could further be modified that companies which first hold strong patent positions in highly attractive technological fields are more successful than those competitors which later achieve strong patent positions in the same technological fields. Both hypotheses can either be tested in a cross-section or panel analysis, where the latter allows to incorporate lag-structures between independent and dependent variables.

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