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Patent information for strategic technology management

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Abstract

The information in patent data can be used for strategic planning purposes. A conceptual framework is developed showing the use of patent information in core areas of technology management. This paper addresses how patent information can be used for competitor monitoring, technology assessment, R&D portfolio management, the identification and assessment of potential sources for the external generation of technological knowledge, especially by means of mergers and acquisitions, and human resource management. Indicators of patenting strategies and various portfolio concepts which can be used for these purposes are described. Because of its strategic value, it is argued that the retrieval and evaluation of patent data should be institutionalized within the organization in order to ensure the continuous and systematic use of patent information in a company's decision-making processes. How patent information becomes a core element of a firm's knowledge management system is outlined. This type of strategic patent information is geared toward two important recipients: (1) senior management who uses this information for decision-making purposes in important areas of technology management and (2) external stakeholders of the firm, such as shareholders and analysts, who have an increasing interest in assessing a firm's technological competence because of its strong impact on the firm's future competitiveness.

Keywords: Patent information; Knowledge management; Strategic planning; Technology management; Patent quality; Patent portfolios; Technology share; Financial analysts

1. The value of patent information for strategic planning

Technological change has been found to have a decisive impact on the competitive structure in many industries. A study of the US hard drive industry showed that companies which had led the markets were driven out because they did not recognize the potential of new, disruptive technologies [1]. The importance of technology for competitive advantage has caused a substantial increase in industrial research and development (R&D) spending [2]. Maximizing the contribution of R&D to a firm's strategic and commercial objectives is the fundamental objective of technology management. Technology management comprises the management of the creation, storage and use of technological knowledge. Technological knowledge can be created internally by the firm's own R&D activities and used internally in products, processes and services. Important technological knowledge should be stored for use in subsequent R&D projects. Since important and, in particular, tacit knowledge is stored in the minds of inventors, human resource management in R&D becomes a means to store specific forms of knowledge. The transfer of technological knowledge from external sources to the firm, e.g. by means of licensing, R&D alliances, M&A etc., has gained importance in recent years. The primary motivations of firms driving this development are the achievement of efficiency gains through reduced development time and cost, access to superior knowledge outside the firm and the reduction of technological risks. At the same time, knowledge can be leveraged outside the firm, e.g. by licensing. Table 1 illustrates this basic framework of technology management.

Patents can support technology management in all five areas of the conceptual framework (Table 1). The use of patents in technology management can be classified according to the two major functions of patents: First, a granted patent protects the inventor, at least for a period of time, from imitation. Thus, patent protection supports the internal use of technology. Effective patent protection has been identified as an important source of competitive advantage [3,4]. Patented technology can be

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Table 1
Framework for using patent information in technology management

	Technology creation	Technology storage	Technology use
Patent functions	Information		Protection
Internal	Support of R&D investment decisions (competitor monitoring and technology assessment)	Human resource management in R&D and knowledge management	Effective protection of products, processes and services from imitation
External	Identification and assessment of sources for external technology creation (e.g. M&A; Alliances)	–	Strategic (e.g. cross-licensing) and operational (e.g. patent sale) value maximization of the patent portfolio

used externally to achieve important operational (e.g. by patent sale) and strategic (e.g. access to technology by cross-licensing or R&D alliances) benefits. The latter aspect has become increasingly important in many industries in which a strong patent portfolio is a requirement for gaining access to important technological know-how from external sources [4].

Second, patents contain important information for technology management. The value of patent information can be attributed to a variety of reasons [5,6]: patent data are available even for companies that are not required to report R&D data. They can be allocated to sub-fields of interests, i.e. to business units, products, technological fields or inventors; this enables a more precise competitor analysis. The relatively new patent databases available have greatly enhanced the opportunity to systematically retrieve data on a large scale. Patents are an objective measure of R&D activities because a patent will be examined and eventually granted by the patent office. Furthermore, a large amount of technological information is contained in patents; they are classified according to standardized schemes, e.g. the international patent classification (IPC) which facilitates the detailed analysis of specific technological aspects. In comparison with other information sources, patents are often considered to be the best source for the timely recognition of technological changes [7].

Results from empirical research show a positive relationship between patenting and company performance if patent applications are weighted according to their quality [8–13]. Quality indicators of patents used in these studies are citations, granted patents, and the technological and international scope of patent applications. Beyond the results from these cross-sectional analyses it was shown, for a sample of 50 German mechanical engineering companies, that important patent applications cause subsequent sales increases with a time lag of 2–3 years from the date of the first patent filing [14]. This result supports the use of patent data as an output measure of R&D since they indicate technological activities which lead to subsequent market changes. The output-oriented qualitative patent indicators are a valuable addition to the input-oriented measure of R&D-spending which is indicated by the number of patent applications [14,15].

The globally high number of patent applications reveals that a vast amount of information is available for use in the area of technology management [16]. However, limitations of patent data as an information source must be recognized [17]. Patent protection is less important in some industries, e.g. services. Other means, e.g. trade secrets or trade marks, can be used by firms to protect their technological know-how [18]. The time lag of at least 18 months between the first patent filing and the publication of the patent application may be too long in industries with short technological life cycles. These aspects reduce the value of patent information for technology management. Finally, the economic value of patents varies greatly, reducing the meaningfulness of patent information if it is based on simple patent counts [17]. The following quote expresses a balanced view on the usefulness of patent information: "We have the choice of using patent statistics cautiously and learning what we can from them, or not using them and learning nothing about what they alone can teach us" [19].

Patent information can be used in three important areas of technology management (Table 1). First, analyzing patent information provides relevant information about the competitor's R&D strategies and helps to assess the competitive potential of technologies. Some important questions of technology management addressed in this context include: How can technological changes in the competitive environment of the firm be detected and evaluated? How can the firm's position be evaluated in comparison with the competition in technological fields? How can changes in the competition's technology strategies be identified? How can the R&D budget be allocated to the most promising technologies?

Second, patent information can be used to identify and assess options for the external generation of technological knowledge. Some important questions of technology management addressed in this context include: How can external technological know-how which is of relevance to the firm be identified? How can the technological position of potential acquisitions and R&D alliance partners be evaluated? How can the technological fit between the acquisition target or the R&D alliance partner and one's own firm be determined?

Third, patent information can be used for storing relevant knowledge as a core element of knowledge management and as a tool for human resource management in R&D. Some important questions of technology management addressed in this context include: How relevant knowledge can be made available to recipients in the organization? How can leading inventors in a specific technological field be found? How is it possible to ensure that leading inventors remain in the acquired firm?

These three areas of employing patent information in technology management will be explored further in the following paragraphs.

2. Using patent information for technology management

2.1. Competitor monitoring and technology assessment

Table 2 summarizes an important set of indicators which can be used to analyze companies' patenting strategies. The data necessary to calculate these patenting indicators can be retrieved from available patent databases such as Derwent Information's World Patent Index (WPI). All indicators are most informative if their dynamic development over time is analyzed [6]. A firm's 'patent activity' in certain technological fields is a fundamental patenting indicator and decreasing or increasing a firm's patent activity in a technological field can be interpreted as changing levels of R&D activity and, therefore, future technological and commercial interest. The 'technology share', based on patent applications, measures a firm's competitive position in a technological field. Conceptually, the technology share captures a firm's competitive position in R&D, as does the market share in the marketing domain. A significant drop in a firm's technology share should lead to a reassessment of its R&D strategy [20]. 'R&D emphasis' illustrates the importance placed on a specific technological field within the firm's entire R&D portfolio and highlights differences in companies' R&D strategies.

2.1.1. Patent quality and patent strength

The value of patent information is greatly enhanced if varying levels of a patent's quality is taken into account. It has been suggested in the literature to use the following indicators of patent quality: (1) ratio of granted to filed patents; (2) international scope; (3) technological scope and (4) citation frequency [8–13]. In order to verify these indicators of patent quality and to determine their respective weights on an empirical basis, the procedure summarized in Table 3 should be followed [21]. First, the information contained in a patent document, e.g. from WPI, is converted into numerical indicators of potential interest. Second, relative patent indicators need to be calculated in order to avoid an unwanted distortion. For example, the 'citation frequency' of a patent is influenced by its age. In order to assign a systematically higher weight to old patents, the citation frequency of a patent needs to be measured relatively to the citation frequency of an average patent from the same year. Third, a sample of economically

Table 2
Important patenting indicators for competitor monitoring

Patent indicator	Definition	Meaning
Patent activity (PA_{iF})	Patent applications (PA) of firm i in technological field (TF) F	Extent of R&D expenditures of firm i in TF F (interest of firm i in TF F)
Technology share (based on patent applications)	PA_{iF}/PA of all competitors in TF F	Competitive technological position of firm i in TF F (quantitative)
R&D emphasis	PA_{iF}/Number of firm's (i) total patent applications	Importance of technological field F for firm i (R&D emphasis)
Co-operation intensity	Number of joint patent applications with partners in TF F/PA_{iF}	Access of firm i to external knowledge (and identification of partners)
Share of granted patents (Q_1)	Granted patents of firm i in TF F/PA_{iF}	Technological quality of firm i's patent applications
Technological scope (Q_2)	Diversity and number of IPC classes in firm i's patent applications (PA_{iF})	Technological quality of firm i's patent applications
International scope (Q_3)	Size of patent family and share of triad (US, JP and EPO) patents of PA_{iF}	Economic quality of firm i's patent applications
Citation frequency (Q_4)	Average citation frequency of PA_{iF}	Economic quality of firm i's patent applications
Average patent quality (PQ_{iF})	Sum of all indicators of patent quality (Q_1–Q_4)	Average total quality of all patent applications of firm i in TF F
Patent strength (PS_{iF})	Product of average patent quality (PQ_{iF}) and patent activity (PA_{iF})	Technological strength of firm i in TF F
Technology share (based on patent strength)	PS_{iF}/PS of all competitors in TF F	Competitive technological position of firm i in TF F (qualitative)
Relative technology share	PS_{iF}/Max. patent strength of a firm in TF F	Distance of firm i to the technological leader in TF F

Table 3
Steps to determine overall patent quality

Step 1	Calculation of numerical indicators for each patent application (e.g. patent grant (yes/no), size of patent family, number of citations etc.)
Step 2	Calculation of relative patent indicators to eliminate systematic distortions (e.g. relative citation frequency)
Step 3	Identification of a sample of economically very important patents to the firm (e.g. based on inventor remuneration, profit contribution, expert judgements etc.)
Step 4	Statistical comparison of the sample 'important patents' (step 3) with a randomly selected control group of patents form the firm's patent portfolio
Results:	(1) Quality weights for each patenting indicator (2) Overall patent quality of each patent

important patents and a comparable and randomly chosen control group of patents need to be selected. Fourth, logistic regression analyses are carried out in order to test differences between both groups according to the defined set of quality indicators of patents. As a result, one observes quality weights for each patenting indicator which can be used to calculate an overall index of 'average patent quality' for each patent (Table 2). It must be emphasized that average patent quality is derived from a commercial perspective, i.e., a patent's contribution to a firm's sales and profits. A legal evaluation is not intended by this procedure which focuses entirely on the economic perspective which is most relevant for management.

Once patent quality is determined, overall 'patent strength' can be calculated (Table 2). A better measure of technology share including aspects of patent quality can be derived for each technological field in a similar manner as described above. It shows the competitive position of a firm in a technological field. This indicator should become a core element of balanced scorecards for controlling purposes. The 'relative technology share' transforms the technology share into a range of values between 0 and 1; this facilitates the identification of leading firms and the assessment of technological distances between competitors.

Table 4 illustrates an example showing the impact of patent quality on the assessment of the competitive position of three firms in a specific technological field within the chemical industry. Firm A has filed the highest number of patent applications (68) which leads to a 'relative technology share' of 1. Firm C has filed significantly less patents (22) compared with firms A and B. Thus, it receives a score of 0.32 (22/68) as the lowest value of the relative technology share (without quality) among the three firms. However, the average patent quality for firm C (1.9) is substantially higher than the average patent quality of firms A (0.9) and B (0.6). Based on the patenting indicator patent strength (41), firm C receives a much stronger relative technology share (with quality) score of 0.7 (41/59) which is now much closer to the leading firm A and higher than for firm B which has filed almost three times as many patents (59) as firm C. Table 4 further shows that firm C scores high on all four indicators of patent quality which reinforces the confidence of the earlier aggregate result that the overall average patent quality is high for firm C. This example clearly shows that neglecting the quality aspects of patents would have led to a substantial devaluation of firm C's technological strength and, therefore, its competitive position in this specific area of technology. This type of misjudgment can lead to incorrect decisions in technology management, e.g. regarding the selection of an appropriate acquisition target or an R&D alliance partner.

Table 4
The impact of patent quality on the assessment of competitive positions

	Firm A	Firm B	Firm C
Number of patent applications	68	59	22
Average patent quality	0.9	0.6	1.9
Patent strength	59	35	41
Relative technology share (without quality)	1	0.87	0.32
Relative technology share (with quality)	1	0.61	0.70
Citation frequency*	0.60	1.02	0.97
Ratio of granted patents*	1.19	1.03	1.32
International scope*	1.26	0.42	3.46
Technological scope*	0.88	0.82	1.26

* Relative values which cannot be interpreted in absolute terms; for definition of patenting indicators please refer to Table 2.

2.1.2. Patent portfolios

One of the most important decisions to be made in technology management is the investment of R&D resources; senior management must decide how much of the R&D resources will be spent on which type of technology. Portfolio concepts have been developed in order to facilitate this decision-making process [21]. Portfolios have the advantage that they structure and visualize complex problems while focusing on the most relevant decision-making criteria. Portfolios have thus gained popularity over the years among managers; technology portfolios are used to support strategic R&D planning [5]. However, these approaches have three major drawbacks: they are based on subjective assessments made by respondents; they fail to incorporate the competition due to a lack of necessary information; they

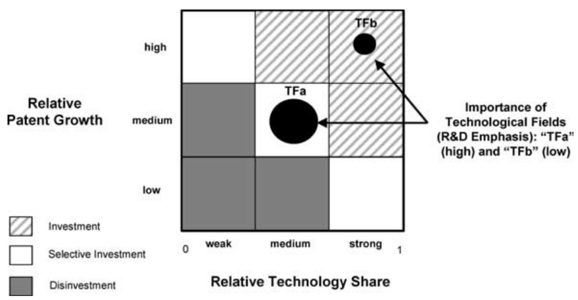

Fig. 1. The patent portfolio.

are static, not allowing for the analysis of dynamic technological developments [6,21]. To overcome these problems, patent portfolios, which are technology portfolios using patent data, have been developed [5,6,22].

The allocation of patents to technological fields is the prerequisite for creating portfolios. In Fig. 1, two technological fields TFa and TFb are considered. The patent portfolio has the same basic structure as most two-dimensional portfolio illustrations. On the abscissa a firm's relative technology share is measured by relating its patent strength (Table 2) to the highest patent strength in the specific technological field. This allows for the speedy identification of the leading firm per technological field (which receives a value of 1), as well as to assess the distances between each competing company and the leading company. As in other portfolios, the abscissa value is determined predominately by the behavior of the firm under consideration [5,6].

On the ordinate we observe that the attractiveness of each technological field is measured by using relative growth rates of patent applications. Patent growth in recent years relative to patent growth in preceding years is measured because it emphasizes recent developments in patent growth. It is assumed that technological fields with high relative patent growth rates will be more attractive in the future than those fields with low relative patent growth. The ordinate values are influenced by all of the companies that file patents in the respective technological fields [5,6]. Empirical studies show a positive and lagged relationship between patent growth and competitive changes in the market [23].

The size of the circles in Fig. 1 indicates the importance of each technological field within the company's R&D portfolio (R&D emphasis; Table 2). The company puts a high emphasis on TFa and a low emphasis on TFb. The R&D emphasis is calculated by the number of patent applications in a technological field divided by the total number of patent applications filed by the respective company. R&D emphasis is an internal variable impacted only by the firm itself [5,6].

The rankings in a patent portfolio provide senior management with valuable information regarding their R&D investment decisions. In general, firms should increase R&D spending in fields with medium to high relative patent growth, especially where they also have medium to strong relative technology shares. Firms should also tend to spend less in areas with lower relative patent growth and weaker relative technology shares. Positions on the diagonal require a careful examination before a final decision is made. For example, in a situation in which the relative technology share in a technological field with high rates of relative patent growth is weak, various strategic options need to be considered. The firm may chose to develop the technology in-house because it is considered to be of high competitive importance in the future. Alternatively, the firm may consider acquiring this technology from the leading company which can easily be identified in the patent portfolio (relative technology share = 1). Finally, the firm may decide to ignore this technology because it is classified as a non-core area according to the overall business strategy [5,6].

Fig. 2 shows an example of a patent portfolio for one firm. This particular company holds strong patent positions in many of the technological fields under consideration although the focus is on the technological fields with the lowest relative patent growth rates and a competitor dominates the fastest growing technological field. Management should, therefore, consider shifting R&D resources from slower to faster growing technological fields.

In sum, the proposed patent portfolio method can be used to evaluate the strengths and weaknesses of competing companies with regard to different technological fields. Patent portfolios provide valuable information for decision makers regarding strategic R&D investments, i.e. how much of the R&D budget should be spent on which technological field. Furthermore, patent portfolio analyses can be used to identify and assess opportunities for external knowledge creation and licensing opportunities (Table 1). Finally, it should be stressed that any portfolio analysis should be conducted

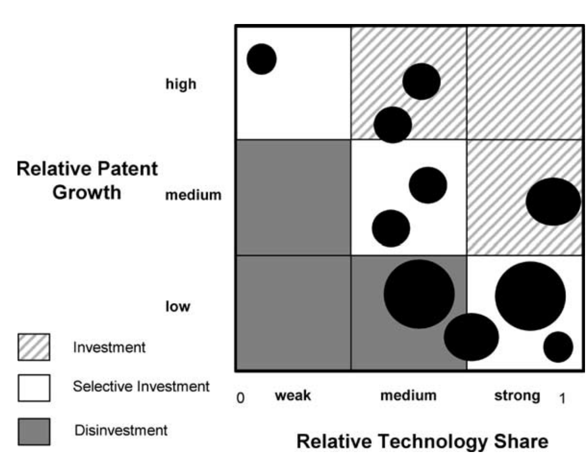

Fig. 2. An example of a patent portfolio.

with caution. Portfolios display only a limited amount of information required to make final decisions. Portfolios should, therefore, be viewed as a valuable tool to structure and visualize a complex situation to facilitate discussions among senior management to support decision-making [21].

2.1.3. Integrated patent and marketing portfolios

Strategic R&D investment decisions should not be solely based on technological considerations but they should also take market requirements into account. A more successful alignment between R&D and market requirements can be achieved by integrating the patent portfolio with existing market portfolios [21]. To maintain the advantage of having objective data for the portfolios, the Boston Consulting Group 'market share/ growth matrix' is selected as the market portfolio and is integrated with the patent portfolio. Integrating patent and market portfolios into one portfolio illustration by means of a joint dimension of attractiveness (market growth) is justified because R&D should be aligned with market conditions [21]. Fig. 3 shows the integrated portfolio and summarizes generic combinations of R&D and marketing strategies. If both technology and product are placed in corresponding fields of the integrated market and patent portfolio, represented by the combinations Aa, Bb, Cc and Dd in Fig. 3, the functional strategies are successfully aligned, as required by management theory. Senior managers should pay special attention to those situations where the portfolio positions are not aligned to an appropriate degree and, in these cases, causes and consequences of the portfolio positions need to be carefully assessed. A strong technological position in areas with low market growth and low market shares (Dc) may lead to a cutback in R&D expenditures in this technological field. A strong technological position in areas with high market growth and low market share (Ba) may require more marketing or sales activity or may indicate great licensing opportunity to the market leader if the firm fails to exploit the technological advantage on the market itself [21].

The integrated portfolio concept has been applied in the chemical industry [21]. Based on this experience, the following advantages of the proposed concept can be summarized: (1) immediate recommendations for R&D-management and marketing to better align functional strategies; (2) improvement of inter-functional communication at the strategic level (as with Quality Function Deployment, a frequently used product design tool in which important product attributes valued by the customer are translated into product design characteristics which can be influenced by R&D, at the project level); (3) reduction of discussion time about the foundations of the tool leading to a more focused discussion of content (strategic implications; productive discussion of "why" these portfolio positions have developed) due to the use of objective data, and (4) a high degree of face validity [21]. Face validity refers to the fact that the results were considered to be very plausible by the managers of the chemical firm, i.e., they felt that the integrated portfolios represented the competitive structure in their industry adequately.

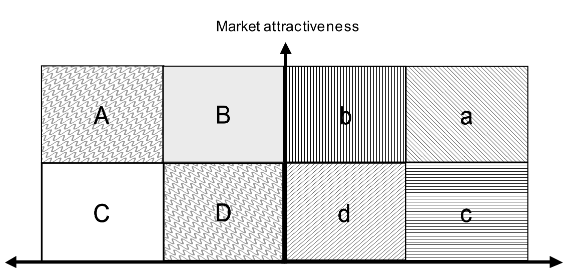

Fig. 3. Integration of market and patent portfolio.

2.2. Identification and assessment of M&A options

The number of mergers and acquisitions (M&A) has increased substantially recently for various reasons. An important motivation for M&As is to gain access to technological knowledge which is of long-term strategic interest to the company [24]. In these instances, ownership of technology and capturing the value of tacit knowledge are critical to establishing a sustained competitive advantage. Acquisition has become a strategy in many high-tech areas where high technological risks and restricted amounts of internal R&D resources exist. Important success factors for technology-driven M&As are the selection of the most appropriate M&A target and the target's subsequent integration into the organization itself. The selection decision requires the identification and assessment of various M&A options which can be achieved by analyzing patent data.

Table 5 summarizes a conceptual framework for identifying and assessing M&A options based on patent information. A fundamental distinction is made according to the prime motive of the acquisition. Strategy A assumes that access to the desired technology is the prime objective of the acquisition whereas strategy B assumes that technological aspects do not motivate the acquisition. Many M&As follow the latter strategy, however, management needs to manage the companies' combined technology position. The main objective in the case of strategy A is the selection of the acquisition target. In both instances, analyzing patent data can assist in making better decisions for achieving the desired goals of the M&A transaction.

In the case of strategy A, the technological field of interest should first be defined. Companies should incorporate competing technologies as potential substitutes, avoiding a too narrow focus in the analysis. This

Table 5
Identifying and assessing M&A options based on patent data

	Strategy A: Access to technology is the prime motive of the acquisition	Strategy B: Access to technology is *not* the motive of the acquisition
Objectives	Optimal acquisition decision with respect to the target technology	Optimal management of the acquisition's impact on the firms' combined technology position
Identification of M&A options and data retrieval	(1) Definition of technological field (incl. potential substitutes) based on patent classifications and key words; sequential refinement of patent search strategy with experts (also outside the company) (2) Patent data retrieval and identification of targets (list of patentees)	(1) Patent data retrieval for the acquisition target and assignment to technological fields and inventors (2) Individual and combined patent portfolio for acquirer and target; inventor portfolio for the target firm
Assessment of M&A options	*Assessment of each M&A target* (1) within the group of targets: Patenting indicators: R&D emphasis; technology share; dynamic development of technology share over time; technology attractiveness (patent growth); legal status of patents; inventors (2) in comparison with the acquirer's technological position: Assessment of technological synergies or redundancies of technological positions (patent portfolio analysis)	*Assessment of the target's and acquirer's combined patent portfolio* (1) in identical technological fields: Patenting indicators: R&D emphasis; technology share; dynamic development of technology share over time; technology attractiveness (patent growth); legal status of patents; inventors (2) in new technological fields added by the target firm including the target firm's other competitors (see 1): Identification of new technological opportunities
Decision support	(1) Selection of acquisition target (2) Mode of acquisition (or other forms of knowledge transfer) (3) Acquisition management (e.g. inventors)	(1) Alignment of R&D strategies (selection of best combination of portfolio positions; development of further technological competencies) (2) Acquisition management (e.g. inventors)

step in the process is of crucial importance because it determines the quality of the data to be used in further analyses. After the retrieval of patent data a list of patentees identifies potential M&A options.

Each M&A target must be assessed within the group of all potential M&A targets by using some of the suggested patenting indicators (Table 2). R&D emphasis indicates how much the M&A target focuses on the technology of interest. A value of 1 for R&D emphasis is ideal because the firm can be acquired without any additional R&D capacity of minor interest to the acquiring firm. Technology share (with patent quality) identifies the present leader in the technological field and the development of the technology share over time indicates the dynamic path which has led to today's observed patent position. This analysis distinguishes the incumbent firm from a new entrant where the latter type may be more promising as an M&A target because it is gaining in technology share [6]. The relative patent growth shows the attractiveness of competing technologies; M&A targets which have a strong relative technology share in fast growing technological fields are more attractive than those which have a strong position in declining technological fields. These three pieces of information can be visualized in a patent portfolio showing the positioning of the M&A targets (Fig. 1). In addition, decisions about an M&A target require information about the legal status of patents and the distribution of patents among inventors. Leading inventors become visible in the inventor portfolio (Fig. 4). The long-term success of an M&A transaction can be in danger, if leading inventors leave the acquired firm. Finally, the acquirer's technological position should be compared to the M&A targets in the patent portfolio (Fig. 1) in order to assess synergies or redundancies between firms.

The acquired information assists decision makers in three respects: (1) to select the most appropriate M&A target; (2) to define the mode of acquisition or to chose alternative means of transferring the desired knowledge,

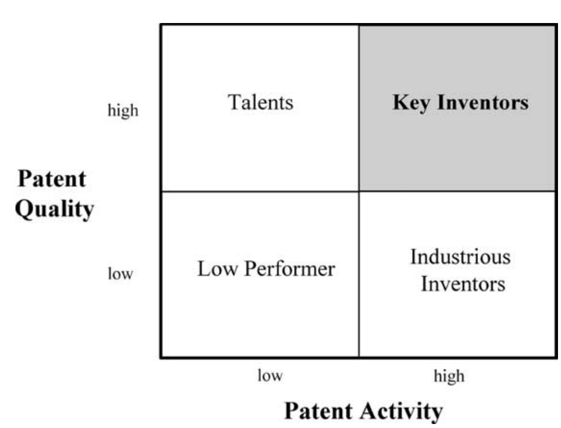

Fig. 4. The inventor portfolio.

e.g. by licensing or forming an R&D alliance if the redundancies are too high, and (3) to support the acquisition management, e.g. by better integrating 'key inventors' to avoid them leaving the firm or reducing their patenting output.

In the case of strategy B, patent data need to be retrieved only for the specific firm which is about to be acquired for motives which are not of a technological nature. The individual and combined technology positions of both firms can be displayed in the patent portfolio which identifies their synergies and redundancies. The assessment of both companies' patent portfolios facilitates the identification of each firm's core technological competencies. Management can then combine the technological capabilities in a manner that makes it possible to construct an optimal joint patent portfolio, i.e. by divesting or combining the respective activities. The acquiring firm should pay special attention to those technological fields of the acquired firm which had not been pursued internally. The M&A target's position in those technological fields should be analyzed against those of the respective competitors, e.g. in a patent portfolio. The acquiring firm may have the opportunity to develop and further strengthen new competencies in those technological fields in which the M&A target is in a leading position. In order to fully secure the explicit and implicit knowledge in areas which are new to the acquiring firm, it is essential to identify and to retain the leading inventors in these technological fields (Fig. 4). Means by which to accomplish these objectives are discussed in the next paragraph.

2.3. Human resource management

The inventor portfolio is a helpful tool for human resource management in R&D. The inventor portfolio distinguishes between four types of inventors (Fig. 4). The top right quadrant contains the so-called key inventors, characterized by high patenting activities as well as by high patenting quality. Patent quality at the inventor level can be measured in the same conceptual way as proposed for firms (Table 2). The counterpart of key inventors is the so-called 'low performer' which is found in the bottom left quadrant. The top left quadrant contains the 'talents' which are characterized by little patenting activity of a relatively high quality. The counterpart of the talent is the 'industrious inventor' who is responsible for many patents of relatively low quality.

Empirical research shows that key inventors are very rare in industrial R&D labs and that they contribute significantly to their firm's patenting output. A study of over 2000 inventors in 43 companies revealed that only 6.9% of all inventors can be classified as key inventors. This very small group of key inventors is, to a very large extent, responsible for the technological performance of a company and, thus, for the company's competitiveness. The key inventor share of a firm's patenting output may achieve a maximum of 80% [25]. The existence and importance of key inventors have important implications for effective human resource management in R&D.

Measures ought to be taken to ensure the preservation of the knowledge of key inventors in the company. This can be achieved by tying the inventor to the company through the right incentives, by storing the knowledge independently of single inventors and by making early succession arrangements if the inventor is leaving the firm. As each of these measures implies specific limitations, they should not be used in isolation. The inventor-independent storage of knowledge fails when so-called implicit or tacit knowledge is involved. It can be assumed that an important characteristic of key inventors is their considerable implicit knowledge. This problem can at least be partially solved by using socializing mechanisms to transfer implicit knowledge to other colleagues. These colleagues could come from the group of talents (Fig. 4). Talents have already shown their capabilities since their R&D work has resulted in important patents, as is the case for key inventors. They have established the necessary reputation needed to be accepted by key inventors. Human resource management in R&D should, therefore, regularly monitor the inventor portfolio (Fig. 4) and bring talents and key inventors together in joint R&D projects. Tacit knowledge will eventually be transferred from the key inventor to the talent and will thus remain in the firm, even if the key inventor leaves [25].

Key inventors meet the basic requirements to become technological gatekeepers. Technological gatekeepers are important boundary-crossing individuals who are capable of identifying relevant knowledge outside the firm and transferring it to the organization. Technological gatekeepers thus account, to a large extent, for the absorptive capacity of their respective firms. An empirical study shows that key inventors often perform the characteristic tasks of a technological gatekeeper. It is, therefore, possible to identify a potential candidate for gate keeping activities by its position in the inventor portfolio (Fig. 4). Other characteristics required to become a technological gatekeeper (communication skills and a large external network) should be promoted by specific training opportunities and the establishment of numerous external contacts for inventors, e.g. through conference visits [25].

The patent-based identification of 'key inventors' provides an interesting opportunity for headhunting purposes. Leading inventors in a specific technological field can be easily identified in the inventor portfolio (Fig. 4). The headhunting of 'key inventors' can be an alternative to the costly acquisition and complicated integration of an entire company. This approach is particularly effective when the relevant knowledge is concentrated in a limited number of 'key inventors' [25].

Conversely, in a case of a technologically motivated acquisition of a company, the acquiring company must ensure that the key inventors will remain in the acquired company after the takeover. If the acquiring company is not able to retain the key inventors, the success of the entire transaction is endangered. An empirical study of 43 acquisitions found that one-third of the key inventors left their company within three years after the acquisition [24]. High fluctuation was especially observed in those cases where key inventors perceived large cultural differences between the R&D departments of the acquiring and the acquired firm. Key inventors who remained with their company were found to significantly reduce their patenting output after the acquisition; these performance reductions occurred in almost all acquired companies. Acquisitions, therefore, appear to substantially impact the behavior of leading inventors. For this reason, key inventors in the acquisition target need to be identified prior to the transaction and measures ought to be taken during the integration phase to retain key inventors and to ensure that their patenting output is not reduced or even lost [24].

3. Implementation: patent information as a core element of knowledge management

From the discussion above it becomes evident that patent data are a valuable information source which allow decision makers (1) to assess their own technology portfolio in comparison with the competition, (2) to assess the attractiveness of technologies, especially new technologies posing a threat or a new opportunity for the existing business, (3) to recognize strategic changes in the firm's competitive environment, (4) to identify and assess external sources for knowledge generation (e.g. M&A, R&D alliances etc.), (5) to assess the patent situation in new business areas which may be explored, (6) to evaluate important market partners, especially customers and suppliers, to determine if the firm's R&D strategy is in alignment with the R&D strategy of its major customers and if R&D alliances exist with the most competent suppliers, and (7) to improve human resource management regarding leading inventors in specific technological fields.

For these reasons, patent data must be understood as a strategic information source, which contributes important information to the effective and efficient management of technology. This type of patent information addresses two major groups of recipients inside and outside the organization. First, it addresses decision makers from senior management inside the firm who make important strategic decisions, e.g. on the R&D budget or on M&A. The strategic value of patent information becomes evident in its contribution to better decision-making in relevant areas of the firm. Second, strategic patent information addresses external stakeholders and analysts whose perception of the firm's technological competence can have a major impact on the firm's stock market performance [26]. Showing changes in the firm's positioning in the patent portfolio as an indicator of increasing competence and competitiveness to analysts may have a recognizable and lasting effect on the analysts' perception. A summary of relevant patenting indicators should, therefore, become part of the firm's regular reports to important stakeholders, e.g. in annual reports.

The retrieval and evaluation of patent data should be institutionalized within the organization in order to ensure the continuous and systematic use of patent information in a company's decision-making processes. Patent information should become a core element of a firm's knowledge management system. The above mentioned types of recipients of patent information at the senior management level and outside the firm require that complex and rich patent information is presented in a manner that is familiar to the target audience. The patenting indicators and portfolio approaches presented here certainly meet this criteria. Software is available to achieve an efficient handling of large quantities of patent data [27]. Exploratory empirical evidence suggests that firms which use patent information for strategic planning purposes as an integral part of their professional patent management system perform better than those firms which do not yet pay attention to this aspect [3]. Thus, firms should realize the value of patent information for strategic technology management and routinely assess patent information as part of the firm's strategic planning processes as well as the communication strategy to external stakeholders.

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