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The Use of Science and Technology Indicators in Strategic Planning

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Science and technology indicators are being incorporated by commercial organizations and this article indicates areas where they can assist the strategic planning processes. They provide a means of quantifying the strengths and weaknesses of organizations in relation to their research and development activities and market strategies. A case study assesses and analyses the technological strength of a proposed merger.

(1) Introduction

While a large array of indicators exists to measure, for instance, the financial or market performance of commercial organizations, quantitative techniques to assess the scientific and technological capabilities of companies are still at their infant stage. In contrast, such methods are widely used to compare scientific and technological strengths between countries, and are an established and important input to national policy-making.

Borrowing from this experience, commercial organizations now too are gradually incorporating science and technology indicators, primarily based on patent and scientific article analysis, in their strategic planning processes. While the potential range of applications seems only limited by the strategic planner's imagination, important areas where science and technology indicators provide valuable insight in addition to the more established analyses, as partly illustrated in this article, are:

- ☆ Screening of the technological capabilities of a potential merger or joint venture partner, or acquisition target.
- ☆ Analysis of a company's technology portfolio relative to its competitors.
- ☆ Analysis of the evolution of competitors' technology portfolios, providing early warning of future market strategies.
- ☆ Comparison of the productivity of laboratories within a firm or between firms.

In general, using science and technology indicators in strategic planning will assist a company in setting priorities between competing demands for corporate R & D funds, and benchmark productivity. More specifically, such indicators are an important step in measuring the alignment of current and intended corporate R & D activities with corresponding market strategies.

(2) Science and Technology Indicators

Science and technology indicators measure a company's or country's corresponding activities and performance through analysis of patents and research publications. Such indicators express the scale, quality and distribution of scientific and technological efforts, mostly relative to their competitors.

Analysis of patents and publications—the publicly available output of, respectively, technological activity and scientific research—allows for a reasonable, if not perfect assessment of research and development productivity. For instance, the number of patents is a measure of the scale of a company's technological effort, while patent citation indicators reflect the quality and acceptance of its technology. Such analysis is based on two fundamental premises. Firstly, the number of publications in scientific journals is a legitimate indicator of research productivity. Secondly, the citation of these papers in other articles, or patents, is

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a legitimate reflection of their quality. These premises are both widely accepted today.[1]

Research publications and patents can, for present purposes, be defined as follows.

Publications
Publications are the primary vehicle through which scientists communicate their findings to the research community. In the U.S., scientific publications are collected by the National Science Foundation (NSF) and by the Institute for Scientific Information (ISI), where they are classified and made accessible to other researchers. Worldwide, some 5000 scientific papers are published daily. The ISI examines the articles of around 3000 leading scientific journals, and lists the authors and other articles cited by these publications. The 3000 journals cover virtually all relevant literature. Publications have been collected, according to internationally agreed definitions, by the U.S. government on a regular basis since the early 1960s. Citations are counted and published in the Science Citation Index (SCI). The SCI lists the authors cited in a particular year, and the journals in which the citations appear. When an author is cited in other publications, it means that his or her articles have a certain quality. The impact of the articles on others is measured by the number of such citations. If the number of citations decreases (or increases) in time, it indicates that the subject (or scientist) is declining (or increasing) in importance.

Patents
A patent is the exclusive right to a product that has proven to be new and to have a practical application.

In the U.S. patents carry several descriptors, of which the more important are:

☆ Patent number.

☆ Date patent awarded.

☆ Title.

☆ Inventor(s) and their location.

☆ Application date.

☆ Classificiation of the patent in the U.S.A.

☆ References cited (U.S. patent references and publications).

☆ Abstract of the technical description of the invention.

In practice much patent analysis makes use of the U.S. patent database. The reason for using U.S. rather than European patents is due to the fact that they are more detailed, contain the necessary information and references needed for analysis, and are suitably classified—which is not always the case in Europe.

The U.S. patent system is highly international in scope. Several studies worldwide have shown that it is the most suitable one for international technology comparisons. Major reasons are:

(a) Forty to fifty per cent of the U.S. patents are of foreign origin (Figure 1).

(b) The U.S. is the largest single market place for technological products. Consequently, almost all major companies patent their significant inventions in the U.S.

(c) The U.S. patent system is completely computerized. This, for instance, makes it possible to identify leading-edge, high-impact patents by measuring how often they are cited. It is similarily possible to measure how close a company's technology is to the scientific frontier through its citations to the scientific literature.

These features make the American patent system a very comprehensive database of registered technological advances, relatively free of domestic bias and containing few unimportant or trivial patents. Consequently a system of analysis based on U.S. patent databases implies access to a large volume of patents. In addition, the inclusion of citations in this patent system allows for qualitative assessment of both a company's and its competitors' technological positions.

For instance, if a patent is highly cited, which means 'prior art' to a large number of subsequent patents, it is assumed that this highly-cited patent is important, and signifies a technical advance.

Thus, highly-cited patents can be regarded as indicators of an organization's technical excellence. Similarly, when an organization's patents heavily cite the scientific literature, this indicates that the organization's technology is close to the scientific frontier, indicating a leading edge position.

In conclusion, patents are now widely accepted by both policy makers and analysts as a valid measure of technological activity and, due to the rigorous nature of the U.S. patent validation procedure, are available in considerable statistic detail and for long periods of time.

Nevertheless there are a number of difficulties which should be kept in mind when analysing both publications and patents:

☆ Citation practices differ significantly between scientific fields, i.e. in some fields researchers tend to cite recent articles more frequently than others. These differences can significantly affect the values of citation based indicators.

☆ Citation practices within a field may change through time.

☆ Considerable difficulties arise from the fact that the SCI has included more and more source

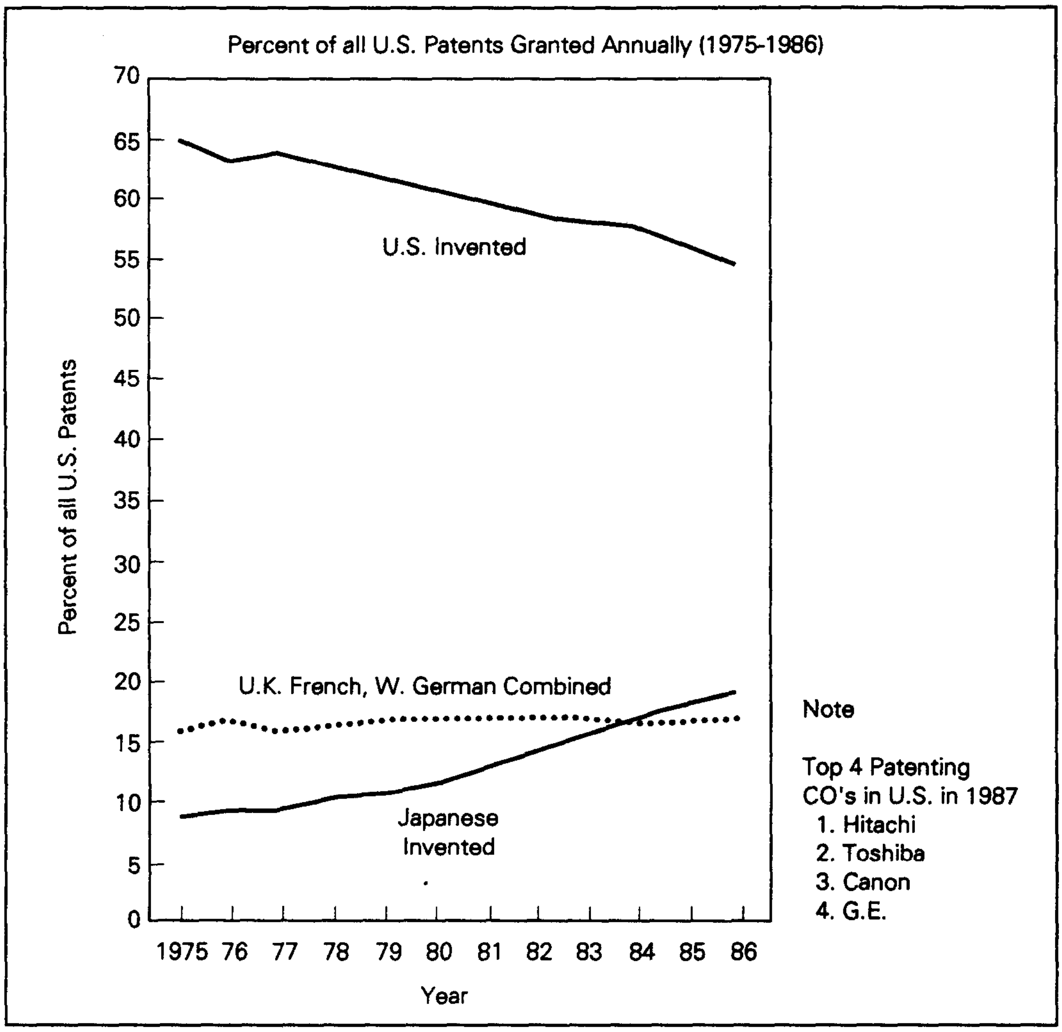

Figure 1. Percentage of all U.S. patents granted annually 1975–1986
Source: CHI Research, New Jersey, U.S.A.

journals during the decade, and that non-journal material (e.g. books) is also included.[2]

These difficulties are mostly connected with the analysis of scientific articles. In patent analysis they are of a much less serious nature.

(3) The Link Between Publications and Patents

Patents often cite other patents and/or scientific publications. As already stated, these citations are indicators of technical or scientific quality or impact. The following characteristics of the link between patents and publications are particularly important:

☆ The *extent* to which patent applications and examiners refer to scientific research findings (as evidenced by their citation of the scientific literature).

☆ The *nature* of the cited research activity. Are the citations referring to basic research or applied work, to a narrow or wide swathe of scientific investigation, to old or recent papers?

☆ The acknowledged source of *financial support* for the research cited by the applicant and the examiner.

Connecting patent citations to scientific literature is not an easy task, necessitating computerized techniques to handle the large amount of data. A considerable part of the data handling is 'normalization' work. For example, a large variety of journal abbreviations needs to be standardized. Further standardization of pages, volumes and authors may be required, etc. In addition, for each reference, a tag pointing to the original citing patent is necessary.

An important aspect of the patent publication link is whether the scientific papers cited by patents are older, classic papers that underlie current scientific work, or whether the patents show a strong dependence upon present literature. Scientific articles are typically first cited in patents some 3–5 years after their original publication.

Overall, science and technology are becoming more closely interlinked. For instance, the distinction between cutting-edge biotechnology and modern bioscience has almost completely disappeared.

Indeed, much of current high technology is nearly indistinguishable from science.

This not only creates problems for analysis but also for the individual scientist. Thus, his social responsibility to publish reports of his work conflicts with his commercial responsibility to keep his research advances confidential until protected by patents. This blending and conflict of responsibilities stands in sharp contrast to the traditional view of science and technology: science as an area where the accumulation of knowledge is driven by the propensity of scientists to publish, while technology is driven by the need for commercial utilization of knowledge.

(4) Science Analysis

Science analysis provides insight into the complex structure of science. Science indicators give an assessment of the strength, productivity and quality of the research conducted by a given country, a research organization, or any other unit of analysis. Such indicators are always measures relative to 'competing' entities. Profiles of scientific organizations, the evolution of the science base in time, and the uncovering of scientific linkages or networks are among the typical products of in-depth analysis. The volume and value of published (science) literature can be measured by counting publications and citations by or to papers.

Due to two important developments, i.e. the exponential growth of science to the point where it is now an important component of modern economic activity, and the associated support of 'big science' by government, bibliometric techniques are increasingly used to facilitate counting and subsequent analysis.

As a consequence, bibliometric analysis has now become an effective tool for making explicit the performance of research groups or individuals, allowing them to be evaluated over lengthy periods of time, and as such constitutes an important instrument in the hands of those responsible for formulating research policy. For instance, one specific result of the bibliometric analysis of science activity is that the productivity of individuals seems to vary widely, and that truly creative scientists publish often, are highly cited, and contribute to the progress of the science to a degree which many times exceeds the average.[3] Top scientists account for some 50–75 per cent of all scientific advances. Thus, it is critically important that a policy be in place which leverages these talents, e.g. by building centres of excellence around them. Investment in research, development and co-operation between universities and other basic research institutions is becoming increasingly important for the ability of countries and industries to keep pace with rapid technological advances. This raises important policy questions such as:

☆ What is the quality of scientific research done and what are its specific strengths and weaknesses?

☆ Are there any scientific or socio-economic reasons why specific research activities are absent, and what are the long-term implications?

These questions can be answered by analysing science literature databases. For instance, it is possible to obtain a list of highly-cited papers written by EC scientists. Listings can be obtained for several years, which gives a good insight into the evolution of their scientific publications. As a final step, very highly cited EC scientific sectors can be identified in order to locate existing areas of excellence.

It is similarly possible to identify the sectors in which universities or large laboratories are active, by classifying the journals in which these institutions publish papers. The system developed by the National Science Foundation divides the 3000 journals it examines into 106 different subfields which, in turn, are aggregated into nine major fields of science. With this kind of classification it is possible to identify the differences in areas of emphasis between research organizations, and their respective strengths and weaknesses.

(5) Technology Analysis

Technology analysis provides a means to formulate relevant policies in each selected domain. The evolution of a given technology, its linkages to science and other technologies, and the shift in technological emphasis can be monitored, etc.

Technology analysis uses patent counting and clustering, and citation analysis to evaluate corporate, industry-wide, and national technological strength. One important application is examination of patent trends over time. This could reveal whether enthusiasm for a particular technology is growing or diminishing.

Key policy-directed questions which may be answered by technology analysis are:

☆ Which companies or countries dominate a given technology?

☆ To what extent are large corporations influencing the level and pattern of countries' technological activities?

☆ How do large corporations distribute their technological activities amongst sectors and countries?

☆ Who owns the key patents?

☆ How active is a given country in a particular high technology of interest to its government? What is the effect of funding the volume of patents in the targeted technology?

Important direct applications of technology analysis include:

Competitor Assessment
Provides a direct measure of the scale, quality and emphasis of a competitor's (another organization or country) technology portfolio.

Merger and Acquisition Targeting
A potentially serious problem in M & A is the technical compatibility of the companies involved. Companies have often merged with or acquired other firms which are technologically distant—discovering only too late that major problems of technical compatibility constitute a hindrance to integration and smooth performance.

Thus, it is essential to screen acquisition targets for technological fit. Conversely, suitable candidates for acquisition can readily be identified given the desired technological profile.

The major advantage of using technological profiles in M & A is the global scope of the search. This is much more difficult with more conventional approaches. In addition, it provides an indication of the technological quality of the target company (see Table 1).

Table 1. Steps in merger/acquisition targeting

Objective: To identify and assess appropriate M & A candidates based on technological synergy with the client company.

This will involve:

☆ *Identifying* a company with strong technological links to the client company, using patent citation techniques.

☆ *Assessing* the technological position of the target company in a manner analogous to the standard financial valuation techniques.

☆ Locating *alternatives* to the target company which could indicate a better fit to the client's needs.

☆ Estimating *future* prospects for technological performance by analysing past and current high-impact key technologies, innovations and innovators.

☆ Identifying successor technologies to those of the target, and whether they represent *threats or opportunities* to the client company.

Case Study: Assessing the Technological Strength of a Proposed Merger

In order to match the leading company in a high-technology industry, two of its competitors contemplate a merger. Financial analysis shows that the merger would enable the new company to equal the leader in sales volume and financial strength. However, a question remains as to whether the newly merged firm would also match the leader in technological power.

Figure 2 shows the combined patenting activity of the two potential partners in comparison with that of the industry leader. Until 1983, the number of patents issued to the two partners developed quite similarly. In subsequent years, however, the patenting activity of the proposed merger drops rapidly relative to that of the industry leader.

Figure 3 shows the evolution of the technological impact index for both the industry leader and the proposed merger. The technological impact index reflects the quality of patents by measuring the number of highly cited patents within its total patenting activity relative to the industry average. An index larger than 1·0 shows above-average performance and, vice versa, an index of less than 1·0 reveals failure to match the industry norm.

Figure 3 shows that the quality of the industry leader's patents has substantially improved over the years, in contrast with that of the proposed merger and that, since the late 1970s, a large quality gap has developed.

From both figures it is clear that, during recent years, the industry leader has technologically outperformed the proposed merger. In addition, further analysis also showed a large disparity in the respective technological strengths of the two potential merger partners.

These results cast serious doubts on the longer-term profitability of the merger, and whether the partners fit each other technologically.

Obviously, analyses such as illustrated in the (simplified) example above do not provide a full answer to evaluating the technological capabilities of the firms concerned. Technological breakthroughs not always result in corresponding patent activity for a variety of reasons and, moreover, significant recent inventions may not yet show up as patents because of delays in the patenting system. Nevertheless, this does not invalidate the power of patent analysis to raise issues which otherwise may escape attention or receive more subjective answers.

Technology Portfolio
A major task of top management is shaping the company's business portfolio. However, it is equally important to understand and shape a firm's 'technology' portfolio (Figure 4).

In Figure 4 the vertical axis represents technological evolution, from 'emerging' to 'base' technology. The horizontal axis shows a company's competitive position, i.e. the number of patents it issued divided by the number of patents issued by its most active competitor. The diameter of the circle represents the number of patents issued during the period indi-

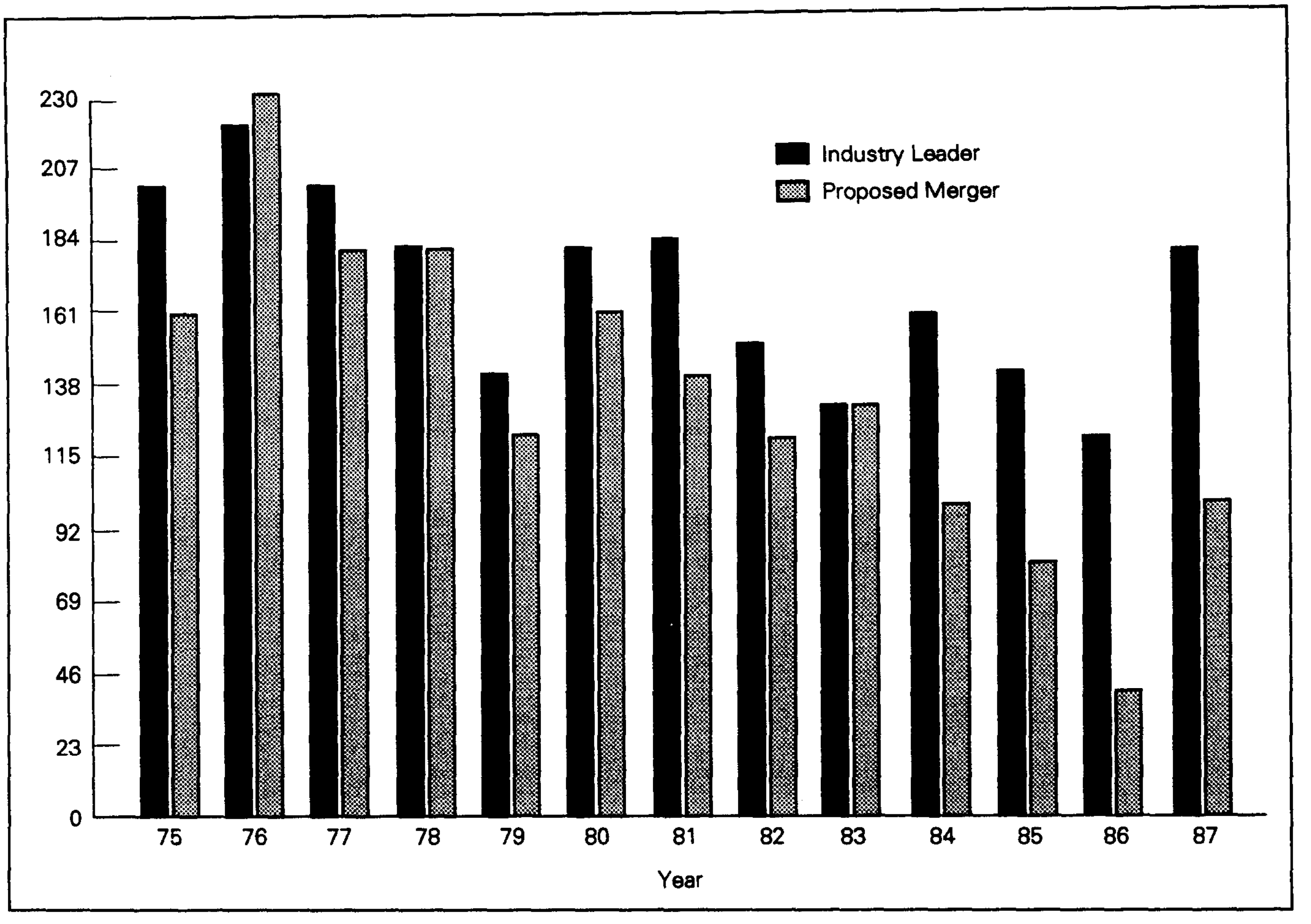

Figure 2. Number of patents issued annually

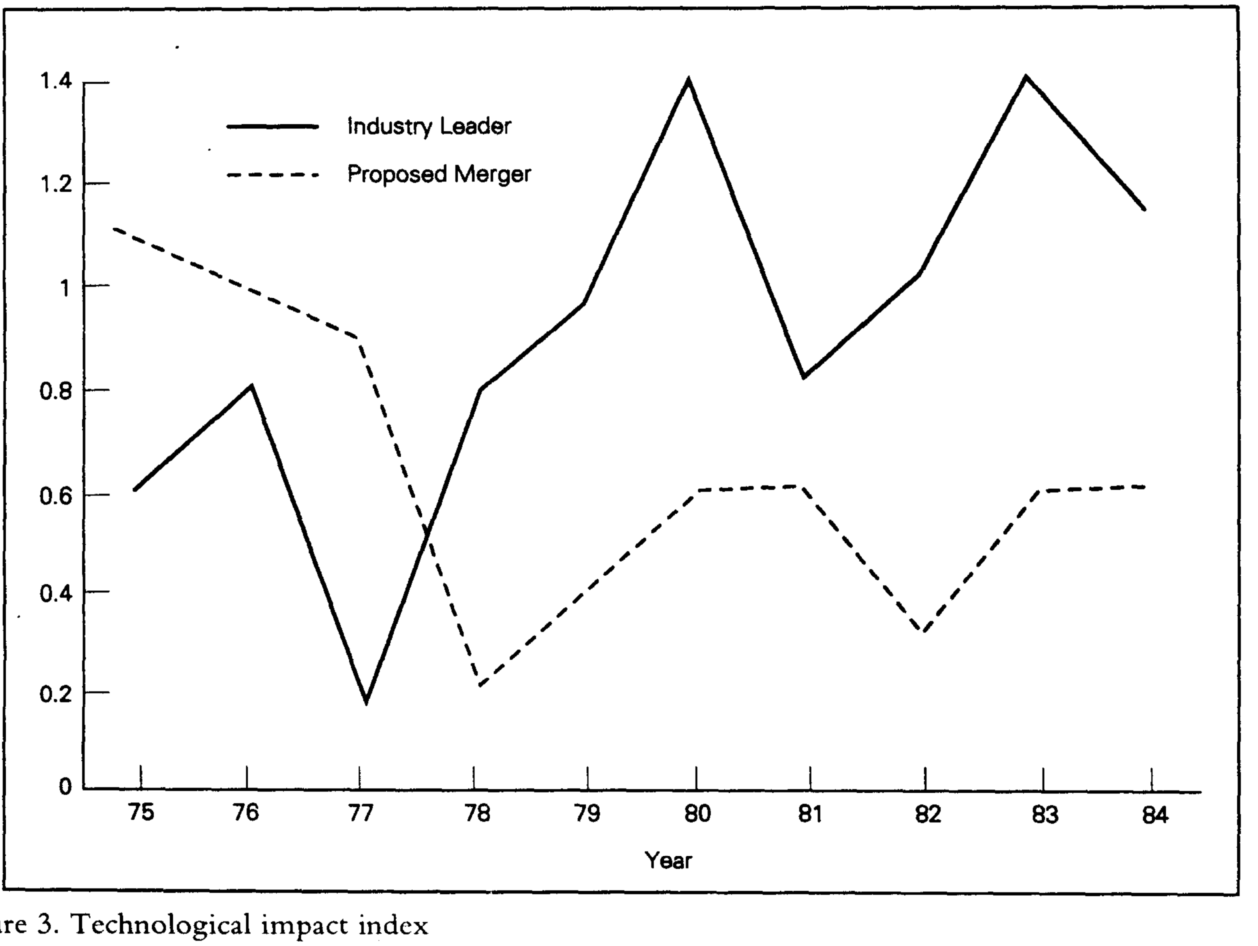

Figure 3. Technological impact index

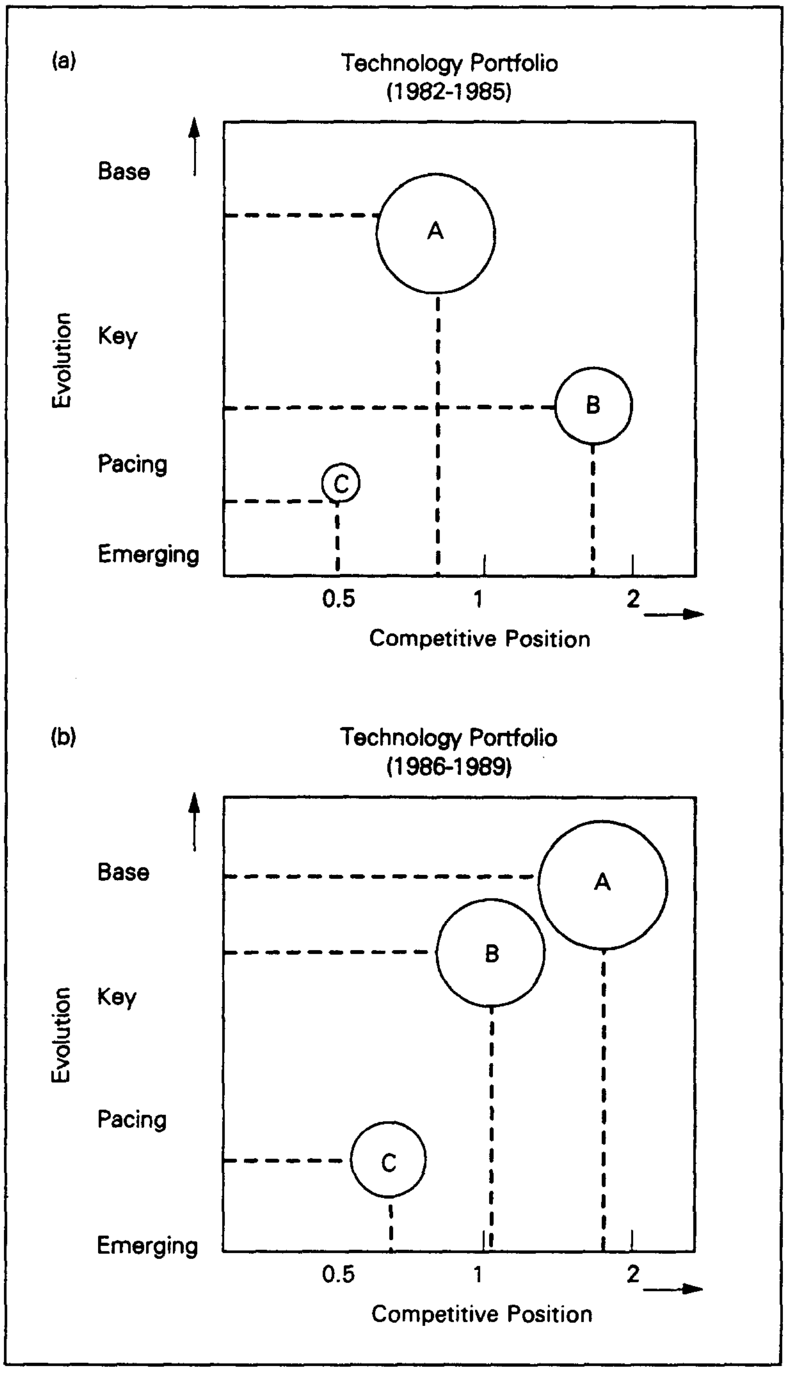

Figure 4(a). Technology portfolio, 1982–1985. Figure 4(b). Technology portfolio, 1986–1989

cated. In this example a company is analysed in terms of three of its technologies. The periods chosen are 1982/1985 and 1986/1989.

☆ *Technology A:* The firm has invested considerable resources in this base technology, as demonstrated by the large number of patents, with as resulting in a position of leadership in the period 1986/1989.[4]

☆ *Technology B:* The company is losing its previously highly competitive position in this key technology, despite the fact that it has obtained more patents in 1986/1989 than in the previous period.

☆ *Technology C:* An emerging technology developing into a key one. The company is slightly improving its position in this, as yet, uncertain sector. However, considerable effort will be required to further enhance or maintain its position in view of the rapidly increasing overall number of patents granted.

This brief portfolio analysis raises several questions:

☆ Is the company over-investing in base technologies?

☆ Why is its position in the vital key technology weakening so rapidly?

☆ Is the company prepared to match its competitors' investments in the emerging 'C' technology?

Overall, the analysis suggests that the company is misallocating its R & D funds, and that new policies need to be formulated.

Management Recommendations

Science and technology indicators are primarily a means to quantify the strengths and weaknesses of organizations in these respective areas. Experience so far suggests that they are best applied at relatively high levels of aggregation and longer periods of time.

The major benefit of using such indicators in strategic planning is that they infuse a measure of objectivity in assessing scientific and technological capabilities, and as such provide a valuable check on possibly outdated assumptions. In addition, when applied to competing organizations, they may provide early signals of new strategic thrusts of competitors long before they become visible in the market, and the relative productivity of one's own organization's R & D activities.

The use of these indicators is not without problems or pitfalls. Specifically, there are issues of definition, time lags, whether the indicators are indeed a reliable measure of the capabilities analysed, etc. None of these objections is particular to the field of science and technology, but as their use in strategic planning for commercial organizations is as yet at an early stage, some extra caution is warranted. Finally, the process of developing appropriate indicators and their measurement may, depending on the application, require substantial effort.

Overall, and in view of the enormous resources dedicated to scientific and technological activities by many industrial firms, the benefits of systematically measuring and monitoring these activities appear to outweigh the costs by a long way.

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(2) H. F. Moed, W. J. M. Burger, J. G. Frankfort and A. F. J. van Raan, On the Measurement of Research Performance: The Use of Bibliometric Indicators, Research Policy Unit of the University of Leiden, Leiden, pp. 6–7 (1987).

(3) F. Narin, *op. cit.*, p. 8.

(4) The classification of technologies into emerging, pacing, key and base categories was first introduced by the consultancy firm A. D. Little in 1971. Emerging technologies are in the laboratory stage, with as yet a promising but unknown competitive impact. Pacing technologies are under experimentation by some competitors, and their impact is likely to be important. Key technologies are widely embodied in products and processes, providing their users with a competitive advantage (differentiation). Base technologies are necessary to be in business.

Additional Literature

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