Tech-Line® BACKGROUND PAPER

by

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I. GENERAL INTRODUCTION

Forecasting a company's probability of success is enormously complicated, and depends on many financial, managerial and technological variables. In the financial realm the analyst has a wide variety of quantitative financial indicators available to aid in the analysis; up until recently, however, the managerial and technological inputs to the models have been based on less objective, more qualitative data. The new Tech-Line® Technology Indicators system created by CHI Research is designed to address the technology part of the problem, by bringing quantitative indicators of company technological strength "out of the black box and onto the spreadsheets," and into the models.

Technological knowledge and innovation are central forces driving modern, high-tech companies. Quantitative indicators of company technological strengths will allow securities analysts, other investment professionals, and economists to explicitly include company technology strengths in their analyses.

The data in the first On-line Tech-Line® covers 1,139 companies, (including top universities, agencies and organizations) in 26 industry groups in 30 technology areas, over 10 years with 9 technology indicators, providing approximately 4,000,000 data elements for analyzing company performance.

Before the advent of technology indicators, analysts assessed the technological strengths of companies from R&D budgets, announcements by management, interviewing R&D managers, new products coming to market and other important, but qualitative information. Occasionally, patent analysis was used as an input, especially by the economists, but was not of much use to the financial community because the data were of low quality and inaccessible. Specifically, three major problems have limited the production of this kind of indicator in the past: identifying company patents, putting them into usable categories, and identifying quality in the patent portfolio.

Tech-Line addresses all three problems. To produce Tech-Line®, CHI developed techniques which unify the more than 19,000 variant names and subsidiaries of the 1,139 top patenting companies, regroup the patents into 30 technology areas and 26 industry groups familiar to analysts, and use advanced patent citation indicators to provide measures of the quality of the patents within each of the technology areas, for each of the companies, for each year.

All of these ideas will be discussed in much greater detail in subsequent sections of this background paper. For the moment, accepting the idea that company patents are correctly identified, that the technology areas make sense, and that citation analysis identifies quality in the patent portfolios, then the following are a sample of the questions that can be addressed with this kind of patent portfolio data:

Which companies have the highest impact patents in semiconductors?

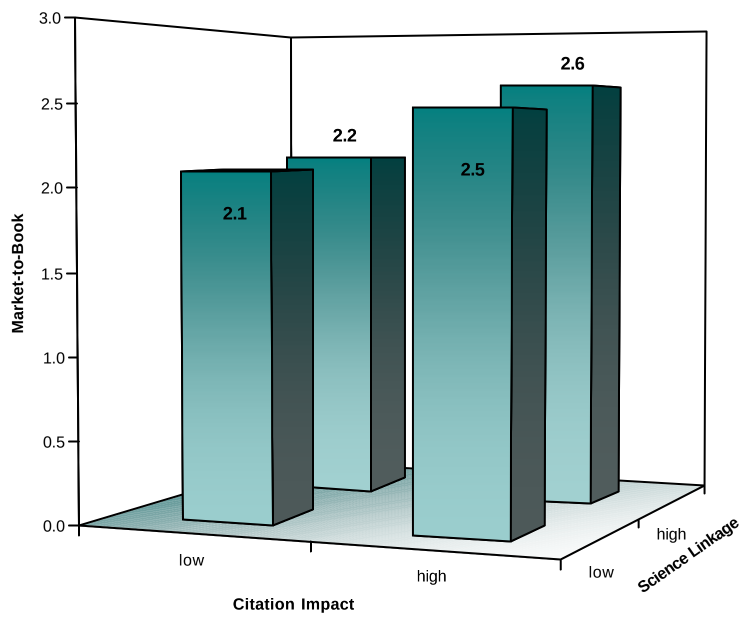
In an M&A situation, which of the companies has the most valuable patent portfolio?

How concentrated is a company's R&D across different technology categories?

How much do patent portfolio properties add to the prediction of stock market prices?

Figure 1 indicates that this may be quite a significant factor. (See also Section III).

Figure 1: CHEMICAL
Median Portfolio M/B Ratio Based on Classifying Firms Patent Impact & Science Linkage in the Previous Three Years, Averaged over Six Prediction Periods



Which smaller companies have leading edge technology portfolios in biotechnology?

How similar are the technological profiles of the major pharmaceutical companies?

How completely has Monsanto shifted its research emphasis into Agriculture?

Would the merger of Glaxo-Wellcome, and SmithKline Beecham have been a good one from the point-of-view of the technological leadership of Glaxo-Wellcome?

Tech-Line data can answer these and many other questions about the relationship of technology to economic and financial performance.

The rest of this paper contains four sections.

Section II, Technical Introduction, discusses the basic ideas behind the database and its application.

Section III is a review of the key research literature behind the database.

Section IV defines and discusses each of the indicators used in Tech-Line.

Section V is a bibliography of the papers referred to.

Detailed documents on all aspects of these technology indicators are available at www.chiresearch.com.

II. TECHNICAL INTRODUCTION

Tech-Line provides a series of quantitative indicators of company technological strengths, based on patent portfolio analysis. All of these indicators (and many more specialized ones) have been used internally by CHI Research, Inc. in its consulting practice, tracking the world's technology for industrial and public clients. However, these have not been widely available before, to the financial, investment and economics communities because of difficulties in obtaining unified, clean company data to work with, difficulties in technology definition, and difficulties in differentiating between run-of-the-mill and important patents.

Company Identification & Reassignments

Company identification requires a massive process of consolidation of company names. The 1,139 Tech-Line companies – where "companies" includes some major research laboratories, government agencies, universities, and other entities patenting in the United States – exist in the U.S. patent system under more than 19,000 different assignee names. For example, the patents of Bayer include the patents from the more than 150 different assignee names under which Bayer and its subsidiaries have patented in the United States.

The 1,139 Tech-Line companies include:

460 U.S. companies,
565 non-U.S. companies,
66 universities
30 govt. agencies, and

18 research institutes,

accounting for about 63 percent of all U.S. patents.

In addition to company identification, hundreds of thousands of patents originally assigned to one company have been reassigned as a result of property or asset sales, mergers and acquisitions, various changes in corporate structure, and so forth; those reassigned patents are assigned to their current corporate owners.

Technology Categorizations

Classification problems have also bedeviled the use of patent data in strategic and financial analysis. The most obvious way to partition patents is by the patent classification, assigned to a patent by the patent examiners. However, there are hundreds of major classes and many tens of thousands of subclasses, covering all of technology, used by the U.S. Patent Office. Moreover, these classifications are invention-art-based, rather than application specific, so that, for example, a classification describing a blade for a rotating bladed member might cover both a desk fan and for a jet engine. So devising a way to partition patents by classification requires a high degree of knowledge and experience.

Tech-Line partitions patents based on the International Patent Classification (IPC) system, which has a somewhat more industrial orientation than U.S. patent classifications. The 30 technology areas in Tech-Line (listed on **Table 1** in Section IV) are based on the first given IPC on each patent. (There can be more than one IPC-assigned, but the first is usually considered to be the main classification.) These categories should go a long towards meeting the general needs of the non-technical community for patent data in categories that make sense from a corporate viewpoint.

Identifying Important Patents

The third major problem is that of identifying important patents, from the many tens of thousands of patents issued each year. For this we use techniques developed from patent citation analysis, to characterize a company's patent portfolio overall, and within each of the 30 technology areas.

The basic idea of patent citation analysis is that highly cited patents – patents that are listed as "references cited" on many later patents, are generally of much greater importance than patents which are never cited, or cited only a few times. The reason for this is that a patent which contains an important new invention – or major advance – can set off a stream of follow-on inventions, all of which may cite back to the original, important invention upon which they are building.

The key indicators used in Tech-Line, summarized below, and defined carefully in Section IV, are the following:

Number of Patents: indicates Company Technology Activity.

Definition: A count of Type 1 (regular, utility) patents issued in the U.S. patent system, from 1987 to the present.

Cites per Patent: indicates the impact of a company's patents

This indicator is based on cited year; for example, all 1990 company patents as cited in subsequent years.

Current Impact Index (CII): fundamental indicator of patent portfolio quality.

Definition: The number of times the company's previous 5 years of patents, in a technology area, were cited from the current year, divided by the average citations received by all U.S. patents in that technology area from the current year. Expected = 1.0.

Technology Strength (TS): indicates patent portfolio strength

Definition: Number of Patents x Current Impact Index – that is patent portfolio size inflated or deflated by patent quality.

Technology Cycle Time (TCT): indicates speed of invention

Definition: The median age in years of the U.S. patent references cited on the front page of the company's patents.

Science Linkage (SL): indicates how leading edge is the company's technology.

Definition: The average number of science papers referenced on the front page of the company's patents.

Science Strength (SS): indicates how much the company uses science in building its patent portfolio.

Definition: Number of Patents x Science Linkage – that is patent portfolio size inflated or deflated by extent of science linkage. This is a count of the total number of science links in the company patent portfolio.

III. RESEARCH BACKGROUND

In this section we will review the evidence that indicators of company technological strength, based on patent portfolio analysis, provide a valid way of assessing the quality and value of a company's patented technology. We will do this by first reviewing the background research in science and patent citation analyses, and in economics. All these studies point to the conclusion that citation analysis provides significant measures of quality when assessing portfolios of publications or patents. In addition, there is emerging evidence that patent portfolio analysis, including citation indicators of the impact of the holdings in those portfolios, are indicative of, and in some cases predictive of, company technological, economic and stock market success.

Figure 1, for example, from some preliminary and ongoing research at NYU, indicated that companies which have highly science linked and highly cited patents may have substantially higher stock market/book ratios than companies with less highly science linked, less highly cited patents.

The main point of this section is that in both the scientific and the technological realm there is compelling evidence that high citation – to research papers in the scientific literature, and to issued U.S. patents in the technological literature – is associated with the importance of the scientific or technological discoveries being cited. Since this association is a statistical one it does not guarantee that every highly cited paper or every highly cited patent is of importance, or that a paper or patent that is not highly cited is not of importance. It does argue, however, that a company with a portfolio of highly cited, highly science linked patents is more likely to be technologically successful than one that does not have such a portfolio.

Just having a strong intellectual property portfolio does not, of course, guarantee a company's success, and many additional factors affect the ability of a company to move from quality patents to quality products or even to high profits. The decade of troubles at IBM, for example, is certainly illustrative of this, since IBM has always had very high quality, highly cited research in its labs.

The key studies discussed in this section were selected to capture the parallel growth of the three disciplines behind Tech-Line: science citation analysis, patent citation analysis, and closely related economic and policy analysis. Each of those studies has an additional bibliography, and from those the reader can get to literally hundreds of papers, which lie in the relevant background.

Science Citation Analysis

The origins of large scale citation analysis clearly lies with the work of Dr. Eugene Garfield, who first proposed the *Science Citation Index* in the 1950's, as a tool to increase the power of scientists to retrieve prior scientific papers (Garfield, 1955). Garfield also pointed out that in evaluating science it would be important to be able to trace the impact that a given paper has had, because all scientific work builds on earlier scientific work, and for a scientists to be able to fully understand the impact his own work is having he should have a tabulation of its citation impact, and of all the later papers that cite it.

In the early 1960's Garfield created the *Science Citation Index*, which has since grown to a major resource for science, now covering more than 4,000 scientific journals, more than half a million papers per year, and more than 5 million citations annually.

Although Garfield and his colleagues were well aware of the potential use of citation data in measuring the impact of individual papers, the widespread acceptance of science citation data in evaluation is associated with the creation by the National Science Foundation of the first *Science Indicators* report in 1972. Narin and his colleagues at CHI Research (then called Computer Horizons, Inc.) utilized the *Science Citation Index* data for *Science Indicators*, and created national and international scientific performance indicators. They used counts of publications, and most importantly, counts of how frequently those publications were cited, to create the first major indicators of national scientific performance, used in that report.

The large scale use of publication and citation techniques has continued in the subsequent *Science Indicators* reports, issued every two years since the 1972 report. For example, the *Science and Engineering Indicators 1998* report contained many tables and graphs based on this kind of bibliometric data.

As part of the general development of *Science Indicators* techniques CHI, under contract with the National Science Foundation, produced a monograph entitled "Evaluative Bibliometrics" (Narin, 1976), which reviewed the state-of-the-art of citation analysis techniques, and particularly their application to the evaluation of the performance of scientific institutions. In particular, in Chapter V of "Evaluative Bibliometrics" 24 different validation studies are summarized, all of which support the idea that high citation in the scientific literature is associated with positive peer opinions of the importance of scientific papers, with peer rankings of research institutions, and with other independent indicators of quality and impact of sets of research papers.

One of the most fascinating and telling demonstrations of the importance of very high citation is a series of papers that have been published related to the bibliometric characteristics of Nobel laureates in science. In an early paper discussing the quality of research and Nobel prizes, Inhaber noted "The quality of the work of Nobel laureates in Physics, as measured by citations, is an order of magnitude higher than that of other scientists" (Inhaber and Prednowek, 1976, p34).

Garfield himself has written about this extensively, and published a relatively comprehensive table illustrating the very high citations received by papers of Nobel laureates. Specifically he looked at 125 Nobel laureates in the fields of chemistry, physics, physiology, and medicine, and found that 80 percent had published what he calls citation classics, that is papers in the most cited 1,000 articles in the *SCI*, 1961-1982, or papers that are cited more than 300 times, corresponding roughly to the top 4/10,000 of all published scientific papers (Garfield, 1986).

The area of citation analysis continues to be a vibrant one, with a steady stream of papers applying these techniques to the evaluations of groups of scientists, research departments, institutions, and nations. This work is particularly active in Europe, with major bibliometrics research and education programs in all the major European countries. The journal *Scientometrics,* edited in Hungary, is devoted almost entirely to this field, and is an important resource for anyone looking to update themselves on the many applications of citation analysis in science. Finally, in April 1998, Dr. Ron Kostoff placed an extensive monograph on various metrics of science on the Internet. This monograph may be accessed directly at **http://www.dtic.mil/dtic/kostoff/index.html**. Kostoff's monograph is self-contained and extensive, and contains more than 5,000 references to earlier works.

The early validation techniques covered the full range of studies still being used in research evaluation. They covered correlations between publication and citation measures of national, institutional, research group, and individual performance, and external rankings. At the national level, for example, an early policy analysis by Derek de Solla Price showed that nations publish research papers roughly in proportion to their Gross Domestic Product (GDP); that is, in proportion to their economic size, not to their population or land area or anything else (Price, 1969). Much later CHI showed that this also carries over into technology, and that other nations' inventors patent in the U.S. patent system in general proportion to their national economic size as measured by GDP (Narin, 1991).

At the institutional level, citation techniques have been applied extensively to the ranking of university departments. This had been done systematically in the United States in a series of reports in which relatively large numbers of senior academics ranked major university departments. In a paper published in 1978, and reprinted in 1980, CHI showed that not only do these peer rankings of universities correlate well with publication rankings, but that the correlations are always increased substantially when citation data is included; that is, the rankings of university departments based on a combination of number of papers and how frequently they are cited are much more highly correlated with peer rankings than ones based on publication counts alone (Anderson, Narin, McAllister, 1978).

Basics of Patent Citation Analysis

When a U.S. patent is granted it typically contains eight or nine "References Cited - U.S. patents" on its front page, two references cited to foreign patents, and one to two non-patent references cited. These references link the just-issued patent to the earlier cited prior art, and limit the claims of the just-issued patent. They point out where essential and related art already exists, and delineate the property rights of the invention as determined by the U.S. Patent and Trademark Office.

The 'references cited' on U.S. patents are a fundamental requirement of patent law. When a U.S. patent is issued it has to satisfy three general criteria: it must be useful, it must be novel, and it must not be obvious. The novelty requirement is the primary factor leading to the references which appear on the front page of the patent, since it is the responsibility of the patent applicant and his attorney, and of the patent examiner, to identify, through various references cited, all of the important prior art upon which the issued patent improves. These references are chosen and/or screened by the patent examiner, who is "not called upon to cite all references that are available, but only the best" (Patent & Trademark Office, 1995).

When this referencing pattern is turned around, and all of the subsequent citations to a given patent are tabulated, one obtains the fundamental information used in patent citation analysis, namely, a count of how often a given patent is cited in later patents. These distributions tend to be very skewed: there are large numbers of patents that are cited only a few times, and only a small number of patents cited more than ten times. For example, for patents issued in 1988, and cited in the next 7 years, half the patents are cited 2 or fewer times, 75 percent are cited 5 or fewer times, and only one percent of the patents are cited 24 or more times. Overall, after 10 or more years the average cites/patent is around 6.

As was the case with science citation analysis there is, of course, no official standard by which the importance of a patent may be judged except, perhaps, for the Federal Court's designation of "pioneering patents." Therefore, most of the studies of citation frequency and patent importance are based upon the opinions of knowledgeable scientists or engineers, or correlations with non-patent measures. However, in the case of pioneering patents, we have direct legal indicator of patent importance, and as will be shown in a moment, pioneering patents are cited on average six or more times as frequently as average patents issued at the same time.

The first paper of which we are aware that looked at patent citations as a way of finding important patents was a very early study done by Reisner at IBM, who experimented with the use of citation analysis to find key patents (Reisner, 1963). By tracing the references from one patent to another, Reisner found 43 of 60 patents she was looking for.

Computerized citation data covering all U.S. patents first became available in 1975. In the following year, in the Sixth Technology Assessment and Forecast report, the Patent & Trademark Office, tabulated the patents which were most highly cited and suggested that "the number of times a patent document is cited may be a measure of its technological significance" (OTAF, 6th Report, 1976).

In 1978 Ellis, Hepburn and Oppenheim in the U.K. experimented with citation networks, tracing from patents to identify key discoveries and turning points.

The first relatively formal study of patent citation analysis was carried out by CHI Research under the sponsorship of the National Science Foundation (Carpenter, Narin & Woolf, 1981). At the time the study was proposed, in the late 1970's, the Science Indicators Unit at the National Science Foundation was considering whether to add technology indicators, based on patent citations, to the stable of science literature indicators, which were then being used in the *Science Indicators* reports. NSF commissioned CHI to do a study to see whether patents associated with important discoveries were more highly cited than average patents.

A set of 100 important patents and a set of 102 control patents were selected. The set of important patents was obtained by identifying a key patent underlying a product, which had received the IR-100 award, established by the journal *Industrial Research & Development*. This award "honors the 100 most significant new technical products – and the innovators responsible for them – developed during the year" (*Industrial Research & Development*, *13*, p.3, December 1980).

Patents related to the 1969 and 1970 awards were used, in order to ensure that there was sufficient time for the patents to be cited to their full potential.

The results of that study are summarized in the following tabulation:

	IR-100	**Control**
Total Patents	100	102
Total Cites	494	208
Cites/Patent	4.94	2.04
Patents Cited > 10 times	17	4

Clearly, the IR-100 patents are much more highly cited, and this difference is due to the presence of highly cited patents in the IR-100 set.

Following this study, patent citation indicators were added to the *Science Indicators* report (by then called *Science and Engineering Indicators*), and their use has expanded over the subsequent years.

Another formal validation study carried out by Carpenter and his colleagues at CHI in 1983, tested whether the citations from issued U.S. patents could be used to measure the science dependence and the foreign dependence of patented technologies. Rankings based on the number of citations per patent to the scientific literature, and on the number of citations to foreign-origin material were compared to peer rankings of the science and foreign dependence of the patents. Overall, a high degree of agreement was found between the expert opinions as to the science and foreign dependence, and the corresponding bibliometric rankings. For example, the eight technologies judged most science dependent by experts averaged 0.92 cites per patent to scientific journal papers, while the eight technologies judged least science dependent had only 0.05 references per patent to journal papers.

Another citation validation study was carried out by Worcester Polytech Institute students and the U.S. Patent & Trademark Office. The abstract of that report succinctly summarized it.

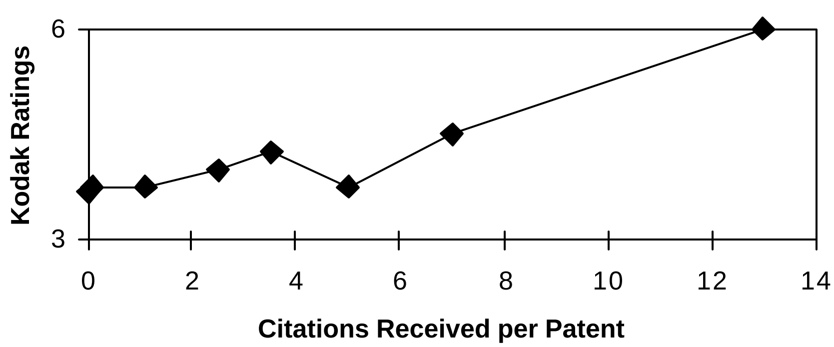
"This report, prepared for the United States Patent & Trademark Office, analyzes the importance of patents frequently cited by patent examiners. Information regarding the commercial and technical significance of the 419 most highly cited patents from 1975 and 1980 was obtained through a survey of patent attorneys and patent examiners. Characteristics of an important patent were determined through the survey. The results were found to support the hypothesis that highly cited patents are important" (Worcester Polytech, 1988).

A quite formal validation study of patent citation importance within an industrial context was carried out by CHI Research in cooperation with Eastman Kodak Laboratories. Kodak was interested in the possibility of using patent citation data in an analysis of their own and some of their competitor's technology, and desired to independently validate whether, within an industrial laboratory, high patent citation was associated with knowledgeable peer assessment of the importance of the patents. In that study, a collection of nearly 100 Kodak patents in their core area of Silver Halide Technology were divided into sets of 16 each, and the sets given to senior lab staff for evaluation. Every patent was evaluated by three or four different people. As a result, the rankings of the patents could be cross-tabulated. The Kodak evaluators were senior intellectual property staff, senior lab management, and senior lab scientists. In the case of scientists, the patents they were given to rank were screened, to make sure that they did not rank their own patents. Each person was asked to rank the patents based on how much each has changed the state-of-the-art in the field of the invention.

The result of that study is very well summarized in Figure 2 which shows quite clearly that whether a patent is cited one, two, or three times does not seem to make much difference in the peer ranking, but that patents cited more than five times, that is, relatively highly cited patents, were ranked far more highly by the Kodak staff. This finding is quite statistically significant, especially for group 8, the most highly cited patents. Of the 15 respondents in the study, eight gave group 8 patents the highest average rating. Using the binomial model, the probability of this is 0.0002 (Albert, Avery, Narin & McAllister, 1991).

Figure 2

Average rating versus average citations received for eight patent groups: Kodak highly cited patents are much more highly rated

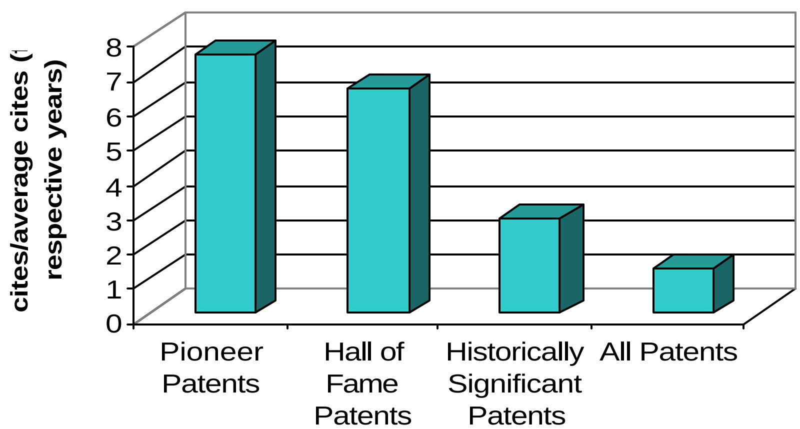


The most recent evidence for the importance of highly cited patents comes from within the Patent office itself, from the strong associations between citation frequency and Patent Office recognition, and in the extremely high citation to pioneering patents.

CHI has looked at the citation frequency of three different categories of patents: patents listed in the National Inventor's Hall of Fame, patents of Historical Significance in a list prepared by the U.S. Department of Commerce for the U.S. bicentennial, and patents that had been adjudged as pioneering patents by the Federal District Court.

A summary of this data is shown in Figure 3, which plots citation indices for the three sets of patents: Pioneering, Hall of Fame and Historically Significant. Because the patents are distributed over a relatively long period of time, we divided the number of times each patent was cited by the expected number of times patents issued in the same year have been cited, counting citations in our database from 1971 through March of 1995. The results are striking. Pioneering patents are cited almost seven times as often as expected; Hall of Fame patents are cited more than six times as often as expected, and historically significant almost 2.5 times as often as expected. And, in fact, of all the patents looked at, only one was cited fewer times than expected. This is certainly a very direct validation of the idea that important patents tend to be cited much more heavily than average.

Figure 3
Very High Citation Indices Found for Selected Patents



Patents Granted 1960-1995. Citations from 1971- March 1995.

A recent paper by F. M. Scherer of Harvard, and colleagues in Europe and at CHI, looked at a sample of U.S. and German patented inventions, on which profitability information – the private value of the patents – was obtained (Harhoff, Narin, Scherer & Vogel, 1999). They considered only patents for which all the fees had been paid to keep the patents in force in Germany for the full 18 years of the patents, and then queried the owners of those patents as to the asset value of the patent – essentially asking, what is the smallest amount they would have been willing to sell this patent to an independent third party for in 1980? In the German patent system the two patents in the highest value category were much more highly cited than the others; in the U.S. patent system the patent citation frequency of the patents with an estimated value of $20 million or above were substantially more highly cited than the patents with lesser estimated values.

Economic and Policy Analysis

In this section we review a few of the studies in the sequence supporting the idea that there is positive relationship between important technological advances and economic outcomes. This is the so called "linear model" of innovation: the idea that invention and innovations originate in basic and applied research, progressing into technological and economic benefit. This simple linear model has been supplanted by much more complex views of the process with many feedback loops, but the origins of technical knowledge in basic research still lie at the core of this process (Turney, 1991).

It is also, of course, widely accepted today that research makes an important contribution to economic growth, and in his statement on technology for America's economic growth, President Clinton stated that "scientific advances are the well-spring of technical innovations. The benefits are seen in economic growth, improved health care, and many other areas" (Clinton & Gore, 1993).

A recent paper of ours discussed quite extensively the increasing linkage between U.S. technology and public science, and demonstrated that the underlying citation by patents to research papers, used in Tech-Line as science linkage, has increased dramatically over the last decade (Narin, Hamilton & Olivastro, 1997).

As far back as the late 1960's, systematic efforts were underway to trace the linkage between research and economically important innovations. A key study done then was the TRACES study (Technology in Retrospect and Critical Events in Science) performed under NSF's sponsorship at IIT Research Institute (Narin, 1968). TRACES looked at five economically important innovations including magnetic ferrites, video recording, and the contraceptive pill, and traced back to their origins in applied and basic research.

The key advance imbedded in TRACES was the semi-quantitative approach. Although citation analysis was not utilized, partially because citation data was essentially inaccessible then, there was an attempt to classify, count and identify the key events leading up to the innovations.

By the early 1980's, it was possible to obtain reasonably large scale patent data, and Griliches and his colleagues at Harvard, and the National Bureau of Economic Research (NBER) began a long series of quantitative studies looking at the economic importance of patents. In a 1981 paper Griliches found a significant relationship between the market value of the firms, and its "intangible" capital, provided by past R&D expenditures and the number of patents (Griliches, 1981).

A particularly interesting paper in this sequence, by Ariel Pakes in 1985, "On Patents R&D and the Stock Market Rate of Return," found that an unanticipated patent is associated with an increase in firm value of $865,000.

In 1990 Griliches comprehensively surveyed the use of patent statistics as economic indicators (Griliches, 1990).

Those studies, and most of the economic studies up to recent time were very aggregate, based on corporate identifications that were either not unified at all, or not nearly as refined as those that are available now on Tech-Line, and without the augmentation that citation analysis adds.

In 1987, Narin and his colleagues studied a group of 18 U.S. pharmaceutical companies, and showed that the numbers of patents they obtained, and especially whether the companies had highly cited patents, were both correlated with peer opinions of the companies, and with increases in pharmaceutical company sales and profits (Narin, Noma & Perry, 1987). That study showed quite clearly that highly cited patents tended to occur around economically important inventions such as Tagamet for SmithKline, and that these important technological events lead, in that industry, to increases in company sales and profits. In fact, the Tagamet patents that were highly cited in the 1980's are still underpinnings of SmithKline Beecham today.

A somewhat different approach, with the same results, was taken in a study by Trajtenberg, with the marvelous title "A Penny for Your Quotes" ("quotes" is the European term often used for citations) (Trajtenberg, 1990). Trajtenberg analyzed patent citation patterns associated with advances in CAT scanners, and showed a close association between citation-based patent indices and independent measures of the social value of innovations for computed tomography scanners. Of particular significance is his finding that "the weighting scheme appears to be non-linear (increasing) in the number of citations, implying that the information content of citations rises at the margin" (p. 172). This directly supports the idea that highly cited patents are of particular technical importance.

In a broader study, Franko, at the University of Massachusetts, showed that U.S. and U.K. losses in global markets in the 1960-1986 time frame may have been caused by a lack of investment in technology, compared to their Japanese and continental European competitors. Specifically, he says

> "The proportion of corporate sales revenues allocated to commercially oriented R&D emerges as a, perhaps the, principal indicator of subsequent sales growth performance relative to competition over 5-10 year periods. Insofar as many U.S. and U.K. firms have lost global market share relative to Asian and European competitors over the past two decades, a significant contributory factor would appear to have been negligence on the

> part of many U.S. and U.K. firms of investment in technology as a factor determining strategic, competitive advance" (Franko, 1989).

An interesting observation is that the superior technological performance of the U.S. in the mid-to-late 1990's is associated with an increasing U.S. inventor share of U.S. patents, back up to over 50 percent of the patents granted in the U.S.

In a beautifully written general article in *Scientific America*, Rosenberg and Birdzel at Stanford put forth the thesis that the linkage of knowledge and technology, and the freedom to absorb and use it in industry, was the fundamental driving force behind the economic rise of the West. Specifically, that

> "Close links between the growth of scientific knowledge and the rise of technology have permitted the market economies of the Western nations to achieve unprecedented prosperity" (Rosenberg & Birdzel, 1990).

A few years later, *Business Week* published the two Patent Scoreboards using CHI Research data to rank major companies across 10 different industries (Coy & Carey, 1992 and Buderi et al 1993). These Patent Scoreboards were two of the first times when these ideas were introduced directly to the business community, so that analysts could look at the relationship between the business performance of companies and their technological strengths.

There is also a growing awareness of the value of intellectual capital – of which patents are a major component. This is reflected in a recent article in *Fortune* " Your Company's Most Valuable Asset: Intellectual Capital" by Stewart, which asserted that the modern company is really driven by knowledge, and not by bricks and structures (Stewart, 1994).

The economists associated with the NBER are now using patent citation techniques in a wide variety of ways studying spillovers of research from company-to-company, and university-to-company, studying the characteristics of successful companies, and in general, demonstrating the acceptance of the notion that patent citation is equivalent, in the statistical sense, to high impact technology. A paper by Jaffe, Trajtenberg and Henderson (1993) provides a linkage into this literature.

Interest is also rapidly growing in trying to find ways of valuing corporate intangibles for financial purposes. The intangibles research project, headed by Professor Baruch Lev at The Stern School of Business at New York University, is addressing the accounting treatment of corporate investment and intangibles such as R&D, franchise, and brand development. In particular, a study by Professor Lev showed that the accounting rule which lets an acquiring company set a value for the "in process" research and development assets, and immediately write-off that amount, significantly allows the acquirers to avoid future charges to earnings from good will, and thus tends to provide companies with a boost to their future earnings (Deng & Lev, 1998).

In a work that is still underway, Bronwyn Hall and her colleagues in the NBER are looking at market value and patent citations, using a new database that has been assembled by NBER for research purposes. Their research, while still preliminary, is quite advanced in its mathematical techniques, and is being used to estimate how much citations to patents contribute to such indicators as the market value of a company. Amongst their many findings are that "citation weighted patents do better, especially in the earlier years when the citation measure is more complete" and that "an increase of one citation per patent is associated with a three to four percent increase in market value at the firm level." (Hall, Jaffe and Trajtenberg, 1998)

Finally, a relevant and important preliminary study by Professor Lev and his student Zhen Deng, assisted by CHI, looked at the relationship between Tech-Line variables, and various financial indicators, including R&D budgets, and stock market performance (Deng, Lev and Narin, 1998). In particular, they found companies whose patents had above average current impact indices (CII's) and science linkage indicators (SL's) tended to have significantly higher market-to-book ratios, and stock market returns, both contemporaneously and for a number of years into the future (see Figure 1). That finding is one of the key pieces of evidence that indicators of corporate technological performance, based on patents and patent citations, may provide significant new tools to securities and financial analysts.

IV. INDICATOR DEFINITIONS

This chapter will cover, in some detail, the specific indicators used in Tech-Line, as well as the many decisions and unifications that must be undertaken to create a usable technology indicators database.

We will start with the choice of patents to include, and the identification of the company (assignee) that owns the patent currently, proceed to the most basic indicator, the cites per patent received by a patent from subsequently issued patents. We will then define the Current Impact Index, a synchronous citation indicator which characterizes the quality of the most recent 5 years of a company's patents, and then on to Technology Cycle Time which characterizes the rapidity with which companies invent, and Science Linkage which shows whether a company's patents are linked to scientific research, a strong indicator of leading edge position across a wide range of science-based advanced technologies. A few composite indicators constructed from these basic ones, will also be defined.

4.1. Number of Patents: indicates company technology activity.

Definition: A count of a company's Type 1 (regular, utility) patents issued in the U.S. patent system, from 1987 to the present.

For its patent counts Tech-Line considers only regular (Type I) U.S. utility patents. Other categories of U.S. patents such as plant patents, design patents, reissues, continuations, and so forth, are not counted, in order to keep the focus of the database on the key category of patents which contributes to corporate technological strengths.

4.1.1. Company Name Unification

When a U.S. patent is issued it is issued to the inventor and, if the inventor works for a company, the rights to that patents are normally assigned to that company, which is then identified as the assignee of the patent.

The first problem is that companies obtain their patents under many different names. Companies may patent under divisional names; subsidiaries may get patents in their own individual names; companies name change over time, and so forth. CHI has gone through a massive unification of these various assignee names for the 1,100 companies covered in Tech-Line, which are constructed by combining more than 19,000 different original assignee names, in a major attempt to correctly identify the company to which patents are assigned in the first place. For example, the following shows a few of the names under which patents assigned to Hitachi were filed, and which have been unified in Tech-Line.

Step 1: Typographical Unification

Hitachi Maxell, Ltd.
Hitachi Maxell Ltd.
Hitachi Maxwell, Ltd

→ **Hitachi Maxell, Ltd.**

Step 2. Company Unification

Hitachi Denshi KK Ltd.
Hitachi Keiyo Eng. Co., Ltd.
Hitachi Seiko, Ltd.
Hitachi Kiden Kogyo KK
Hitachi Lighting, Ltd
Hitachi, Ltd
Japan Servo Co., Ltd
Hitachi Maxell, Ltd

→ **Hitachi, Ltd**

4.1.2. Company Restatement

The second problem related to assigning a patent to a company is mergers, acquisitions, and divestitures, which CHI has attempted to take into account by restating all of the companies as of the end of 1997.

More specifically, insofar as we can tell which patents belong to a subsidiary or part of a divested or acquired company, these patents are moved with a merger/acquisition. For example, the patents of SmithKline Beecham include not only patents under that name, but patents that were originally filed under SmithKline and French Laboratories, Beckman Instruments, Beecham etc. This process is carried out by scanning a number of resources, but is by no means perfect, especially for the smaller companies, so that the corporate identification in Tech-Line, while better and more up to date than any database of which we are aware, is certainly not perfect.

4.1.3. Reassignments

Another major attribute of the Tech-Line database is that we have attempted to account for major reassignments of patents. When a merger and acquisition takes place, or a major area of technology is sold, it sometimes happens that a reassignments of the patents is registered in the Patent Office from the original assignee to a new assignee. This reassignment is captured in a complex, extremely difficult to process database produced by the Patent Office. CHI has processed this database and moved, via reassignment, hundreds of thousands of patents from the original assignees to their new assignees, including many patents moved across Tech-Line companies. Some of the reassignments are not very important from a company strength viewpoint ,such as from one part of a company or one version of a company's name to another, while others are indicative of the genuine transferal of intellectual property from one company to another. As well as we could, the reassignments, which were recorded by the Patent Office, affecting the Tech-Line companies have been accounted for, and the reassigned patents are, within Tech-Line, assigned to their current owners.

4.1.4. Restatement Limitation

It is very important to mention, however, that companies do not, by any means, always reassign their patents, even when major divestitures and acquisitions occur. For example, the old patents of AT&T were not reassigned to Lucent by registration of the reassignment at the USPTO. However, there is a public record in SEC documents of which patents went to Lucent and NCR from AT&T; we have made use of those public filings to assign to Lucent the great majority of the patents, which were originally assigned to AT&T. In cases where patents were not explicitly reassigned, and we have not found any public record of them, the patents stayed with the original company. For example, Imation, which was split off from 3M, and now is beginning to patent vigorously under its name, does not appear to have been reassigned any back 3M patents, and therefore does not yet have enough patents to be included as a Tech-Line company.

4.1.5. Choice of Companies

The on-line Tech-Line database was built upon earlier CD-ROM versions of Tech-Line. The criteria for selecting companies in those earlier times were relatively large numbers of patents in the late 1980's and early 1990's, with each edition of Tech-Line adding to it companies that had newly emerged as major patenters. However, the earlier versions broke the data down into broad sets of chemical, electrical, and pharmaceutical companies, and the coverage was not even across other areas, so that while most of the top 1,100 patenting companies are covered in Tech-Line, there may be a few companies, with recent rapid increases in patenting, that we have missed. We will attempt to get any that should be there covered in the future releases of Tech-Line, which may also be expanded to cover smaller companies.

Lists of all the companies covered in Tech-Line are given on the CHI home page at www.chiresearch.com. The coverage is very international. Approximately one-half of all U.S. patents are foreign invented, and thus is reflected in the Tech-Line company proportions. More specifically, the July 1998 first edition of Tech-Line covers the following:

48 Percent U.S. Organizations
52 Percent Foreign Organizations

Specifically:

355 U.S. Parent Companies
105 U.S. Subsidiaries
469 Non-U.S. Parent Companies
96 Non-U.S. Subsidiaries
30 Government Agencies (10 U.S.)
18 Research Institutes (13 U.S.)
66 Universities (64 U.S.)

4.2. Patent Growth Percent and Percent of Company Patents in Area

There are two indicators are directly based on the number and growth rate of patents. These are Patent Growth Percent in Area and Percent of Company Patents in Area. Patent Growth Percent in Area, from one period to the next, is just the number of patents in the current period minus the number of patents in the previous period, divided by the number of patents in the previous period, expressed as a percent.

The percent of company patents in area is, just as it says, 100 times the number of patents in the area, divided by the total number of patents for the company.

Both of these are illustrated for all Tech-Line companies in the first edition of Tech-Line on-line in Table 1.

Table 1
Patent Growth and Concentration Indicators
All Tech-Line® Companies, 1993-1997

Technology Area	No. of Patents 1993-1997	Patent Growth % in Area	% of Co. Patents in Area
1 Agriculture	4542	6	1.3
2 Oil and Gas	4604	-19	1.3
3 Power Generation and Distribution	4730	0	1.3
4 Food and Tobacco	2641	-18	0.8
5 Textiles and Apparel	4165	5	1.2
6 Wood and Paper	2035	8	0.6
7 Chemicals	40828	4	11.6
8 Pharmaceuticals	12610	23	3.6
9 Biotechnology	6113	89	1.7
10 Medical Equipment	8348	43	2.4
11 Medical Electronics	3769	73	1.1
12 Plastics, Polymers and Rubber	20117	2	5.7
13 Glass, Clay and Cement	2880	-16	0.8
14 Primary Metals	1913	-15	0.5
15 Fabricated Metals	4879	1	1.4
16 Industrial Machinery and Tools	14426	-4	4.1
17 Industrial Process Equipment	9488	-2	2.7

Technology Area	No. of Patents 1993-1997	Patent Growth % in Area	% of Co. Patents in Area
18 Office Equipment and Cameras	22076	23	6.3
19 Heating and Ventilation	2211	22	0.6
20 Miscellaneous Machinery	11250	-5	3.2
21 Computers and Peripherals	37078	81	10.6
22 Telecommunications	33350	44	9.5
23 Semiconductors and Electronics	26740	39	7.6
24 Measuring and Control Equipment	16333	0	4.7
25 Electrical Appliances and Computer	17132	12	4.9
26 Motor Vehicles and Parts	13169	0	3.8
27 Aerospace and Parts	1996	-6	0.6
28 Other Transport	2518	-4	0.7
29 Miscellaneous Manufacturing	15477	2	4.4
99 Other	3530	1	1
All	350948	16	100

Note that the largest area is chemicals with 11.6 percent of all the patents, followed by computers and peripherals at 10.6 percent.

It is also apparent that the high-tech areas are expanding fastest. The most rapidly growing area over that five years period is biotechnology, with a growth rate of 89 percent, followed by computers and peripherals with a growth rate of 80 percent, and medical electronics with a growth rate of 73 percent.

Still growing at a rapid rate, but distinctly down from the top three are medical equipment at 43 percent, telecommunications at 43 percent, and semiconductors and electronic components at 38 percent. In addition, there are three other areas growing faster than the patent system: pharmaceuticals at 23 percent, office equipment and cameras at the same 23 percent, and heating and ventilation at 22 percent, compared to the overall Tech-Line growth rate of 16 percent. The areas that seem to be shrinking in patenting most rapidly are oil and gas at -19 percent, food and tobacco at -18 percent, and glass, clay, and cement, and primary metals at respectively -16 and -15 percent. There are real differences in the rates of growth of patenting within different areas: as has been mentioned before, it is crucially important that comparisons be made within technology areas.

4.3. Cites Per Patent: indicates the impact of a company's patents

Definition: A count of the citations received by a company's patents from front pages of subsequent patents. For example, cites per patent for 1990 patents reports the number of times a company's 1990 patents were mentioned on U.S. patents issued afterwards.

In patent citation analysis, high citation counts are often associated with important inventions, ones that are fundamental to future inventions. Companies with highly cited patents may be more advanced than their competitors, with more valuable patent portfolios. After six years, the average U.S. patent is cited about 5 times.

Comparing cites per patent one must be very careful to do the comparisons within a given technology area, and to do them at a specific year. The next section will discuss the variation of citations from technology area to technology area.

The reason that comparisons can only be made at a specific year is that citations accumulate over time. For the first on-line edition of Tech-Line, the counts of cites per patent were counts of all citations received by a given patent from all U.S. patents issued through June 1998.

The net result of that is that a U.S. patent issued in 1990 will have more than seven years of citation from U.S. patents, whereas a patent issued in 1992 will only have citations from five subsequent years of U.S. patents. This is illustrated in Table 2, which shows the cites per patent for all of the patents in Tech-Line in all technology areas for each of the years 1988 through 1997.

Table 2
Cites per Patent Received by All Tech-Line® Patents

Year	Cites per Patent
1988	6.6
1989	5.9
1990	5.4
1991	4.8
1992	4.2
1993	3.4
1994	2.6

1995	1.6
1996	0.8
1997	0.1

Note: Counts citations through June 16, 1998 for U.S.

4.4. Current Impact Index (CII): indicates patent portfolio quality.

Definition: The number of times a company's most recent five years of patents are cited in the current year, relative to the entire patent database. A value of 1.0 represents average citation frequency; a value 2.0 represents twice average citation frequency; and 0.25 represents 25 percent of average citation frequency within the technology.

The key characteristic of the Current Impact Index is that is a synchronous indicator, looking backwards from the current year to the previous five years. As a result, it moves with financial indicators, and it is sensitive to a company's current technology. Having ten or fifteen year old extremely highly cited patents, for example, does not effect the Current Impact Index, only the patents the company has been issued over the last five years. Essentially, the Current Impact Index is the weighted sum of the citation ratios for each of the past five year's company patents, as cited by all patents in the current year. The following shows some data which will illustrate the computation of CII for a hypothetical company ABC.

Number of Patents Issued in Year

	1986	**1987**	**1988**	**1989**	**1990**
World	71,662	72,860	81,954	76,542	95,530
ABC	104	250	125	180	285

Number of Citations from 1991 to Year

	1986	**1987**	**1988**	**1989**	**1990**
World	35,321	36,854	50,765	40,970	52,635
ABC	62	130	65	102	165

Average Cites per Patent from 1991 to Year

	1986	1987	1988	1989	1990
World	0.49	0.51	0.62	0.53	0.55
ABC	0.60	0.52	0.52	0.57	0.58

For each of the previous five years we form a citation ratio, essentially the ratio of average cites to ABC's patents divided by the average cites to all patents. For example, for each of the five years covered by the above table we have the following citation ratios.

ABC's Citation Ratios (Ratio to World)

1986	1987	1988	1989	1990
1.22	1.02	0.83	1.07	1.05

The final step in calculating the CII is to take the weighted sum of these ratios, weighted by the number of patents the company has in each of those previous five years. The following illustrates this.

$$CII = \frac{1.22 \times 104 + 1.02 \times 250 + 0.83 \times 125 + 1.07 \times 180 + 1.05 \times 285}{104 + 250 + 125 + 180 + 285} = 1.03$$

Note that CII is a citing year indicator. It gives you the impact or quality of the company's patents based on citing from the current year, looking back. This is the opposite of the more standard cites per patent indicator, which is based on cited year and sums all of the citations received by a patent from all subsequent years.

Note that for the entire patent system the expected CII is 1.0. Therefore, a company whose patents have a CII of 1.5 has patents issued in the previous five years which are cited 50 percent more than expected from the current year.

Because the Current Impact Index looks back just 5 years, one important characteristics of it is that when a company starts running out of new, bright inventions, its Current Impact Index starts to fall relative quickly. This gives the analyst a perhaps stronger picture of what's likely to happen with a company's technology in the near future. However, in some industries such as the pharmaceutical industry, there is a very long time between patents and products, which, perhaps, should be factored into the analysis.

However, the essence of all of these citation indicators is to capture the fundamental technological strengths and capability of a company, and not to identify exactly which products or discoveries are going to be commercially important. There is much too much uncertainty in technology to do that with any kind of a general indicator. To use a sports metaphor, it is virtually impossible to know which player on a team will score, but by analyzing the talents on both teams, you can greatly improve your prediction of which team will win.

The basic idea behind technology indicators is that they are a necessary, but not sufficient condition for company success. While it is not sufficient for a company's success for it to have a strong, creative technological and inventive capability, it is certainly necessary, if the company is going to be competitive in any of the technology driven fields. A company either has to have or develop that technology in-house, or to license it in, or it will be a strong competitive disadvantage.

The following Table 3 shows the five-year CII, by technology area, compared to the entire patent system, for all Tech-Line companies combined.

Table 3
Current Impact Index by Technology Area
All Tech-Line® Companies, 1993-1997

Technology Area	Current Impact Index
1 Agriculture	0.64
2 Oil and Gas	0.84
3 Power Generation and Distribution	0.90
4 Food and Tobacco	0.91
5 Textiles and Apparel	0.79
6 Wood and Paper	0.99
7 Chemicals	0.79
8 Pharmaceuticals	0.79
9 Biotechnology	0.68
10 Medical Equipment	2.38

Technology Area	Current Impact Index
11 Medical Electronics	1.77
12 Plastics, Polymers and Rubber	0.77
13 Glass, Clay and Cement	0.78
14 Primary Metals	0.59
15 Fabricated Metals	0.82
16 Industrial Machinery and Tools	0.77
17 Industrial Process Equipment	0.89
18 Office Equipment and Cameras	1.22
19 Heating and Ventilation	0.95
20 Miscellaneous Machinery	0.86
21 Computers and Peripherals	1.88
22 Telecommunications	1.65
23 Semiconductors and Electronic	1.35
24 Measuring and Control Equipment	1.02
25 Electrical Appliances and Computer	1.01
26 Motor Vehicles and Parts	1.33
27 Aerospace and Parts	0.68
28 Other Transport	0.70
29 Miscellaneous Manufacturing	0.88
99 Other	1.06
All	1.14

Note again that there are substantial differences from technology-to-technology. The highest CII is in the medical equipment area for that five-year period, at 2.38, whereas the lowest, in agriculture, is only 0.64, indicating roughly that medical equipment patents are almost four times as highly cited as patents in the area of agriculture.

The second important observation from that table is that the All number is 1.14, not 1.00. The reason for that is that CII is calculated against the entire U.S. patent system, whereas the Tech-Line companies only account for 63 percent of the U.S. patents. The fact that this number is substantially higher than 1.0 indicates, just as one would expect, that the major companies, covered in Tech-Line, have patents which are more highly cited than the entire patent system. In fact, patents owned by individual inventors and not assigned to companies in the U.S. system are much less frequently cited than patents that are assigned to companies.

4.5. Technology Strength(TS): indicates patent portfolio strength

Definition: Number of Patents x Current Impact Index – that is, patent portfolio size inflated or deflated by patent quality

Note that we have tried, with our technology strength indicator, to capture both the size of the company's technological activity, through the number of patents, and the quality through the Current Impact Index. There is, we must admit, a slight logical inconsistency in the way technological strength is defined, in that the number of patents is the number of patents in the current year, and the CII citation indicator is based on cites to the company's most recent 5 years of patents. The implicit assumption in technology strength is that the company's newly issued patents will be of similar impact and quality as the company's recent patents.

4.6. Technology Cycle Time (TCT): indicates speed of innovation

Definition: The median age in years of the U.S. patent references cited on the front page of the company's patents.

Fast moving technologies such as electronics have cycle times as short as three to four years. Slow moving technologies such as ship and boat building may have technology cycle times as long as 15 years or more. Companies with shorter cycle times than their competitors in a given technology area may be advancing more quickly from prior technology to current technology.

Technology Cycle Time, TCT, captures some elements of the rapidity with which a company is inventing, since it measures, in essence, the time between the previous patents upon which the current patent is improving, and the current patent. As mentioned in the previous paragraph, it varies very substantially from one technology area to another. The following table illustrates this. TCT also varies from country-to-country. Japanese invented U.S. patents, for example, tend to have much shorter Technology Cycle Time than U.S.-invented patents, which in turn tend to have shorter cycle times than European-invented patents, and this difference is particularly notable in such technologies as electronics. We interpret this as indicating that the Japanese companies are innovating very rapidly, possibly making incremental but rapid changes in their technology and products, whereas the European companies tend to be innovating at a very much slower rate, particularly in electronics, with U.S. companies somewhat in the middle.

Table 4
Technology Cycle Time by Technology Area
All Tech-Line® Companies, 1993-1997

Technology Area	Technology Cycle Time (1993-97), in Years
1 Agriculture	10.2
2 Oil and Gas	11.9
3 Power Generation and Distribution	9.0
4 Food and Tobacco	11.9
5 Textiles and Apparel	12.9
6 Wood and Paper	12.3
7 Chemicals	9.0
8 Pharmaceuticals	8.1
9 Biotechnology	7.7
10 Medical Equipment	8.3
11 Medical Electronics	6.7
12 Plastics, Polymers and Rubber	10.2
13 Glass, Clay and Cement	10.1
14 Primary Metals	10.3
15 Fabricated Metals	10.1

Technology Area	Technology Cycle Time (1993-97), in Years
16 Industrial Machinery and Tools	10.7
17 Industrial Process Equipment	11.1
18 Office Equipment and Cameras	6.7
19 Heating and Ventilation	10.4
20 Miscellaneous Machinery	12.3
21 Computers and Peripherals	5.8
22 Telecommunications	5.7
23 Semiconductors and Electronic	6.0
24 Measuring and Control Equipment	7.7
25 Electrical Appliances and Computer	8.3
26 Motor Vehicles and Parts	7.1
27 Aerospace and Parts	13.2
28 Other Transport	11.1
29 Miscellaneous Manufacturing	10.1
99 Other	9.7
All	8.0

Another particularly interesting aspect of Technology Cycle Time is that it sometimes can be used, along with the rate of increase of patents, to identify areas in which a company is intensively active, because if a company is increasing its patenting, and at the forefront of a technological area, then it will tend to have a short Technology Cycle Time. We sometimes find that companies which are relatively slow overall in their inventive cycles will be very fast in one area, and that is often the area in which they are known to be technology leaders.

As with many of the other indicators the computation of TCT is not totally straightforward .

For one, we use the median rather than the average age of the cited references because there are, very often, one or two old classic references used in a patent, and if we use the average these one or two very old references would distort the data. The actual computation of this is illustrated in Table 5, where we show the six U.S. patent references given in U.S. patent 5,200,004.

Table 5

Technology Cycle Time Illustration

Patent 05200004
Application Date 1991-12-16
Issue Date 1993-04-06

Title Permanent Magnet

	Year	Patent Number	Age
References to	1957	2810640	36
US Patents	1966	3241930	27
	1988	4722869	5
	1988	4770718	5
	1990	4925741	3
	1991	5043025	2

Next to the patent and the year, which is normally given in the reference, is the age of each of those references, from the point of view of the patent issued in 1993.

The problem is: what is the median, since it falls between two patents, each of which appear to be of age five years.

In order to approximate this we make the assumption that when there are multiple references of the same age (in years) they are evenly distributed across the year. The Technology Cycle time, as computed for that patent, would then be 5.5 years.

4.7. Science Linkage (SL): indicates how leading edge is the company's technology

Definition: The average number of science papers referenced on the front page of the company's patents.

High science linkage indicates that a company is building its technology based on advances in science. Companies at the forefront of a technology tend to have higher science linkage than their competitors. This type of referencing is growing rapidly. The average is roughly 1 per patent; drug & medicine patents often have 5 or more, leading edge biotechnology patents 15 or more, and Genentech's patents 25 or more.

Science Linkage is a particularly interesting indicator, and one that has received a lot of coverage in the press recently because CHI's research has shown that some 75 percent of all of the science references cited on the front pages of U.S. patents had their origins in public science; that is, they were based on research done at universities, government laboratories, various non-profit research institutions, and so forth (Narin, Hamilton & Olivastro, 1997). We thus established quantitative evidence for a major role of fundamental, mainstream basic research in support of leading edge industrial technology. This work has been reported in a number of papers, as well as covered in *The New York Times* (Broad, 1997) and elsewhere.

The construction of the basic data for the Science Linkage indicator is quite complex and tedious because we differentiate between science references, which are included, and other non patent literature references which are excluded. When a U.S. patent is issued, in the category "other references cited" are a wide variety of materials, including publications that are clearly scientific, and many that are not. For example, there are many thousands of references to technology disclosure bulletins, which we exclude from our science linkage calculations.

In order to make that distinction we have, by a combination of computer matching and manual verification and correction, processed more than two million non-patent references from 1983 on, and are currently processing close to 14,000 per week – that is, there are currently more than 14,000 non-patent references per week in the front pages of U.S. patents.

Figure 4 illustrates how this choice is made. That particular patent, number 5,200,001 for a permanent magnet, contains seven non-patent references. Of those seven we considered five to be science references – that is references to published scientific papers and to papers at formal scientific meetings. Reference 3 we did not consider to be a science reference because it is to a manuscript which may or may not have been distributed at a scientific meeting, and Reference 5, to the Patent Abstracts of Japan, is almost certainly not a scientific paper.

Figure 4: Science Reference Illustration

Patent	05200001	
Application Date	190-11-29	
Title	Permanent magnet	
References to Non-Patent Literature	Science	1:M.Endoh Et Al., "Magnetic Properties and Thermal Stabilities of Ga Substituted Nd-Fe-Co-B Mangets," IEEE Trans on Magenetics, Vol. Mag-23, No. 5, P. 2290 (Sep. 1987).
	Science	2: X. Shen Et Al., "The Effect of Molybdenum on the Magnetic Properties of the Nd-Fe-Co-B System," J. Appl. Phys., 61(8), P. 3433 (1987).
	Non-science	3: Liu Guozeng Et Al., "Effect of Mo Addition on the Magnetic Properties and Thermal Stability of Sintered (Prnd)-Fe-Co-Al-B Magnet," Ag-23, Paper distributed at Kyoto, Japan in May 1989.
	Science	4: IEEE Transactions of Magnetics, Vol. 25, No. 5, Sep. 1989, N.Y. US, Pp. 3770-3772; W. Rodewald & P. Schrey: "Structural and Magnetic Properties of Sintered Nd14.4Fe67.0-Xc011.8Moxb6.8 Magnets."
	Non-Science	5: Patent Abstracts of Japan, Vol. 12, No. 82 (C-481) (2929) Mar. 15, 1988, and Jp-A-62218543 (Seiko) Sep. 25, 1987.
	Science	6: Proc. 8Th Int. Workshop of Rare Earth Magnets 1985 Bg Pp. 541-552, A. Maocai Et Al. "Effects of Additive Elements of Magnetic Properties of Sintered Nd-B-Fe Magnet."
	Science	7: IEEE Transactions on Magnetics, Vol. 26, No. 5, Sep. 1990, N.Y. US, 1960-1962, S. Hirosawa Et Al.: "High Coercivity Nd-Fe-B Dysprosium."

In the highly science dependent fields such as biotechnology, the great majority of the non-patent references are, in fact, science references. However, in many other fields including some areas of electronics and many of the mechanical areas, most of the non-patent references are not, in fact, science references, and this differentiation is likely to be very important, since it seems that the linkage to science is the driving force behind many important areas of technology.

The fact that Science Linkage varies quite widely from technology to technology is shown by the following Table 6, which lists the average science linkage measure for the five years 1993-1997 for all Tech-Line companies, in each of the 30 technology areas.

Table 6

Science Linkage by Technology Area
All Tech-Line Companies, 1993-1997

Technology Area	Science Linkage (Science References/ Patent)
1 Agriculture	3.3
2 Oil and Gas	0.8
3 Power Generation and Distribution	0.7
4 Food and Tobacco	1.3
5 Textiles and Apparel	0.3
6 Wood and Paper	0.9
7 Chemicals	2.7
8 Pharmaceuticals	7.3
9 Biotechnology	14.4
10 Medical Equipment	1.1
11 Medical Electronics	2.2
12 Plastics, Polymers and Rubber	0.9
13 Glass, Clay and Cement	1.0
14 Primary Metals	0.9

Technology Area	Science Linkage (Science References/ Patent)
15 Fabricated Metals	0.7
16 Industrial Machinery and Tools	0.2
17 Industrial Process Equipment	0.7
18 Office Equipment and Cameras	0.4
19 Heating and Ventilation	0.2
20 Miscellaneous Machinery	0.1
21 Computers and Peripherals	1.0
22 Telecommunications	0.8
23 Semiconductors and Electronic	1.3
24 Measuring and Control Equipment	0.9
25 Electrical Appliances and Computer	0.4
26 Motor Vehicles and Parts	0.1
27 Aerospace and Parts	0.3
28 Other Transport	0.1
29 Miscellaneous Manufacturing	0.6
99 Other	0.9
All	1.5

Quite clearly there is a wide range of science linkage with biotechnology, at 14.4, close to double that of the next highest area, which is pharmaceuticals at 7.3.

Interestingly enough the third highest area is agriculture. This is almost certainly due to the biotechnology revolution, and the many advances in plant and animal genetics which are revolutionizing agricultural technology.

The fourth most science linked area is chemicals, and this is undoubtedly a combination of the fact that chemistry is very science linked and that some biologically active agents are classified into chemical rather than pharmaceutical classes.

The fifth is medical electronics.

The areas which are the least science linked are just those areas one would expect, miscellaneous machinery, motor vehicles and parts, and other transport, each which have less than one-tenth of a science reference per patent on average.

4.8. Science Strength (SS): indicates how much the company uses science in building its patent portfolio

> **Definition**: Number of Patents x Science Linkage – that is patent portfolio size inflated or deflated by extent of science linkage. This is a count of the total number of science links in the company patent portfolio.

Taken together, the combination of unified patent counts and technology quality indicators in Tech-Line® should go far toward providing analysts with new, detailed insight into company technological strengths, and the prospects for future company success.

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