New Concepts of Measuring Technological Change

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1. Introduction

It has becoming increasingly important with regard to the growing international competition in industry in the fields of industrial innovation as well as research to have available rational methods of determining the state of the art of technology on an international comparative basis.

Especially in the late 70s and early 80s the fear of an increasing technological gap between Western Europe and the USA on the one hand and Japan on the other revived. Parallel to the introduction of technological "anti-gap" policies of certain countries, projects and studies were embarked upon, or resumed, concerning the question of a quantitative measuring of technical standards and shortfalls. Relevant work came from Japan, North America and Western Europe.

The results of research and development (R&D) as well as the market success of technically new products cannot be measured in terms of the customary scientific understanding of "measuring" a variable. A way out of these difficulties is the use of **indicators**. Indicators must be viewed as "representatives" for the actual variables and are not identical to R&D or innovation output or success. Major effectiveness can therefore only be achieved through qualitative interpretation and the synopsis of the largest possible number of different kind of indicators for studying innovation dynamics and the technological change.

A systematic distinction can be made in line with the chronological sequence of innovation processes between expenditure, throughput and returns (or output) indicators.

FIGURE 1 (Input-Output Model for R&D and S&T indicators)

The figure maps the various types of science and technology (S&T) indicators being used in R&D and innovation studies in respect to six stages which are commonly differentiated for the sake of analytical clarity. In reality, of course, the boarderlines between these stages are unclear as the innovation process is not linear.

Most popular, since the figures are easily obtainable, is the description of innovation processes and the quantity of sectorial or national R&D by using the **input-indicators "R&D personnel"** and **"R&D expenditures"**. Often used in respect to international comparisons is the R&D intensity (gross R&D expenditure per gross domestic product).

FIGURE 2 (R&D intensity and foreign trade specialization in OECD countries 1985)

Figure 2 illustrates the R&D performance of OECD countries in 1985 in relation to their foreign trade specialization in R&D-intensive products 1986 (the RCA indicator will be explained later on). As expected, Japan, the USA, Sweden, and West Germany are in the lead, whereas in Portugal, Greece and Turkey R&D only plays a minor role. Nevertheless it has to be emphasized that the input-indicators only allow interpretation on the amount of manpower and capital invested in R&D, but cannot give any idea on the results of the invested capital, as not every million spent on research yields to corresponding results. Still, for the early detection of innovation processes, personnel and expenditure figures are a useful tool.

The results of **fundamental or basic research** cannot be described or analysed with economic figures, as neither figures can be obtained nor are the results of basic research patentable. For example, the direct success of space, defense and health research are not reflected in the national productivity accounts, as Griliches (1987) mentioned. For that case the only possible indicators used in recent studies are article counts in scientific journals and citation analysis.

Patents can be used for the measurement of development output, sometimes years ahead of the market introduction of a new product or process. In general, there are two faces of patent indicators: on the one hand the development success is documented; on the other, economic interest in certain future markets is indicated, especially by applying for a foreign patent. Therefore a good patent indicator for the measurement of development output is not automatically good for the measurement of potential innovations (market success). Depending on the problem, selective use of various indicators should be made. This is not only true for patents, but for the whole indicator system.

Foreign trade statistics are also included in the indicator system, for example to "measure" trade in R&D-intensive products. Despite the fact that there are different lists in use for defining R&D-intensive products, foreign trade figures can easily be found. The problem with this indicator is that

- the breakdown of the product groups is not as deep as to effectively analyse specific products
- trade figures only show the market results of innovations but not the creation of the innovation which is usually some years ahead of market introduction and product trading.

Also the causes of success or failure in the innovation process remain open. Posner (1961) mentioned that trade may be caused by the existence of some technical know-how in one country not available elsewhere, even though there may be no international differences in relative endowment of factors of production. This is why trade figures can supplement analysis on innovation dynamics, but should not be used as the methodical basis for such analysis because of the time lag inherent in trade figures.

A new concept in the field of so-called output indicators has been developed since the end of 1984 as part of the activities pursued by our institute. This method, called **technometrics**, permits systematic international comparison between specifications covering new products or processes already on the market or still in the laboratory stage.

The technometric indicators are established in a direct relation to the trade-figures as well as to patent and literature statistics. Thus it is possible to detect lines of research and innovation dynamics from the early stages and to convert them into an output-oriented description of the efficiency of science and technology activities. As reported before, the various S&T indicators should be used only selective, depending on the type of R&D to be studied.

One should also bear in mind that the indicators are the tool of analysis, not its results. Only combining indicator figures is not sufficient to assess the process of R&D and innovation. A proper interpretation of the findings based on expert opinion has to be given. As the technometric method draws on expert knowledge, this particular indicator may play a central role in an indicator network.

Therefore this paper concentrates on the technometrics approach as a new concept of measuring technological change.

2. Technometric Model

The term "technometrics" is ambigous: for one thing it was formed in analogy with "econometrics" and "bibliometrics" and means the "measurement of technology"; for another, it designates a specific metrication in the mathematical sense.

Technometrics aims at the determination of technical specifications of national products and processes and their international comparison. This means that the basis of this concept is not formed by whole branches or product groups, but by the different technical specifications of a single product or process.

Technometric indicators are aggregated numbers composed of several technical specifications of a technique or product, i.e. of various physical units. So the individual element of the indicator is the technical characteristic.

Characteristics define either a property of the product or the production process. If the same product or process is capable of serving different purposes simultaneously, for which the characteristics vary in their importance, functional characteristics or weighted priorities have to be introduced. Whereas process and product characteristics contain discrete physical entities and are hence objective, the functional characteristics, or priority lists, contain individual or collective considerations concerning the purposes of the product or the process and cannot, therefore, be objective.

One of the first tasks within the approach is the selection of product specifications. It is done in a kind of delphi-study by asking experts from industry and research (in Fraunhofer-Society we have the advantage of easy access to experts in different fields of technology) for important specifications of the products or processes to be investigated. The derived specification lists will then be discussed, adjusted and sometimes reduced and constitute the basis for data collection. For both reasons, building specification lists and collecting data, technometrics relies heavily on experts opinion.

Contrary to the use of economic figures and indicators, the approach cannot utilize data already computed in several statistics, but has to produce its own data. These data are derived from technical data sheets and exhibition literature, and above all as a result of a large number of personal discussions and interviews with experts in industrial development laboratories on the basis of a pre-prepared specification questionaire.

Technological disparities within an economy are excluded from the investigation, since different national firms competing with one another can all profit from the same R&D know-how, the same human capital and the same research infrastructure. Therefore the highest technical standards among domestic firms are in each case regarded as the national standard. For that reason the technologically leading company in the special field to be investigated has to be found. If it is included, and it usually is by asking experts or by asking companies for their strongest competitor, the representative character of the results is always ensured. By scanning the industrial landscape a lot of additional information on a microlevel can be derived. But they do not show up on a company basis in any written report. These information are only used for a better assessment of the calculated technometric figures since technometrics is based on a confidential relation between industry and our institute.

Approximately ten thousand technical specifications covering products and processes from West Germany, the United States, Japan, and other countries have been stored in the intitute's computer-aided technometric cadastre since 1986. Fields under investigation have been:

- Enzymes (immobilized biocatalysts)
- Genetically engineered medical drugs
- Solar cells and modules
- Laser beam sources
- Sensors
- Industrial robots
- Medical diagnostics (DNA-probe-diagnostics and monoclonal antibodies)
- Biological waste-water treatment.

The problem with single technological specifications is that they may be ranked, but cannot be cardinally aggregated to form indicators. A metric system, therefore, must be introduced. It consists of a transformation of the technical characteristics into a dimensionless intervall [0,1]. If countries are compared by technological specifications one by one (no aggregation), then the metric conserves the ordinal ranking of the original figures. In aggregate technometric indicators those items with considerable international disparities dominate the distinctions and indicator values.

FIGURE 3 (Technometric metric)

$$K^*(i,j,k) = \frac{K_{max}(i,j,k) - K_{min}(i,j,k_{min})}{K_{max}(i,j,k_{max}) - K_{min}(i,j,k_{min})}$$

K^* = Metric specification figure
i = product or process
j = technical specification
k = subset (company, group of institutions, country) index

K_{max} (i,j,k) is the maximum value of the specification j of product i under investigation in subset k

K_{min} (i,j,k_{min}) is the minimum value of the specification recorded in all investigated subsets

K_{max} (i,j,k_{max}) is the maximum value of the specification recorded for all subsets.

The formula can be explained as follows:
The technological standard of the country which has made the greatest progress in terms of the specifications under review defines the international maximum value $K^*=1$. The metric value for the other countries is determined by the spread of the standards within each country and between different countries.

If the scale of the specification is inverse, e.g. in fuel consumption of cars, that is, if the minimum value of K represents the highest technological level, an inverse formula holds.

The different K values of specifications which describe one product or process, are then aggregated into a product or process K-value; in case of equal important specifications just by calculating the average, in the other case by weighing each specification and calculating the weighted average. Different K-values of products and processes in one technological field can also be combined into one overall indicator, but with the result of hiding product or specification information.

In literature a number of similar approaches can be found, but only a very few of the proposed concepts aim at a quantitative comparison of purely technological specifications at an international level.

Introducing the three categories:
- contemporary analysis
- technological analysis and
- international comparable analysis,

out of the few publications which fulfil all three conditions, two are from Manchester University.

Gibbons, Coombs, Saviotti and Stubbs (1982) presented pure technological data on tractors in the UK market. UK firms, West German, Italian and COMECON companies are compared between 1957 and 1977. The same is done for tractors present on the Dutch market.

Saviotti (1985) additionally supplies evidence on motor car technology on the UK market from 1955 to 1983. Priorities or weighting of the technical specifications are determinded either by factor analysis or by a hedonic price method.

Thus, the technometric method seems to fill an analytical gap in the framework of S&T indicators.

Compared to all S&T indicators in use (as shown in FIGURE 1), the technometric method is less well-established. Most of the authors in innovation research regard the intermingling of technical information and data with economic information as useless. But the distinction between specification data and economics does not mean that international trade figures and suchlike can be neglected. On the contrary, it is suggested and also done in our studies, to supplement technical indicators by exactly or fairly exactly corresponding trade figures without mixing the data. Keeping economic and technometric indicators apart from each other makes it possible to find "additional clues". Experts may be confronted with (contradictory) technological and econometric figures of the same technology and may find explanations only through these "eye-opening" indicators. In other words, new technologies are hard to define and analyse without explicit incorporation of the knowledge of the science and engineering communities.

3. Example - Monoclonal Antibodies

Antibodies are produced by the B-cells of the immune system. Formerly they were produced by immunizing test animals with antigens. The extracted antisera contained different antibodies, which all could be directed against the same antigen, but were different in their characteristics (polyclonal antibodies).

In 1975, Milstein and Koehler published their pioneering studies on the in-vitro synthesis of monoclonal antibodies for which they were awarded the nobel prize in medicine in 1984.

These monoclonal antibodies are used for immunoassays. The most important applications in immuno diagnostics can be found in the fields of thyroid diagnostics, sexual hormons, tumormarkers, infectional diseases and the control of blood banks, for example on HTLV-1, Syphillis, Hepatitis B, HIV.

Immuno diagnostics on the basis of monoclonal antibodies play an important role in modern biotechnology. The annual world market for immuno diagnostics and immuno-asssay-kits is estimated at more than 5 billion US $, out of which 40% are generated in the USA, 10% in Japan and approximately 10% in Western Europe.

Immuno diagnostics on the basis of monoclonal antibodies had been a major subject in a recently completed technometrics project, financed by the Ministry of Research and Technology (BMFT) in Bonn. Project manager was Dr. Reiss of the department of

Technological Change in FhG-ISI. Some of his findings will be used for a short demonstration of the technometric approach.

FIGURE 4 (Technometric profile of selected immunoassays in thyroid diagnostics in 1989)

Figure 4 shows the technometric profile of four different tests in thyroid diagnostics for Germany (DE), the US and Japan as of 1989. The tests are:

T3: Triiodothyronine

T4: Thyroxin

FT4: Free Thyroxin

TSH: Thyroid-stimulating hormone

Each of the tests is characterised by 5 resp. 6 different specifications:

- Sensitivity
- Intra-assay precision
- Inter-assay precision
- Measurement range
- Test duration
- Handling

In most cases the US reached an indicator value of 1 which means that the "best" product specification can be found among US manufacturers. In some cases also Germany and Japan reached highest specifications. A "0" does not mean worst technology, but well introduced on the market with no heights or downs. It marks the lowest (in inverse cases the highest) specification value out of the (representative) sample.

At this point it has to be repeated that the technometric indicator should not be interpretated in a way of economic competitiveness. A highest specification value only indicates that in the specific field of technology a country offers the best technical performance. It may not mean that the product is already successfully marketed and that it is the leading product in its field. It may be excellent but not worth its price or, there is not yet an application sophisticated enough.

As a next step the specification values can be combined in an aggregated technometric indicator for each test. This has been done in figure 5.

FIGURE 5 (Aggregated technometric indicator of selected immunoassays as of 1989)

For the 4 tests in our example West Germany's international position does not rank highest, but shows a second rank in TSH. In the other tests either the US or Japan are in the lead. For FT4 there were no data from Japan obtainable.

In a third step also the combination of the technometric figures of the different tests in one aggregate technometric indicator for the whole technological field is possible. At this point we hide a lot of the specific information the approach is able to generate, but political and governmental decision makers always require broad figures which give an impression of the overall technological position of a country.

FIGURE 6 (Technometric indicators for monoclonal antibodies as of 1989)

For the whole antibody diagnostica investigated the technometric indicator shows the leading technological position of the US, followed by West Germany and Japan. A detailed interpretation, which can be found in the final project report, shows that the technical standard of more traditional products between Germany, the USA and Japan is fairly equal. But great differences can be observed in new developments, especially in the field of genetic engineering, where the US rank first. Japan is quite strong in test automation, whereas West Germany shows good performance in the tests already introduced on the market.

As mentioned before, the whole approach does not consist of calculating technometric indicators only, but also includes economic indicators, especially trade figures and patent statistics.

The question arises if there is indeed the need to conduct costly and time consuming studies for technical monitoring, or if there are other, more established indicators which can be used for the same purpose.

In other studies analysing the international competitiveness of West Germany, we use, for example, data from the international and national trade statistics.

Beside the problem that the trade classification is mostly somewhat broader than the specific technologies to be investigated, the most important objection is that it is only possible to analyse products (not so much processes) which are already on the market. For monitoring new technologies still in the laboratory or testing stage, trade figures are an inefficient tool.

For illustrating in the project the international position of the FRG on diagnostics, data from the German trade statistics were used. The breakdown of goods is according to the "Warenverzeichnis für die Außenhandelsstatistik 1987".
The problem with immunoassays on the basis of monoclonal antibodies is that they are mingled in two groups:

- Group No. 3002 110: "Sera of immunized animals or humans"
- Group No. 3819 620: "Laboratory reactive means without those to analyse blood groups or blood factors".

To gain a better insight into the figures, special coefficients were calculated. These are:
1. The Standard Price (price per weight) [V/kg]
2. The export/import ratio [E/I]
3. The supply share of different countries to the German market [Supp.Sh.]
4. The Revealed Comparative Advantage [RCA].

The RCA indicates the extent to which export surpluses in the product groups under consideration deviate altogether from the average for manufactured industrial products. In the logarithmic version positive values indicate an above-average position and comparative advantages in the product group. The formula is shown in the following figure.

FIGURE 7 (RCA formula)

$$RCA_{ij} = 100 \{ \ln (\frac{E_{ij}}{I_{ij}} : \frac{\Sigma_j E_{ij}}{\Sigma_j I_{ij}}) \}$$

E = Exports　　i = Country
I = Imports　　j = Product

The RCA analyses the bilateral trade relations. Not considering the overall world trade has its reason in the fact that the advanced economies do not always supply products of the same technological content to the various regions of the world, for example appropriate technologies to the developing countries. Therefore, to avoid inhomogenities, the bilateral trade relations between the most advanced economies are preferable. But the analysis is then biased towards "one country under review".

FIGURE 8 (Foreign trade indicator RCA 1987)

In our example the focus will be on the sera. The only country under review is the FRG. The figures show that the position of West Germany is quite weak. In 1987 the RCA for West Germany's trade with the EEC countries was -39, with France and Great Britain much less. Only in the trade relations with Japan West Germany gained comparative advantages - at a Japanese supply share of 0.3%.

TABLE 1 (Other foreign trade indicators 1987)

No RCA-value could be calculated for the US, as there were no German exports of sera to the US in 1987.

Using these results alone it will not be possible to derive a clear picture of Germany's international technological position in immuno diagnostics. Not only are trade figures too late, but also is the breakdown much too unspecific to supply detailed information on this technological field. But in other cases, either when the technology is clearly represented in trade statistics or when the search-strategy is open and the analysis does not start from one very specific technology, then trade figures are indeed able to produce an overview over the international competitiveness in, say, leading-edge technologies, respectively products comprising such technologies which are already on the market. But the task was, frankly speaking, to present some impressions on the highlights of the technometric approach on a very disaggregated level.

4. Summary

The technometric concept is a technic-oriented approach which aims at using technical specifications for contemporary international comparisons of technological positions. It provides important information which cannot be read directly from market results alone. This paper concentrated on technometrics, but there are also other methods to be used, like bibliometrics, patent statistics and trade figures.

It should be clear that the technometric approach, beside its major advantages, is also subject of some restrictions. These include:
- the need to produce own data which is time-consuming and cost-intensive;
- the fact that no open search-strategy will be possible so that only technical segments and not the whole range of R&D activities can be analysed;
- the fact that the technometric examination contains no standardisation for the size of a country, its R&D budget or its R&D personnel;
- up till now only experiences in highly developed countries with a wide range of

companies have been made. It has still to be proved if technometrics is also an instrument for evaluating the technical performance of smaller countries or newly industrialising countries with only a limited range of nationally technical leading companies which would perhaps not supply sufficient information. A joint project on this topic has just recently started in cooperation with the Neaman Institute of the Technion in Israel.

Because of these restrictions and unsolved questions it is suggested to strengthen the network of output indicators by creating correspondences between the classification systems. In the example presented in this paper the breakdown of the trade statistics was much too broad to cope with immuno diagnostics. When introducing patent analysis, concordance problems of combining the Standard International Trade Classification with the International Patent Classification and may be also with the Standard Industrial Classification will arise.

If various comparative indicators are combined and the concordance problem will be solved, then an evaluative type of assessment seems to be possible. For evaluation puposes integrated networks of data have to be constructed, causal or statistical relationships have to be verified. But it should not be assumed that the various indicator relationships always result in highly significant positive correlations. The input-output-model (Fig. 1) suggests that the indicators are not equally valid for a study of the various R&D and innovation phases and the various R&D-performing groups of institutions. As results from studies made in our institute show, that in many cases, however, with allowance for time lags between the indicators, a highly significant positive correlation may be found. For example, in leading-edge technologies patent indicators are approximately two to three years "earlier" than marketable results, i.e. trade indicators (Schmoch 1988, 21). Still, most sets of indicators are far from being complete. Therefore, peer evaluation and personal expertise are an essential addition to science and technology indicators to bridge the inconsistencies and the lack of adaptation within the indicator system. As the technometric approach is largely based on expert interviews, the technometric indicator plays a central role in any science and technology indicator network and in the measurement of technological change.

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