The S. Neaman Institute for
Advanced Studies in Science & Technology
Technion-Israel Institute of
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Fraunhofer Institute for
Systems & Innovation Research
of Karlsruhe, Germany

A TECHNOMETRIC ANALYSIS OF COMPARATIVE ADVANTAGE IN SELECTED HIGH-TECHNOLOGY INDUSTRIES IN ISRAEL

Vol. II: Appendix

Copies of Scientific Papers
prepared during 4 years of research 1990-1993
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The Relation Between Technological Excellence and Export Sales

A Data Envelopment Model and Comparison of Israel to EC Countries

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Submitted to *Research Evaluation*

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Abstract

This study addresses the question: how efficiently do countries translate scientific and technological excellence -- as expressed in various measures such as patent and bibliometric indices-- into export comparative advantage? The use of science and technology in generating exports is first modelled as a two-stage process. A variant of linear programming known as data envelopment analysis [DEA] is then employed to estimate empirically the relative efficiency of Israel and the European Community countries in converting scientific and technological excellence into exports of R&D-intensive products. It is found that Israel, together with Germany, are more efficient than other European nations in the production of scientific and technological outputs, but Israel is far less efficient than EC countries in utilizing its science and technology base of excellence to create high-technology exports. Among the major R&D spenders in Europe, France, Germany and Denmark together form the efficiency frontier in generating comparative advantage from these inputs.

.1. Introduction

World markets for high value-added products are becoming more and more competitive. In an effort to gain competitive advantage in these markets, many countries invest costly resources, from both private and public sources, in an effort to achieve scientific and technological excellence.

Policymakers face two important questions: a) how efficiently are the resources invested in science and technology being used, in terms of their "output" of scientific papers and patents, for example, and in their output of high-quality products and processes? And b) How efficiently is the scientific and technological excellence embodied in products and processes being translated into export sales and market share?

New indicators have recently been developed for measuring quantitatively each aspect of the innovation cycle, beginning with the production of knowledge, through basic and applied research, industrial development, and finally innovation [Grupp, 1991]. These indicators can be regarded as "inputs" and lend themselves to the construction of optimizing economic models in which the efficiency of inputs in generating "outputs" can be empirically estimated. Such models could be a useful guide to policymakers, by showing which inputs are efficiently used and which are not.

Linear and non-linear programming immediately suggest themselves as appropriate tools. However, many measures of scientific and technological excellence are non-monetary in nature -- they do not represent labour-hours or capital dollars, but rather comparative metrics. This makes conventional programming models unusable.

A version of linear programming exists, however, that was explicitly built to measure the efficiency of "decision-making units" (which could be countries, or industries, or individual firms), and that does allow qualitative inputs. This approach, devised by Charnes and Cooper in 1978, is known as Data Envelopment Analysis. Essentially, it examines which "DMU"s (decision-making units) are on their production possibilities frontier, or isoquant and which are not. [Charnes, Cooper & Rhodes, 1978 1979, 1981; Charnes, Cooper & Clarke, 1988].

In this paper, we propose to construct a two-stage model of the relation between technological excellence and export sales, in which resources generate scientific and technological "outputs" (such as patents, citations and publications), and then these "outputs" in turn are used to generate comparative advantage in global markets for high-technology products. The model exploits the existence of a correlated network of indicators that provide quantitative measures of innovation dynamics from the earliest to the last stage of the innovation process [Grupp 1991]. We then illustrate this model with a DEA-based empirical study of this two-stage efficiency, for R&D-intensive products in European Community countries and in Israel: those with R&D expenditures averaging above 3.5 percent of sales.

2. A Model of Technology-based Exports

Public goods tend to have one or both of two economic characteristics: non-rivalry in supply -- consumption of them by one person does not in general leave less of them for someone else -- and non-excludability -- it is inefficient (because of zero or low marginal costs) and often unfeasible to exclude persons from consuming them. Examples are law and order, roads, public health and defense or national security [Bator, 1958].

In many ways, the link between knowledge, research, industrial development and innovation resembles the production of public goods. Knowledge itself is a kind of public good. In particular, when proprietary knowledge is patented, patent law forces the inventor to disclose the fruits of his or her research to the public (though the use of such knowledge for profit-making purposes is limited).

Rather than consist of a direct link between one set of inputs and another set of final outputs (exports), there is a set of chained functions linking basic inputs to intermediate inputs, to final inputs, and ultimately to final outputs [Kline 1991]. Applied research may have among its inputs, basic research; industrial development, in turn, has as one of its inputs, applied research. At each stage, outputs from the previous stage become inputs of the current one.[1]

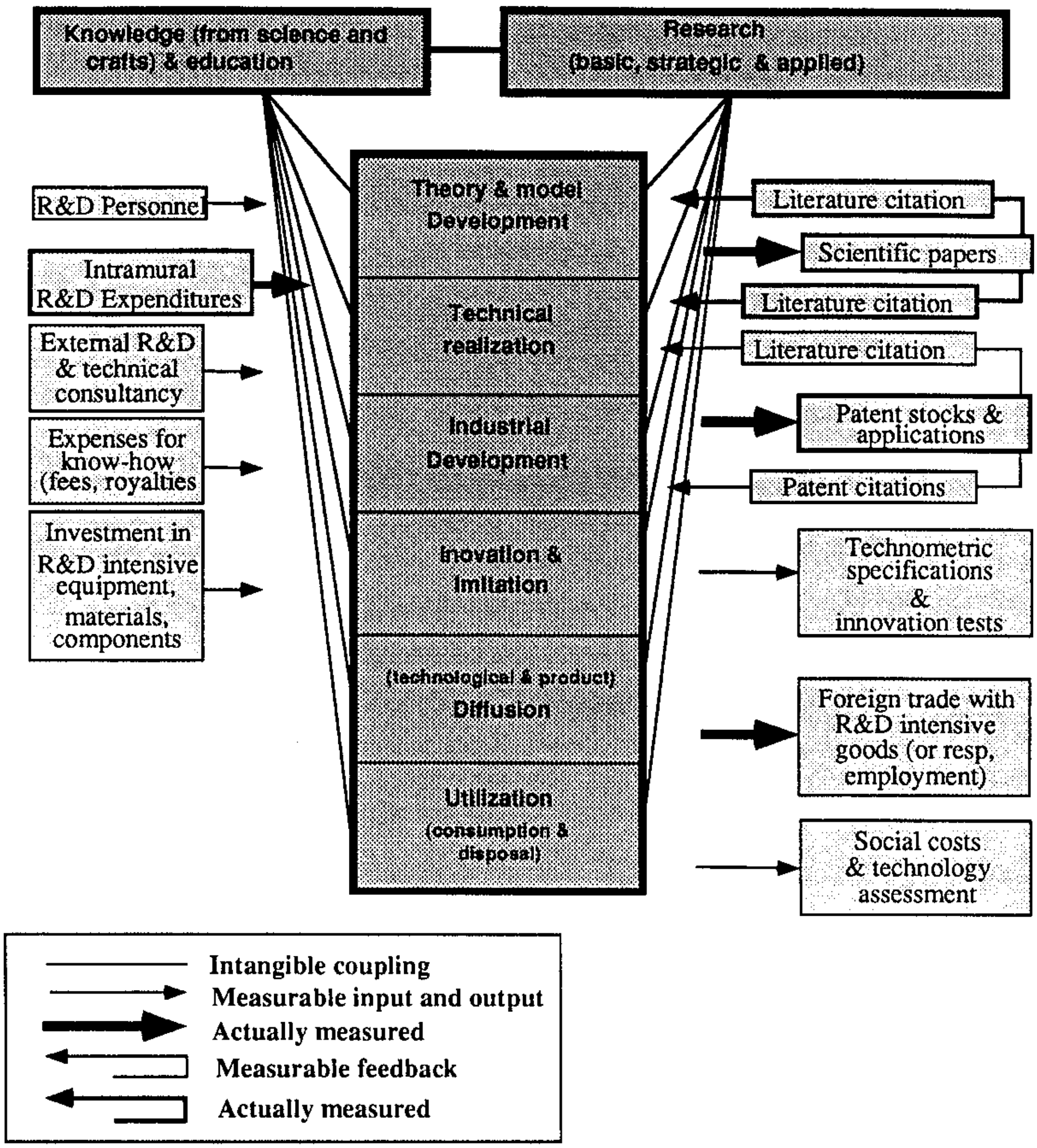
Grupp, Albrecht and Koschatzky [1992] have portrayed the knowledge-innovation cycle as shown in Table 1, and developed a series of useful quantitative indicators to measure performance at each stage, such as: 1. Theory and model development 2. Technical realization 3. Industrial development 4. Innovation, and 5. Production and export of products (diffusion)[2].

In a series of research papers, Grupp, Koschatzky and Hohmeyer. [Grupp, 1991; Koschatzky, 1991; Grupp and Hohmeyer, 1986, 1988] have shown how such indicators can be used to measure and compare performance, across countries, for individual products, product groups, sub-industries or even entire industries.

1 Similar chained functions exist in other areas of public goods, for example, labor hours and patrol cars can produce police patrols, which in turn serve as an input for the output of public safety. This analysis is similar to that in Bradford, Maital and Oates [1969], who posit a two-stage input-output function for public goods: a) stage one, where resource inputs produce "intermediate" public good inputs, e.g. labor hours and patrol cars, as inputs, produce police patrols; and b) stage two, where intermediate public good inputs, like police patrols, produce the public good itself, "public safety" or "law and order".

2 Generally, because of difficulties in quantifying the public good, only stage-one efficiency is measured and studied. They argue that because many public goods are highly labor-intensive, yet have not enjoyed rising productivity owing to new technologies, their units costs have risen rapidly. Some of these same arguments may also apply to Research and Development, which has experienced rapidly rising unit costs and is in many cases highly intensive in skilled-labor.

Table 1. Stages of Research, Development and Innovation, and corresponding Science and Technology indicators



The existence of such quantitative indicators makes possible a further advance in the study of industrial policy -- the construction of quantitative models to measure the efficiency of R&D resource use aimed at export markets. Such studies are required, because the public-good nature of innovation dynamics does not validate the assumption that competitive markets guarantee full or near-full efficiency. As Bator [1958] showed, provision of public goods is subject to market failure. Lack of competitive markets implies that allocative efficiency through the price mechanism cannot be assumed. Other systems rather than self-regulation and market forces must be employed to attain efficiency. The question then arises, how successful are such systems, in various countries, in attaining efficiency of R&D resource use? To answer this question, we begin by constructing a two-stage model of innovation.

A Two-Stage Model of Innovation:

Let X be "R&D resources", measured perhaps by the aggregate expenditure on R&D. Let Y be "R&D output", measured perhaps by the number of patents, publications and citations. Finally, let Z be a measure of comparative advantage in exports of high-technology products.

This suggests a two-stage model:

* **Stage 1: Research and Development efficiency:**

[1] $Y = F(X)$

where Y is a vector of variables that measure R&D success, and X is a vector of variables that measure resources devoted to R&D. The function F(.) measures the efficiency in converting resources into excellence in science and technology -- efficiency we might term **"Y"-efficiency.**

* **Stage 2: Export efficiency:**

[2] $Z = G(Y)$,

where Z is a vector of measures of comparative advantage in high-tech exports. The function G(.) measures the efficiency in translating scientific and technological excellence into exports: **"Z" efficiency.**

Presumably, policymakers charged with implementing industrial policy and with wisely investing resources in basic scientific capability, with the objective of competing in global markets, need to know the level of both "Y" and "Z" efficiency. It has long been claimed that the United States' overall lead in basic science -- as exemplified by the pre-eminence of such Federally-funded laboratories as the National Institutes of Health -- is not efficiently translated into new products. This implies high "Y" efficiency, but because of failings in marketing (and perhaps insulation of Federal labs from industrial companies and consumers), the "Z" efficiency is very low.

This is parallel, for example, to high efficiency in converting police cars and labor hours into police patrols, but low efficiency in transforming police patrols into reductions in crime and high personal security [Bradford, Malt and Oates, 1969]. {Lately, police have discovered, in New York City, Washington D.C. and elsewhere, that the "old" technology of foot patrols has far greater "Z" efficiency in reducing crime}.

In the remainder of this paper, we model both "Z" and "Y"-efficiency through data envelopment methods, and apply it illustratively to a comparison of Israel and the major EC countries.

A Data Envelopment Model:

Let "X" be a vector of inputs measuring R&D resources, and "Y" be a vector of outputs (say, technological excellence, in qualitative units), for a set of decision-making units (in our case, countries [3]). Efficiency is obtained by obtaining the maximum value of output per unit of input. Hence the problem can be framed as:

[3]
$$\text{Max } \theta_o = \sum_{r=1}^{s} u_r y_{ro} / \sum_{i=1}^{m} v_i x_{io}$$

$$\text{s.t.} \sum_{r=1}^{s} u_r y_{ro} / \sum_{i=1}^{m} v_i x_{ij} \leq 1$$

and

$$u_r,\ v_i \geq 1$$

where:

y = outputs, x = inputs

y_{rj} = r-th output of DMU "j", x_{ij} = ith input of DMU "j"

u = weights (i.e. shadow prices) of outputs,

v = weights (i.e. shadow prices) of inputs,

u_r = coefficient of rth ouput that maximize θ_o ;

v_i = coefficients of ith input that maximize θ_o.

j = 1.....n index of Decision-Making Units

i = 1...m index of inputs

r = 1...s index of outputs

This model seeks to maximize θ_o, the ratio of weighted outputs to weighted inputs, for an arbitrary decision-making unit (DMU) "0", subject to the constraint that the same ratio for the other decision-making units should not exceed unity (which is maximal efficiency).

By solving this programming problem (n+1) times, each time with a different DMU serving as the referent "0" unit, the efficient hyperplane can be identified and measured, and each

3 We leave open the question whether "invisible hands" exist that make decisions at the national level of aggregation. In most EC countries and Israel, the respective national governments claim to prosecute a consistent research, technology and industrial policy. In other countries, like the U.S., this may not be the case (e.g., compare Roessner, 1985).

DMU's distance from it can be measured in various ways.

The input and output weights chosen are those that minimize the distance between each DMU and the efficient hyperplane. They have the economic interpretation of "shadow prices".

The above equations are non-linear and therefore pose difficult computational problems. However, Charnes, Rhodes and Cooper [1979] proved that [3] can be easily converted to (n+1) ordinary linear fractional programming problems. This ingenious transformation was the genesis of Data Envelopment Analysis (DEA).

DEA problems may be formulated in output-maximizing or input-minimizing variants, and each DEA problem, however formulated, has a "dual". DEA provides a set of scalar measures of inefficiency. These measures come in pairs -- one set for input-oriented (i.e. input minimizing) measures, and one set for output-oriented (i.e. output maximizing) measures.

The two main scalar measures of inefficiency, for input-minimizing models, are:

a) **Theta**: the proportional reduction in inputs possible in order to obtain the projected input values.

b) **Iota**: an input efficiency score, interpreted as the proximity of the data point to the facet of the piecewise linear envelopment surface, and equal to the total weighted distance between observed and projected points, standardized by inputs.

c) **Sigma**: summed weighted value of the output slack (difference between actual and efficient output), weighted by shadow prices, and excess input values, also weighted by the corresponding shadow prices.

Theta measures only that portion of economic inefficiency that could be eliminated by proportional reduction of inputs. It is the proximity of the data point $\{Y_1, X_1\}$ to the facet of the piecewise linear envelopment surface. Even after reducing inputs by "Theta", however, some inputs may still exhibit slack. Iota measures the total amount of inefficiency, not just the proportional distance along a radius vector. Sigma measures the weighted Euclidean distance between the actual point (Yi Xi) and efficient point (Y^*_i X^*_i).

A property of DEA that makes it particularly suitable for estimating and partitioning inefficiency is that the inputs used in DEA analysis "may also assume a variety of forms which admit of only ordinal measurements, e.g. psychological tests, arithmetic scores, psychomotor skills." [Charnes, Cooper and Rhodes, 1979, p. 429]. In our case, this allows the use of variables that relate to factors like patent and citation performance, not solely to conventional inputs like labor hours or machine hours. The use of such variables, in turn, may permit the partitioning of inefficiency among its proximate causes, including those related to the performance of management Leibenstein and Maital, 1992; Sengupta and Sfeir, 1988; Sherman, 1984]. DEA places no restrictions on the functional form of the production relationships and makes no *a priori* distinction between the relative importance of any two outputs or of any two inputs. While DEA is non-parametric, it is *not* free of the necessity for further modelling and theory. For example, assumptions about the underlying relationships will determine whether the efficient frontier is forced through the origin (constant returns to scale) or allowed *not* to pass through the origin (variable returns to scale).

While DEA is relatively insensitive to model specification (e.g. "input orientation" or "output orientation"), it can be extremely sensitive to variable selection, and data errors (Ahn and Seiford, 1990). Moreover, given enough inputs, all (or most) of the DMU's are rated efficient. This is a direct result of the dimensionality of the input/output space (m + s) relative to n, the number of DMU's (observations).

3. Description of Data

Table 1 in the previous section provides an overview of the various stages of Research, Development and Innovation, along with the input and output indicators and variables that serve to quantify and characerize each stage. This cognitive model (Grupp, Albrecht and Koschatzky, 1992) is cerainly not sufficiently complex to fully cope with the cyclical characteristics of the scientific and technological innovation process, but, without entering into an extended discussion of the complexities of modelling the interrelated science and innovation processes, the Table 1 model may serve to visualize available opportunities for quantifying each stage. At the same time, we note that in measuring the dynamics of science-based innovation, one faces the problem that clear-cut measurement procedures are often difficult to devise and to validate. The "indicators" approach -- construction of input and output variables -- is capable of grasping only a part of the complex innovation-oriented processes and their related feedback mechanisms [Grupp et al., 1992, p. 11].

In this paper, one input variable and four output variables are used for quantifying Stage 1 "R&D" efficiency ("Y" efficiency) is used, and one output variable and four input variables, for Stage 2 "Export" efficiency ("Z" efficiency). The four output variables from Stage 1 become the four input variables of Stage 2.

X variable: The single input variable for Stage 1 efficiency is taken as gross R&D spending (GERD) expressed as a percentage of GDP, as defined and compiled by the OECD [OECD, 1991]. These data are comparable to one another and in some cases are adjusted by the OECD staff. The GERD data, when expressed as a percentage of GDP, bypass the difficult problem of adequate conversion of national currencies. For Israel, national sources (the Central Bureau of Statistics) replace the OECD data; thus, in the case of Israel alone, there may not be full consistency with the R&D data of the remaining countries. Annual averages are taken for the period 1981 - 1985 to overcome annual fluctuations and some missing data. This R&D series includes only the commitment of financial resources to innovation that funds formalized R&D activities, despite the fact that there are many other, complementary ways to engage in research and development activities, such as design improvement, learning by doing, and learning by using (see the review of Dosi [1988]). However, at present, no better quantification of innovation resources exists.

Y variables: These are "throughput" variables, that serve as outputs in Stage 1 and inputs in Stage 2, and are a subset of existing, available bibliometric and patent indicators. They consist of indicators of: Publications, Citations, Patents (single-year) and Cumulative Patents.

a) Scientific publications: Bibliometric indicators are a common measure of research output [van Raan, 1988]. The number of scientific publications is one of those indicators, though admittedly a rather crude one. Only publications in the natural sciences and engineering during 1981-85 are counted in our PUB variable. Biomedical research and other parts of the life sciences are very important for human welfare and health, however this type of research in the 1980's was far less likely to have an impact on technology and on exports. Thus we have excluded publications and citations in the life sciences (though medical technology has been included). Publications data are derived from the Science Citation Index for the EC countries and Israel [Schubert et al., 1989]. We note that Belgium and Luxemburg, which form an economic and monetary union, are treated as a single country, in bibliometric, patent and foreign trade statistics. Publication counts are normalized by dividing by Gross Domestic Product (GDP).

b) Citations: We do not consider the citations indicator as a measure of scientific quality, but rather as a proxy for the degree that scientific publications are exploited. If the publications of a country are frequently cited in the scientific literature, this indicates that the scientific output of this country is recognized internationally. The issue then arises, does the country itself exploit the knowledge it has created, or do scientists, engineers and firms in general in other countries? In some ways, citations are a more important through-put variable than publications, because they serve to measure the utility or impact of research, rather than its gross quantity. Again, as with publications, the natural sciences and engineering are covered, but biomedicine and life sciences are excluded (frequency of citation of papers publishing during 1981-85). The source of citations data is, as for publications, the Science Citation Index, which covers research articles, notes, lettes, meeting abstracts, book reviews, and so on. In our indicator, only articles, reviews, notes and letters were counted as citable items.

c) Patents: Private or corporate research generally produces patents, rather than academic publications [Grupp, 1990]. Patent statistics are an accepted output indicator for strategic and applied research and industrial development.[4] However, the question arises, do publications and citations overlap, in validity, with patent data? It is true that some basic

4 Why not use a direct measure of technical performance level, such as the "technometric" indicator [Grupp, 1991] -- a metric that quantifies the excellence of a product's specifications on a [0,1] scale -- rather than indirect indicators such as patents? The answer is that technometric data are difficult to obtain and costly to compile, and are available only for a few selected countries and products. No comprehensive technometric data exist at present for all EC countries and Israel. In addition, there is a problem of aggregation -- summing technometric indicators for individual products. Technometric analysis is useful in selected areas of technology, but aggregate data are often not available. Patent indicators are therefore used instead. For a discussion of the use of patent indicators to reflect the level of technology, see Grupp [1991].

research institutions, such as universities, take out patents, and some industrial laboratories publish scientific papers. However, it has been found empirically that inventors tend not to cite their own patents in their scientific publications. Thus, the full picture of their work is revealed only when the two interrelated indicators are used together -- patents and publications [Grupp, 1990, p. 448]. As patent applications are legal documents that are valid only in one country, many foreign "duplications" of domestic priority patent applications are generated. The selection of patent data from only one patent office, therefore, does not always yield an indicator that is representative of the world output of inventions. Our study seeks to compare EC countries with Israel. Selection of the regional European Patent Office (EPO) is inappropriate, since it would unfairly bias the data in favor of EC countries and against Israel. Therefore, for purposes of this paper, United States Patent and Trademark Office (USPTO) data are used. They represent the patented invention output in the world's largest market for technology, the United States, which is foreign both to EC countries and to Israel and hence has less bias than the EPO. Since patent output tends to lag behind spending on industrial research and development, we selected annual averages of granted patents for the invention years 1984 through 1986 (normalized by GDP). This patent indicator, PAT, measures the increment to the stock of patented inventions from earlier years, and thus reflects the production of recent technology.

The legal validity of a U.S. patent is for 17 years following its granting. Thus, it is important to consider the stock of protected technology, or patent potential (PATPOT) and not just its increment as measured by PAT. We therefore compiled the number of granted patents for the period 1977 through 1986 (divided by GDP), PATPOT. We did not utilize a full 17-year period, because of the obsolescence of technology due to quick product cycles. Data sources are the same as for PAT. All patent data were supplied by the USPTO on diskettes (version as of Dec. 31, 1990).

We exclude those patents that do not reflect technology important for R&D-intensive (high-tech) exports (see description of Z variable). A patent-to-trade concordance is providedby Grupp and Legler [1992]. Patents for the high-tech products we examine in this paper cover somewhat more than 50 per cent of all patents, with some variation across individual countries.

Z Variable: The dynamic nature of "high technology" presents problems in defining appropriate indicators of high-tech export sales. Many authors associate high technology with R&D intensity. In this paper, we utilize a list of R&D-intensive products as defined by the Standard Industrial Trade Classification (SITC revision III) [Grupp and Legler, 1992]. Products with R&D intensities above 3.5 per cent of gross sales are included. For other purposes, we have distinguished between High-Level products (those with R&D spending of between 3.5 and 8.5 per cent of sales) and Leading-Edge products (those with R&D spending of 8.5 per cent of sales or more). For a list of high-tech products so defined, see the Appendix.

We chose to measure the final Z-variable not as the absolute level of high-tech exports , as defined by the SITC categories, but rather as the relation between exports and imports, which we term "Revealed Comparative Advantage" (RCA). (See definition in the Legend of Table 2). The RCA indicator answers two questions simultaneously:
- Do the domestic suppliers of a product have a solid footing in the marketplace compared with foreign competitors and suppliers of other domestic sectors?
- Do they succeed in substituting domestic production for imports, compared with suppliers in other sectors?

The comparative-advantage concept dates back as far as 1817, when David Ricardo first enunciated the principle of comparative advantage in his famous wine and cloth example. The West German Federal Ministry for Research and Technology -- among other actors in technology policy -- adopted it years ago to regularly report on West German technological competitiveness [Legler, 1987; Grupp and Legler, 1992]. Recently it was revitalized in the United States by Porter [1991]. Another, recent justification of this concept is given by Dosi et al. [1990]. The data are drawn from the OECD's exports and imports statistics ("trade by commodities"), and relate to the year 1988. We chose this year, because the trade effects arising from scientific and technological variables tend to lag by two to four years, in the area of high technology [Grupp, 1991]. For Israel, trade data for 1987 were used, as later data (classified by the Standard International Trade Classification III) were not yet available.

See Table 2 for the data and precise definitions of the variables.

Table 2. **Data** *

Countries	PAT	PUB	CIT	PATPOT	GERD	RCA**
GERMANY (DEU)	16.07	82.59	264.42	58.25	2.54	128.76
FRANCE (FRA)	6.74	74.89	212.14	24.01	2.16	97.90
U.K. (GBR)	7.21	108.4	340.3	26.63	2.34	109.07
NETHERL. (NDL)	9.37	82.57	278.21	30.99	2.01	88.78
BELG/LUX (BEL)	4.25	63.1	157.6	15.2	1.53	109.47
DENMARK (DNK)	4.58	66.81	279.17	15.21	1.18	83.45
ITALY (ITA)	2.85	35.71	87.12	9.42	0.95	76.54
ISRAEL (ISR)	12.88	325.98	967.19	35.59	2.9	69.31
SPAIN (ESP)	0.61	31.86	49.44	1.62	0.45	74.20
GREECE (GRC)	0.19	47.28	62.02	0.59	0.27	12.43
PORTUGAL (PRT)	0.04	12.53	18.59	0.14	0.38	26.94
IRELAND (IRL)	3.4	49.15	111.33	8.39	0.75	111.84

* LEGEND FOR TABLE 2 (see next page)

PAT: number of patents invented between 1984 and 1986 matched to HL (high-level) and LE (leading edge) products, U.S. Patent and Trade Office, as a ratio to GDP.

PUB: number of publications in both scientific and engineering publications, 1981-85 (not including Life Science publications), as a fraction of GDP.

CIT: number of citations to scientific and engineering papers published in 1981-85 periodicals, as a fraction of GDP.

PATPOT: cumulative number of patents, USPTO, invented during1977-86, for both HL and LE goods, as a fraction of GDP.

GERD: Gross R&D Spending, annual average for 1981-85; converted to U.S. dollars using Purchasing Power Parity index of O.E.C.D.; $ billion.
Source: O.E.C.D., *Scientific Indicators.* For Israel: R&D data are taken from the Central Statistical Bureau's Statistical Yearbook. Expressed as a per cent of GDP. Gross Domestic Product: average for 1981-85.

RCA : revealed comparative advantage, for HL and LE goods, for the year 1988, defined as:

$$RCA = 100 \{ (ES^2 - 1)/(ES^2 + 1) \}, \qquad -100 \leq RCA \leq +100$$

where Export Share $ES = \dfrac{EX / IM}{EXTOT / IMTOT}$

EX is a country's total Exports of HL and LE products, IM is that country's Imports of HL and LE manufactured products, EXTOT is the country's total exports of manufactures, and IMTOT is the country's total imports of manufactures.

Country acronyms: are according to the three-digit ISO convention.

** In later analysis, the number of countries was narrowed to eight, with Spain, Portugal, Greece and Ireland eliminated.

In order to make the RCA variable non-negative -- a necessary condition for conducting linear programming analysis -- we added a constant (+ 100) to each country's RCA score, so that all values should become non-negative. These shifted RCA values are shown in Table 2. (The lowest possible RCA value is -100).

4. Empirical Results[5]

Stage 1 Efficiency

Partial Analysis: We begin our analysis of Stage 1 efficiency in converting R&D resources into "outputs" -- patents, patent potential, publications and citations -- by constructing some simple two-dimensional graphs, showing each of the four "outputs" as a function of the independent variable for Stage 1, Gross R&D Spending as a Per Cent of GDP. {See Figures 1 - 4 }. These four graphs show partial production functions -- one output as a function of one input -- but by their nature cannot reveal the aggregate picture that DEA portrays. (See below).

Most countries are on the efficiency frontier, for Stage 1, for at least one of the four R&D outputs. Israel's very high levels of publications and citations, relative to its GDP, places it very high on the efficiency frontiers for these outputs, and even skews them to indicate "increasing marginal product", i.e. a rising gradient. Denmark and the U.K. also appear on efficiency frontiers, indicating strong scientific infrastructure in those countries. With regard to patents and patent potential, Germany, the Netherlands, Denmark and Italy dominate, with Germany enjoying a strong lead.

This initial analysis, therefore, suggests that when the full DEA study is conducted, the efficient Stage 1 countries are likely to include Israel and Germany -- Israel, because of its strong performance in publications and citations, and Germany, because of its strong position in patents.

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5 We are indebted to Prof. Agha Iqbal Ali, of the Univ. of Massachusetts - Amherst, MA., for providing his IDEAS software - Version 3.0.0, Integrated Data Envelopment Analysis [Ali, 1990]. It is now available commercially.

Figure 1: **Patents/GDP vs. Gross R&D Spending/GDP EC Countries & Israel**

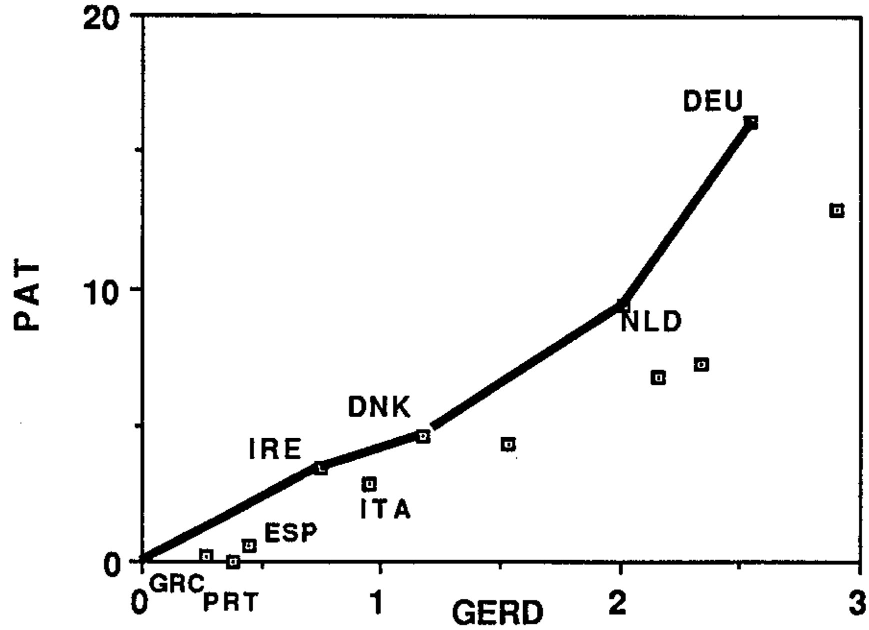


Figure 2: **Patent Potential/GDP vs. Gross R&D Spending/GDP, EC Countries & Israel**

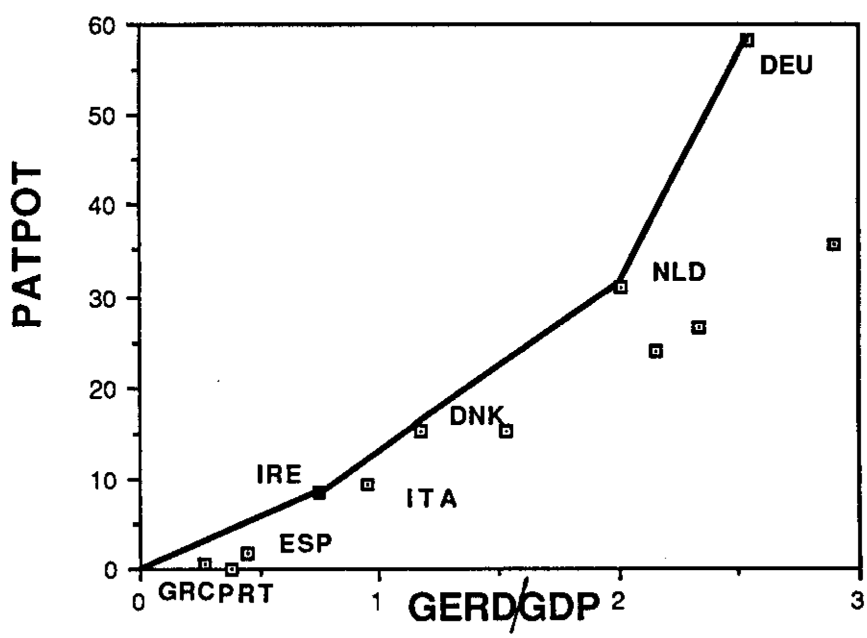


Figure 3:**Publications/GDP vs. Gross R&D Spending/GDP**
EC Countries & Israel

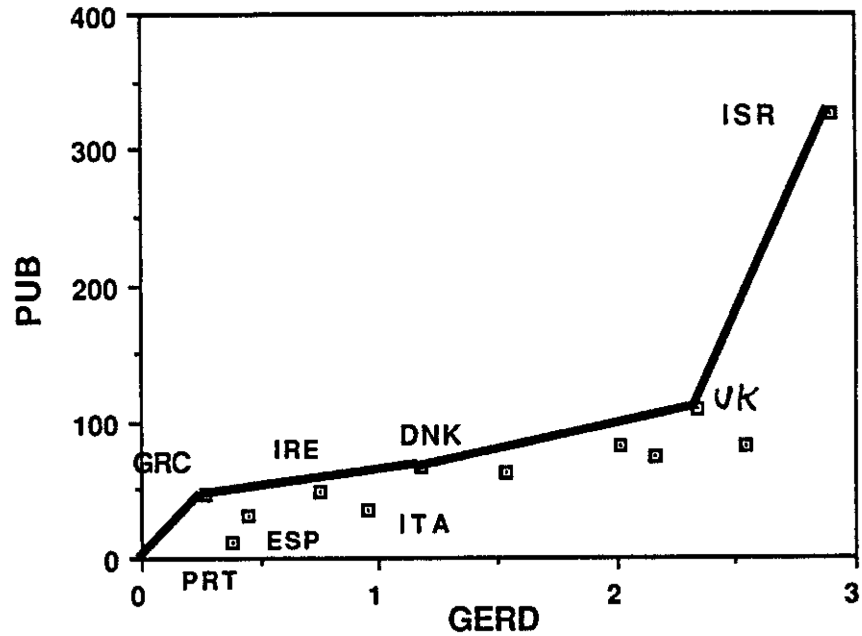
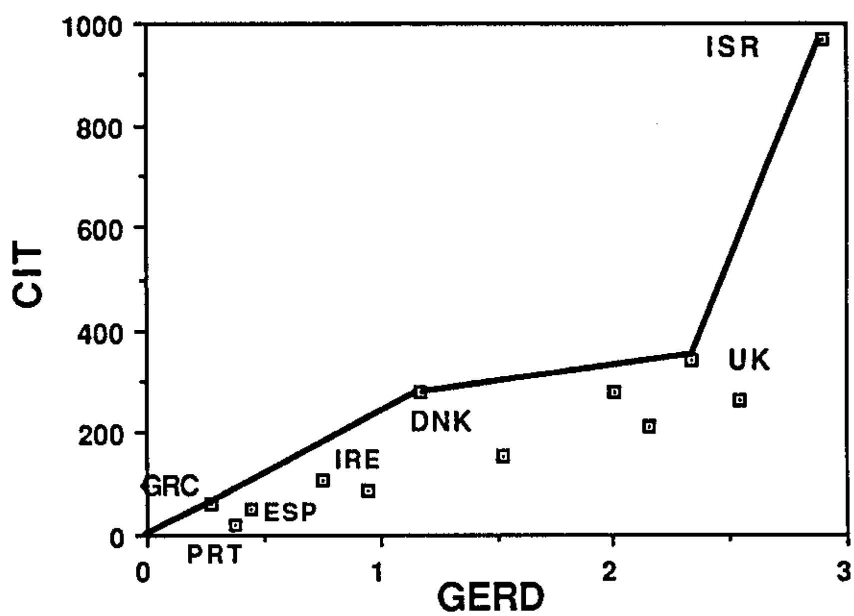


Figure 4: **Ciitations/GDP vs. Gross R&D Spending/GDP**
EC Countries & Israel



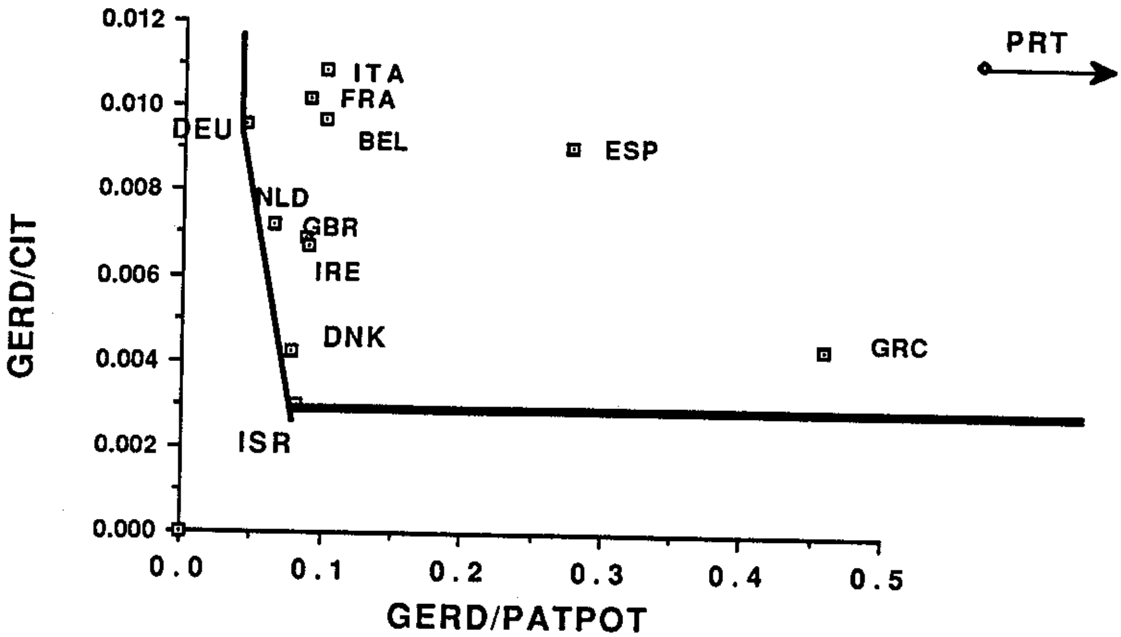
Reduced DEA Results: The four output indicators do not allow for two-dimensional graphical representations of the DEA results. Two of the outputs are valid representaations of "science" (PUB and CIT), and two are valid representations of "industrial development" (PAT and PATPOT). It is therefore tempting to perform a DEA analysis with only two outputs, say, CIT and PATPOT, in order to represent the two dimensions "academic R&D" and "industrial R&D", in a preliminary analysis, and then to compare these "reduced" DEA results to a full DEA analysis.

These reduced DEA results are shown graphically below (See Table 3 and Figure 5).

Table 3: **Reduced "Stage 1" Efficiency in Converting R&D Resources Into Scientific (CIT) and Technological (PATPOT) Outputs**

Country	Iota	Theta	Sigma
Germany	1.00	1.00	0
France	0.56	0.56	0
U.K.	0.65	0.65	0
Netherlands	0.79	0.79	0
Belg./Lux	0.53	0.53	0
Denmark	0.86	0.86	0
Italy	0.51	0.51	0
Israel	1.00	1.00	0
Spain	0.33	0.33	0.20
Greece	0.67	0.69	1.69
Portugal	0.14	0.15	0.54
Ireland	0.65	0.65	0

Figure 5: **Schematic view of isoquants of DEA results reduced to two outputs**



As expected, Germany and Israel are seen as most efficient in Stage 1, but most of the other countries are not overall very distant, according to the SIGMA measure; i.e. the weighted Euclidean distance between their actual position and the efficient "envelope" vanishes. Only the Mediterranean EC countries Spain, Greece and Portugal are more distant from the envelope, and thus less efficient, from the two-dimensional perspective (see also Figure 5). As the DEA analysis was reduced to two outputs only, there is nearly no difference between using the Iota (weighted distance) or the Theta (proportional projection) measures for assessing the efficiency of inputs.

Full DEA Results: Tables 4 and 5 show the results of the data envelopment analysis model, applied to the Stage 1 model of maximizing the ratio of the weighted sum of all four outputs -- PAT, PATPOT, PUB and CIT -- to the single input, GERD, with weights chosen to achieve the highest possible ratio. It will be recalled that "Iota" measures the proportional reduction in inputs needed for a DMU to achieve efficiency (i.e. to be on the efficiency frontier), "Theta" measures the total reduction in inputs for full efficiency, and Sigma is the weighted Euclidean distance of a DMU's actual point from its fully efficient one.

Table 4: **"Stage 1" Efficiency in Converting R&D Resources into Scientific and Technological Outputs**

Country	Iota	Theta	Sigma
Germany	1.0	1.0	0
France	0.57	0.58	16.63
U.K.	0.65	0.65	5.37
Netherlands	0.80	0.81	9.40
Belg./Lux.	0.54	0.57	33.29
Denmark	0.83	0.86	27.03
Italy	0.53	0.55	21.02
Israel	1.0	1.0	0
Spain	0.44	0.50	14.92
Greece	1.0	1.0	0
Portugal	0.20	0.20	0.20
Ireland	0.81	0.86	39.29

Table 5 : **"Stage 1" Output Efficiency: Ratio of Actual Output to Fully-Efficient Output**

Country	PAT	PUB	CIT	PATPOT
Germany	1.0	1.0	1.0	1.0
France	0.95	1.0	0.93	1.0
U.K.	0.88	0.96	1.0	1.0
Netherlands	1.0	0.91	1.0	0.96
Belgium/Lux.	0.91	1.0	0.81	1.0
Denmark	0.91	0.72	1.0	1.0
Italy	1.0	1.0	0.81	1.0
Israel	1.0	1.0	1.0	1.0
Spain	1.0	1.0	0.70	0.94
Greece	1.0	1.0	1.0	1.0
Portugal	0	1.0	1.0	0
Ireland	1.0	1.0	0.67	0.69

The results indicate that for Stage 1, the three efficient "facets" are Israel, Germany and Greece. Measured by Iota and Theta, Denmark is next, followed by Ireland, the Netherlands, U.K., France, Belgium/Luxemburg, and finally Italy and Spain. Portugal is last, largely because its relatively weak patent performance.

Table 5 shows the comparative efficiency in each of the four output dimensions, measured by the ratio of actual output to efficient output, with "efficient" defined by the three facets, Israel, Germany and Greece. Most countries are seen to be "Stage 1 efficient" for at least two (and in some cases, three) of the outputs. In particular, Italy's low overall efficiency score appears to be attributable to inefficiency in the "Citations" dimension alone. This may be related in part to a language bias (as for Spain) and not solely to the low impact of Italian and Spanish science. As for Greece, which was not judged as an efficient country in the reduced DEA analysis, it must be noted that its performance in patents -- comparatively low, as is R&D spending -- increased only recently. Therefore, the related PATPOT output is considerably lower than the actual PAT output. By using only the potential indicator, as was done in the reduced DEA analysis (see Figure 5), past patent performance is emphasized.

Table 5 further shows that the publication output differentiates a bit less between countries than does the citation output. This is the reason we chose the citation data to represent science for the reduced DEA analysis. The PAT and PATPOT data are about the same in variation across countries. Yet, the patent potential indicator, measured over a ten-year period, seems to be a more stable measure for the inventive power of countries, and was thus chosen for the reduced analysis.

Stage 2 Efficiency

Partial Analysis: Figures 6 and 7 show graphically the relation between the Stage 2 output, "Revealed Comparative Advantage", a measure of relative success in high-tech export markets, and two of the Stage 2 inputs, publications and patents. For both of these two partial efficiency frontiers, Germany and Ireland are seen as fully efficient.

Reduced DEA results: Figure 8 portrays the same frontier in a different manner. Here, an "RCA-isoquant" is calculated by means of a reduced DEA analysis, with the two other inputs for science and technology only (analogous to Figure 5; for the reasons why we selected these two data sets, see the discussion for Stage 1 efficiency), showing the values of PATPOT and CIT needed to produce a single unit of RCA. Spain and Portugal seem to form the isoquant, with other smaller countries scattering somewhat, and all the major R&D players in Europe well beyond it. Figure 7 has been provided only because full DEA analysis of Stage 2 is four-dimensional, in inputs, and does not lend itself well to a graphical two-dimensional representation of isoquants. More information is certainly provided by the full DEA analysis below (without Figures). However, we wish to make the point clearly, at this stage, that the rather confusing numerical results need to be analyze carefully for their informational content, before any conclusions can be drawn from them. Such a discussion follows in section 5. From this discussion, it is learned that RCA output analysis should be limited to the major R&D spenders. The reduced DEA isoquants for six major countries are also given in Figure 8. In this case, Denmark, France and Germany form the efficiency frontier.

Figure 6: **Revealed Comparative High-Tech Trade Advantage (RCA) vs. Scientific Output**

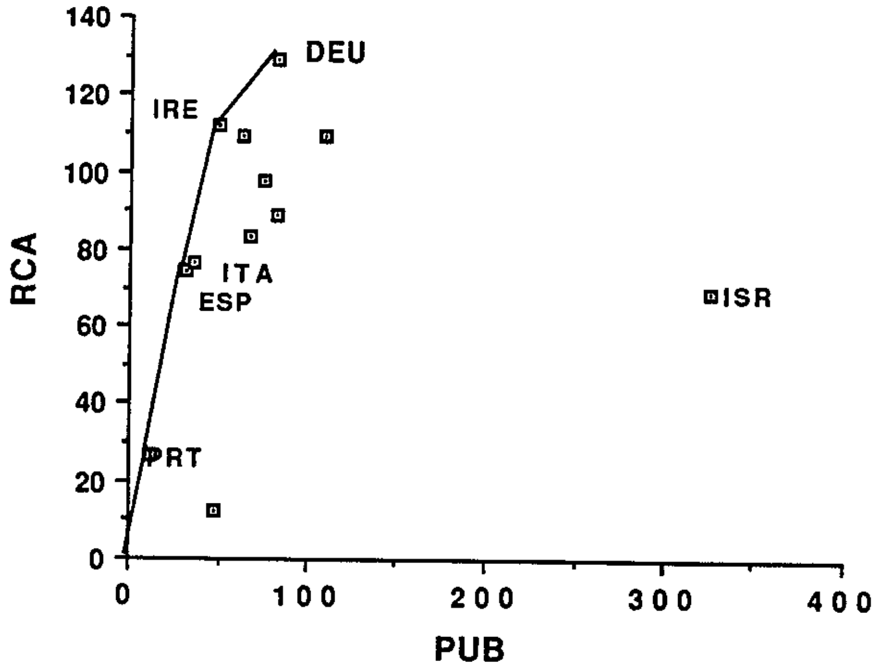


Figure 7: **Revealed Comparative High-Tech Trade Advantage (RCA) vs. Technological Output**

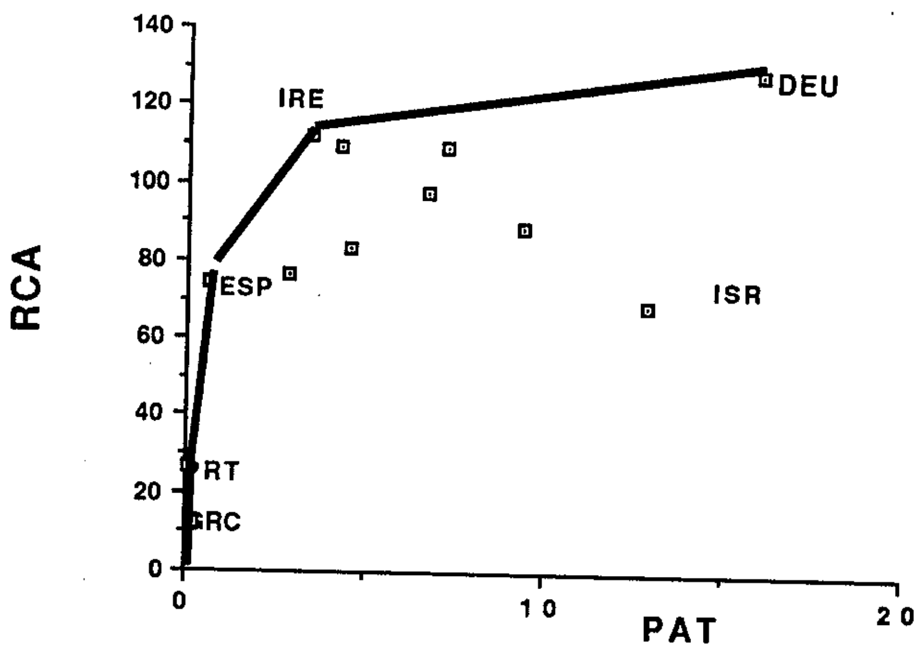
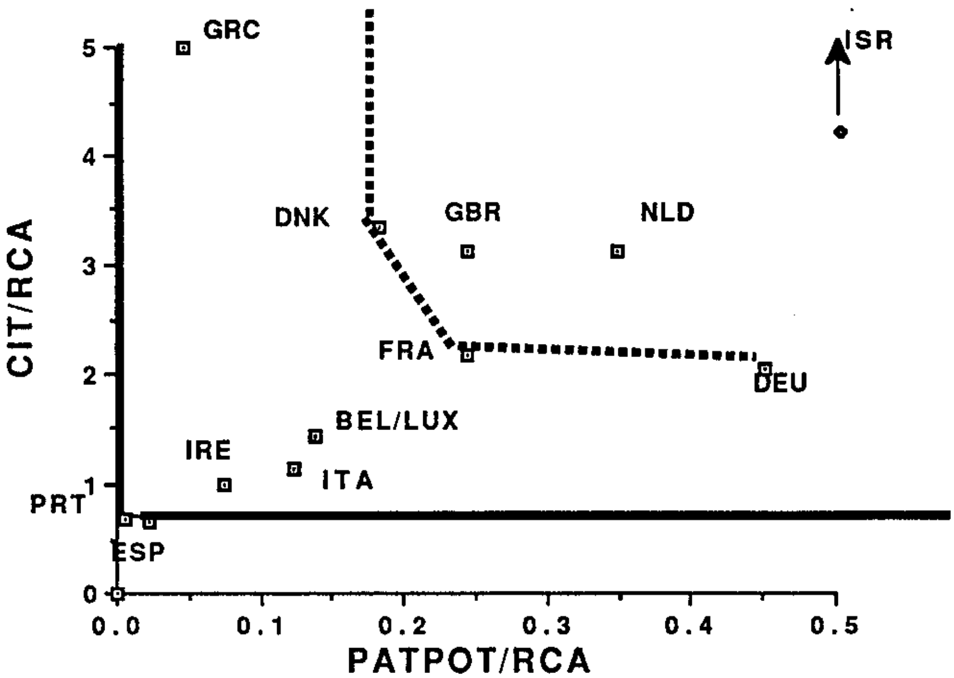


Figure 8: **Schematic View of Isoquants of DEA Results Reduced to Two Inputs (Stage 2)***



Full DEA Analysis: Now we turn to a full DEA analysis of all four inputs, the two "scientific" and the two "technological" ones. As before, Portugal and Spain seem to be at the efficiency frontier, with the smaller countries following, whereas the major R&D actors in Europe including Israel drop out (Table 6). For reasons discussed in the next section, it is tempting to include only above-average R&D investors in the high-tech analysis. Therefore, we perform the same DEA calculations with the more homogeneous sample of those countries that invest more than 1 per cent of their GDP in R&D. This threshold is arbitrary for the moment, but not without solid justification (see section 5). In addition to this cutoff rule, Belgium and Luxembourg are excluded, for reasons mentioned later. Therefore, in this "top 6" analysis, the remaining countries are: Germany, France, U.K., the Netherlands, Denmark and Israel. (The dashed envelope in Figure 8 includes these same top 6 countries in the reduced DEA calculation).

Table 6.
"Stage 2" Efficiency in Converting Science and Technology Excellence into Export Advantage

Country	Iota	Theta	Sigma
Germany	0.33	0.67	137.09
France	0.35	0.56	68.16
U.K.	0.25	0.43	85.69
Netherlands	0.25	0.46	85.25
Belg./Lux.	0.51	0.74	55.66
Denmark	0.26	0.54	102.23
Italy	0.63	0.92	38.17
Israel	0.06	0.09	44.46
Spain	1.00	1.00	0
Greece	0.13	0.14	0.78
Portugal	1.00	1.00	0
Ireland	0.73	0.98	42.41

The three countries (out of the top 6) that form the efficiency frontier for Stage 2 -- transformation of publications, patents and citations into revealed comparative advantage -- are Germany, France and Denmark. They are followed by the U.K., the Netherlands, and finally Israel. The contrast between Israel's efficiency in Stage 1 -- generating scientific and technological outputs from R&D resources -- and its inefficiency in Stage 2 -- generating exports from its scientific and technological excellence -- is striking. It should be emphasized that this result is robust and does not depend on the number of countries compared.

When the relative efficiency of utilizing each of the four inputs is analyzed separately (see Table 8), it is seen that in approximate terms, no country lies along a radius vector that crosses the efficient hyperplane, meaning that there is no major R&D investor in our sample whose relative inefficiency in each of the four contributing inputs -- publications, citations, patents and cumulative patents -- is approximately the same. The U.K. is relatively inefficient in utilizing scientific papers, while the opposite is true for the Netherlands, which has inefficient utilization of patents for generating high-tech exports. Israel is efficient in making her patent potential pay off (that is, her older technology), but is not fully efficient in utilizing recent patents or scientific excellence.

This concludes our presentation of the empirical results. We now turn to a discussion of our numerical findings.

Table 7.

Stage 2 Efficiency Measures for the top 6 R&D Investors, in Converting Science and Technology Excellence into Export Advantage

Country	Iota	Theta	Sigma
Germany	1.0	1.0	0
France	1.0	1.0	0
U.K.	0.90	0.92	15.4
Netherlands	0.80	0.80	0.5
Denmark	1.0	1.0	0
Israel	0.27	0.35	172.43

Table 8

Stage 2 Input Efficiency for the top 6 R&D Investors Ratio of Efficient Input to Actual Input

Country	PAT	PUB	CIT	PATPOT
Germany	1.0	1.0	1.0	1.0
France	1.0	1.0	1.0	1.0
U.K.	1.0	0.87	1.0	0.94
Netherlands	0.95	1.0	1.0	1.0
Denmark	1.0	1.0	1.0	1.0
Israel	0.94	0.82	0.88	1.0

5. Discussion and Conclusions

The conclusions reached with the aid of the Data Envelopment approach are essentially evident in the data themselves. But there are doubtless many instances in which the final result -- and degrees of inefficiency -- are far less obvious from simple inspection of the data. There is a significant advantage in an objective, quantitative approach that yields clearcut numerical estimates of inefficiency and also partitions that inefficiency among the various input dimensions.

The main reservation we must discuss relates to the extent to which the input and output variables reflect R&D processes under national control. For R&D expenditures, this appears to be no problem, as the flow of funds from and to foreign sources is negligible in the sample of countries studied. EC funds overall are low, compared with national appropriations, and they are allocated in our statistics to the country where they are spent. Bibliometric data are assigned by the affiliation of the first author (university, institute, or company) and should reflect national activities quite well (with the exception of multinationally co-authored papers, like this one, and the publication output of supranational research centers).

The foreign trade indicator, RCA, is more problematic. It is by no means certain that high-tech exports are built on technology and science indigenous to the exporting country. The public good "R&D results" is highly mobile. In particular, large multi-national corporations may produce and export from other countries than those where the scientific and technological achievements originate. The degree of high-tech trade advantage will thus depend not only on the existence of scientific or technology gaps but also on the number and nature of high-tech firms that manufacture in that country, and thus on the degrees of opportunity, cumulativeness and appropriability (i.e., interfirm technological capabilities) of the local export sector.

The nature and intensity of economic -- though not technological -- stimuli, that stem from the abundance of particular inputs, or alternately critical scarcities, specific patterns of local demand, and levels of and changes in relative prices, generate a complex interplay between export performance and technology-gap structures among various countries (as measured, for example, by the four input variables used in the Stage 2 analysis above)) [Van Hulst et al, 1991]. As a partial reaction to this interplay, we based our answer to the difficult question, how competitive are R&D-intensive product groups in given countries, not on the level or size of export surpluses but on the relative position compared to all manufactured goods. This is because the propensity to engage in international trade varies widely across product groups for reasons other than technological ones. A high absolute level of exports, for example, can in part be attributed to an undervalued or overvalued currency (leading to decisions by corporations to conduct R&D and manufacturing at cheaper sites abroad) [Grupp, 1991, p. 279]. Thus, it is the relative trde result in R&D-intensive product groups that we chose to measure. Still, this is not a full remedy to the above-mentioned difficulties. Theoretically, it is more correct to consider only bilateral trade relations. After all, it is by no means certain -- indeed, there is some evidence to the contrary -- that the advanced economies always supply products of the same high technological content to the various regions of the world, or of Europe. That is why consideration of trade relations within the most advanced economies is preferable [Grupp, 1991, p. 281].

Preliminary inspection of the data in Table 2 (and also of Figures 1 to 4) reveals that of the dozen countries we analyze, five are clearly not major players in the global market for high-tech products. They are Italy, Spain, Portugal, Greece and Ireland. All spend less than one per cent of their GDP on R&D and have considerably lower levels of patents, citations and publications than the other countries. Ireland does have respectable high-tech exports, but much of that is done by foreign companies locating in Ireland to take advantage of sizeable tax concessions and relatively inexpensive labor and land, and does not reflect local high-tech capabilities.

For the four Mediterranean countries, it is often the case that foreign-owned multi-nationals pursue local high-tech production (e.g. in consumer electronics in Portugal, or in electric cables in Greece, Italy and Spain, or in production of German cars in Spain). Telecommunications equipment in Spain is manufctured by the French-owned Alcatel company (earlier, by the U.S.-owned ITT). AT&T is also strong in joint ventures in these countries [Grupp and Schnoering, 1992]. The "mobile" foreign technologies do count on the output side of the Stage 2 model, but certainly not on the input side -- this is our problem.

The above-mentioned countries seem to be very efficient in stage 2 precisely because they are so weak in related inputs, where we are unable to take account of the imported and foreign-controlled technology. Therefore, we introduce a threshold for our final analysis, excluding countries allocating below 1 per cent of their GDP to Gross R&D spending.

This cut-off rule appears arbitrary -- however, there is an additional argument supporting it. Within the Commission of the European Communities, there exists the concept of "less-favored" regions of the EC. These regions receive dedicated EC funds to foster their local R&D, and there are special subsidies for increasing cohesion within the entire EC.

As "less-favored", the following regions have been specified:
- Portugal, Ireland and Greece (the entire country)
- the south of Italy, Sicily, Sardinia
- Spain, without Greater Madrid and the Barcelona region
- in France, only Corsica
- in the U.K., Northern Ireland

Thus, our 1 per cent threshold for R&D spending corresponds well with the less-favored EC regions as defined above.

In addition to the problems that globalization of technology causes for our analysis, the assignment of patent indicators to various nations may also be disputed. Patents are sorted by countries of origin, according to the residence of the first inventor. The reason not to use the patent assignee's address is that in many cases, the headquarters of the company is given but not the address of the R&D lab where the invention was made. With the reasonable assumption that inventors live close to their lab, the selection of residential addresses tends to reflect well the nation of origin -- with the exception of multi-national inventor teams, guest researchers, commuters, and so on, difficulties we neglect here.

More problematic, however, is the strategic control of technology generated by patents. In most cases, inventors do not decide when, to what extent, for which markets, and for which products, their inventions are used. Nor to they have a say, in general, in licensing, selling or abandoning of patents, insofar as they are employees of commercial firms.

Consider, for instance, Belgium, which spends 1.53 per cent of its GDP on Gross R&D and is therefore well above the cutoff level. Belgian technology is strongly controlled by non-Belgian companies. Patel and Pavitt [1992] reported that 39.7 per cent of national patenting in the United States is due to large foreign-controlled firms, whereas for Western Europe the comparable figure is 6.2 per cent, on average. Belgium had the largest share of national patents generated by foreign capital in their sample of 11 countries. This is a different case from that reflected in the Mediterranean EC countries. Here, foreign-controlled patents are registered in our input data, but we do not know whether the owners of the patents make the related Belgian technology effectie for exports from Belgium. It is known that the Dutch-speaking province of Belgium has traditionally close links with the Netherlands, and the French-speaking province is closely connected with France. The same istrue for the small German-speaking part of Belgium and its ties with Germany. High-tech exports into these three neighboring countries alone comprise half of all Belgian high-tech exports, and high-tech imports from the three countries amount to 60 per cent of total high-tech imports! We thus decided to exclude this country from our analysis, because of its foreign-controlled technology and extremely strong high-tech trade relations with a few neighboring countries, for which large intra-firm trade exists. For these reasons, we chose to confine our final analysis to six countries: Germany, France, U.K., Denmark, and Israel.

Up to now, we did not differentiate between leading-edge technology and high-level commodities (see section 3). These two segments of high technology are differentiated by their R&D intensity. This may be somewhat controversial. A high percentage of sales that is spent on R&D signifies low turnover expectations. Indeed, for every million dollars spent on R&D in leading-edge technology, the average annual turnover is less than $12 million , while a typical figure for high-level consumer technology is $30 million or more [Grupp, 1991, p. 279]. Leading edge technology includes many products subject to tariff and non-tariff protection, such as civilian aircraft and parts, aerospace, pharmaceuticals, and telecommunications. The rleated markets may be subject to regulation, so that a scientific and technological advantage may not easily be converted to trade advantages.

Table 9 provides a synopsis of Stage 1 and Stage 2 DEA results (Theta measures), along with the RCA indexes for leading-edge and high-level product groups. Our conjectures are confirmed in this table. Those countries that emphasize the less sales-effective, often protected area of leading edge technology do not achieve full "Z" efficiency -- U.K., the Netherlands, and Israel. On the efficiency envelope are only those countries with stronger (or at least equal) performance in the high-level markets: Germany, France and Denmark.

Germany's high absolute performance may be related to the fact that it is fully efficient in both stages of the R&D process, while the other nations are either efficient in stage 2 and inefficient in stage 1 (France, more so than Denmark), or mediocre in both phases (U.K. and the Netherlands). As a major Mediterranean R&D nation, Israel does best in stage 1, but is highly inefficient in stage 2. Through her scientific and technological achievements, a relatively large amount of indigenous "Z" inputs originate in Israel. But far too little of these inputs accrue to Israel herself, rather than to other countries. Obviously, war and unstable political relations with neighbor countries are among the unfavorable conditions that hamper the full exploitation of Israel's R&D excellence.

Table 9.
Synopsis of DEA Results and Structural High-Tech Competitiveness

Country	Stage 1 efficiency (Theta)	Stage 2 efficiency (Theta)	Leading-edge competi-tivness	Structural emphasis	High-level competi-tiveness
Germany	1.0	1.0	-14	<	+49
France	0.6	1.0	- 2	=	- 2
United Kingdom	0.7	0.9	+30	>	+ 9
Netherlands	0.8	0.8	- 4	>	-17
Denmark	0.9	1.0	-25	<	-11
Israel	1.0	0.4	-20	>	-36

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Appendix: List of R&D Intensive Products

No	SITC III	Product group (non-official terms)	R&D intensity
1	516	Advanced organic chemicals	Leading-edge goods
2	525	Radio-active materials	Leading-edge goods
3	541	Pharmaceutical products	Leading-edge goods
4	575	Advanced plastics	Leading-edge goods
5	591	Agricultural chemicals	Leading-edge goods
6	714	Turbines and reaction engines	Leading-edge goods
7	718	Nuclear,water,wind power generators.	Leading-edge goods
8	752	Automatic data processing machines	Leading-edge goods
9	764	Telecommunications equipment	Leading-edge goods
10	774	Medical electronics	Leading-edge goods
11	776	Semi-conductor devices	Leading-edge goods
12	778	Advanced electrical machinery	Leading-edge goods
13	792	Aircraft and spacecraft	Leading-edge goods
14	871	Advanced optical instruments	Leading-edge goods
15	874	Advanced measuring instruments	Leading-edge goods
16	891	Arms and ammunition	Leading-edge goods
17	266	Synthetic fibres	High-level products
18	277	Advanced industrial abrasives	High-level products
19	515	Heterocyclic chemistry	High-level products
20	522	Rare inorganic chemicals	High-level products
21	524	Other precious chemicals	High-level products
22	531	Synthetic colouring matter	High-level products
23	533	Pigments. paints, varnishes .	High-level products
24	542	Medicaments	High-level products
25	551	Essential oils. perfume, flavour	High-level products
26	574	Polyethers and resins	High-level products
27	598	Advanced chemical products	High-level products
28	663	Mineral manufactures, fine ceramics	High-level products
29	689	Precious non-ferrous base metals	High-level products
30	724	Textile and leather machinery	High-level products
31	725	Paper and pulp machinery	High-level products
32	726	Printing and bookbinding machinery	High-level products
33	727	Industrial food-processing machines	High-level products
34	728	Advanced machine-tools	High-level products
35	731	Machine-tools working by removing	High-level products
36	733	Machine-tools without removing	High-level products
37	735	Parts for machine-tools	High-level products
38	737	Advanced metalworking equipment	High-level products
39	741	Industrial heating and cooling goods	High-level products
40	744	Mechanical. handling equipment	High-level products
41	745	Other non-electrical machinery	High-level products
42	746	Ball and roller bearings	High-level.products
43	751	Office machines,word-processing	High-level products
44	759	Advanced parts:for computers	High-level products
45	761	Television snd video equipment	High-level products
46	762	Radio-broadcast,radiotelephony goods	High-level products
47	763	Sound and video recorders	High-level products
48	772	Traditional electronics	High-level products
49	773	Optical fibre and other cables	High-level products
50	781	Motor vehicles for persons	High-level products
51	782	Motor vehicles for good transport	High-level products
52	791	Railway vehicles	High-level products
53	872	Medical instruments and appliances	High-level products
54	873	Traditional measuring equipment	High-level products
55	881	Photographic apparatus and equipment	High-level products
56	882	Photo- and cinematographic supplies	High-level products
57	883	Optical fibres, contact, other lenses	High-level products

Technometric Evaluation and Technology Policy:

The Case of Biodiagnostic Kits in Israel

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Abstract

"Technometrics" is a multidimensional index of technological excellence. Technometric profiles permit objective comparisons of product and process quality between companies, industries and nations. They are applicable to services as well as goods, to low-tech as well as high-tech products, and provide basic quantitative indicators sometimes helpful in constructing technology policy. The method of constructing technometric profiles is outlined and a technometric case study of Israel's fledgling biodiagnostic industry is presented, with emphasis on industrial policy.

Introduction

"Policy begins with Measurement"

Lord Kelvin once said that "theory begins with measurement". While many theoretical physicists might debate that point, it is difficult to deny that policy begins with measurement. Public policy -- the attempt to bridge the gap between what is and what ought to be -- is unlikely to succeed in either framing or implementing successful policy decisions without a clear evaluation of the existing situation -- what is.

In discussing industrial and technology policy for a whole nation, or for particular firms or industries, it is essential to have clear answers to the question: **How good are our products and processes, compared to those of competing countries?** The answers to the question, "what is our competitive situation?", must be objective, accurate and quantitative.

A series of metrics for evaluating and comparing technological sophistication have been developed at the Fraunhofer Institute for Systems and Innovation Research (FhG - ISI). (Grupp, 1991; forthcoming). These quantitative indicators have proved useful in measuring the technological level of products and processes and have served as a "yardstick" for comparison with other firms or countries.

The purpose of this paper is to apply technometric indicators to evaluate biodiagnostic kits produced by Israeli firms, and to draw policy implications from this analysis.

The structure of the paper is as follows. Part I provides a brief description of the technometric approach. Part II surveys Israel's biotechnology industry, in general, and the biodiagnostic sub-branch in particular. Part III provides a technometric evaluation of biodiagnostic kits produced in Israel, relative to leading products in Germany, the U.S. and Japan, and Part IV draws the main technology policy implications.

I. The Technometric Approach to Product Evaluation

The technometric approach originated with concern at the German Ministry for Research and Technology in the early 1980's that Germany trailed Japan and the United States in important high-tech areas -- concern that was aroused in particular by the influential book by Nussbaum [1984]. One of the most important early links in the high-tech product-development chain is the innovation stage, where the quality of new products brought to market is evaluated, but well before market or price mechanisms provide any signals. To quantify product quality at this stage, as a means of supplying data confirming or disconfirming the Nussbaum study for the R&D Ministry, a method called "technometrics" was developed by Grupp and associates at FhG-ISI [Grupp and Hohmeyer, 1986, 1988; Grupp, 1990, 1991].

Technometrics is the quantitative measurement of the technological quality or sophistication of a product or process, group of products or processes, or industry. This approach produces a quantitative profile of a product or process, showing graphically its performance characteristics for selected key attributes, in comparison to those of other firms or countries. Such indices can be aggregated across groups of products, to permit comparisons of the comparative technological level of subsectors or even entire industries. Technometric studies, for example, showed Nussbaum's perception that Germany lagged behind the U.S. and Japan overall was untrue, overall, but revealed important areas where Germany was at a competitive disadvantage.

Other, complementary approaches to technological evaluation have been developed (see Saviotti, Stobbs, Coombs and Gibbons [1982] and Saviotti [1985]). A possible disadvantage of technometric studies, it should be noted, is that they rely heavily on primary data collection and peer review and thus tend to be relatively costly and labor-intensive.

Definition:

Every product or process has a set of key specifications or attributes that define its performance, value or ability to satisfy customer wants. Almost by definition, every specification or attribute can be quantified. For instance, in the case of diagnostic kits, a key specification is "reliability" (the proportion of tests in which accurate results are obtained). For assembly robots, 14 key specifications are axes, maximum reach, minimum reach, vertical velocity, horizontal velocity, repetitive accuracy, position acuracy, nominal load, maximum load, drive, vertical reach, hand rotation, angular velocity and lifetime. [Grupp et al., 1990]. All are expressible in quantitative units.

It is always a subjective decision whether an item should be included or not [Grupp and Hohmeyer, 1988]. However, as Clark [1985] and Stankiewicz [1990] have pointed out, as development proceeds, technological diversity gives way to standardization. Particular design approaches achieve dominance and performance criteria are clearly specified. Social processes and patterns of communication between customers will influence the speed and pattern of product (or process) design and broad categorizations are broken down into related subcategories of the characteristics which are refined through experience. Therefore, it is not surprising that (industrial) experts interviewed agree on proposed characteristics and priorities [Grupp, 1990].

Each of these attributes has its own unit of measurement: mm. per second, years of lifetime, etc. Problems then arise in aggregating attributes to build a single quality index. The technometric indicator surmounts this difficulty by converting each measured attribute into a [0,1] metric, enabling construction of weighted averages, etc., and permitting comparisons across products, firms, industries and countries. The "0" point of the metric is set as the technologically-standard attribute; the "1" point is set as the most technologically-sophisticated attribute in existence.

Let subscripts i, j and k represent products, product attributes or characteristics, and subgroup (company, industry or country), respectively.

Let K represent the measurement of an attribute for given i, j and k. The technometric indicator, K* , is defined as:

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

where:

$K_{max}(i,j,k)$ = the **highest** value of product characteristic "j" for product "i", for subgroup k

$K_{min}(i,j,k_{min})$ = the **lowest** value of product characteristic "j", among all members of subgroup k

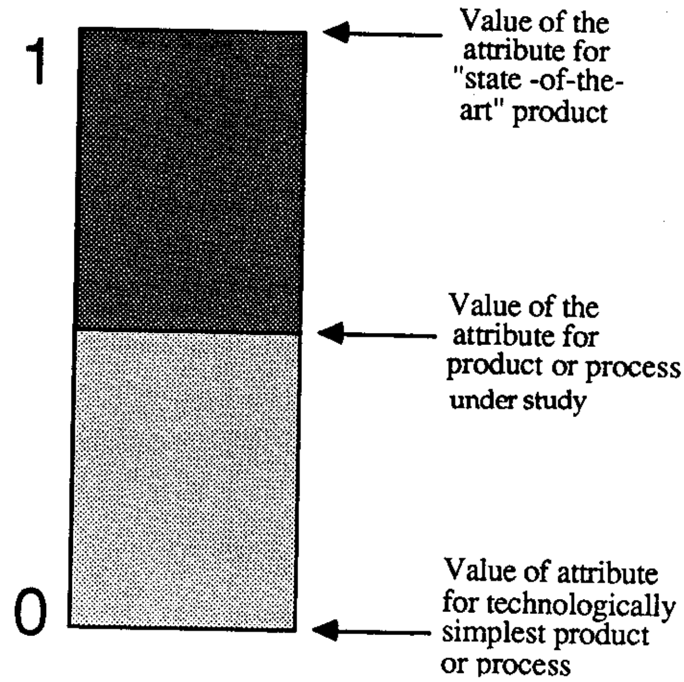
$K_{max}(i,j,k_{max})$ = the **highest** value of product characteristic "j", among all members of subgroup k

Take, for instance, the product "diagnostic kits". One attribute would be "test duration" -- the length of time needed to carry out the diagnostic test. The numerator of [1] would give the difference between the "best" (i.e. shortest) test duration for an Israeli product, compared to the "worst" (i.e. longest) test duration for any of the products under comparison, for several countries. The denominator would give the difference between the best, shortest test duration for the top state-of-the-art product, and the longest test duration for a technologically standard (and probably, relatively inexpensive) product.

What results is a metric, K*, that ranges from zero to one, showing how a product stacks up for that attribute, relative to the state-of-the-art level. Note that in some cases -- as in this one -- lower attribute values represent **higher** levels of technology, requiring the values in the technometric expression to be inverted (by replacing all "max" with "min", and vice-versa, in Equation [1]).
(For a diagrammatic presentation of K*, see Figure 1).

Once key product attributes have been determined from interviews and K* values calculated for each, a technological "profile" of the product can be constructed. It is possible to aggregate K* across all key attributes -- for diagnostic kits, that would include sensitivity, intra-assay precision, inter-assay precision, and handling, as well as test duration -- to achieve an aggregate K* measure for the product or group of products. This aggregate technometric measure can then be correlated with other variables to determine the link between technological excellence and, for instance, market success. Comparisons with economic data indicate that declines in the technometric quality of a product or process, K*,

Figure 1: **A Diagrammatic Representation of the Technometric Index K***



occur 2-3 years before such deterioration finds expression in declining market share or export sales. [Grupp and Hohmeyer, 1988]. This indicates that K* can serve as a useful "early warning indicator" -- ideally, one of a series of such indicators, in conjunction with other market indicators, revealing problems with product quality in sufficient time to take remedial action. Such indicators can be crucially important because generally, by the time it is observed that market share is falling, it is too late to revamp the product and regain sales from competitors. K* can also serve a positive role, indicating products or sectors where a country has competitive advantage, technologically, hence worthy of investment to further marketing and sales efforts in foreign markets and to further improve R&D and production efficiency at home.

While the [0,1] metric permits aggregation of widely-differing product specifications (for instance, accuracy, in per cent, and sensitivity, in mgs.), it does introduce some distortion, because product quality is generally not a linear function of a physical attribute. Diminishing returns to accuracy, for example, are quite likely, implying that a technometric score of 0.9 in accuracy may be less than 50 per cent more useful or helpful than a technometric score of 0.60 .

Feasibility for policy analysis:

Technometric measures can be used at several levels. At the national level, they can be (and have been) used to identify technology gaps in comparison to other nations, and to shape industrial and R&D policy. At the sectoral level, technometric indicators can serve to identify areas of comparative advantage. And at the firm level, they can be used to construct competitive strategy, determine the optimal "mix" of product attributes, plan new generations of products, guide R&D investment, and form part of feasibility studies. [Grupp et al., 1990]. Since 1986, FhG-ISI has constructed technometric indicators for the following products: enzymes (immobilized biocatalysts), biogenetically engineered drugs, photovoltaic cells, lasers, sensors, industrial robots, diagnostic kits, and biological waste water treatment facilities [Grupp and Hohmeyer, 1988; Reiss 1990].

II. The Biodiagnostic Industry in Israel

Recently, Frenkel and Maital conducted a technometric survey of eight companies in Israel that manufacture biodiagnostic kits. The objective was to evaluate product quality and to frame policy recommendations. Comparative technometric data on Germany, Japan and the United States were supplied by Reiss (1990). The results of that survey follow.

The Biotech Industry:

Biotechnology is a branch of technology that seeks to harness biological processes and systems, or living organisms, in order to create useful products and processes for industry, medicine and agriculture. Using live organisms for the benefit of mankind is an old idea, used long ago for making bread, wine and cheese. In recent years, genetic engineering has permitted scientists to alter the building blocks of life itself. Advances in molecular biology have opened new horizons in influencing cellular processes and have made possible, as a result, development of entirely new products.

Scientists predict that toward the end of this century, biotechnology will be of major importance in production of food for both human beings and animals, in treatment of illness for humans and animals, in supply of new raw materials for the chemical industry, and in treatment of industrial wastes and water. According to various estimates, the market for biotechnological products will amount to between 40 and 100 billion dollars.

There main applications of biotechnology are medicine, agriculture, food, and environment. Within medical applications, there are three subsectors: production of drugs and hormones with genetically-modified organisms; production of biosensors and biocatalysts; and production of diagnostic products for determining the nature of illnesses in humans and animals. In this paper, we choose to focus on the biodiagnostic industry.

Biotech Firms in Israel:

Twenty-eight biotechnology firms exist today in Israel. Most of them are small, and are based on products or processes developed in research done in academic institutions. A high percentage of their employees -- close to one-third -- are scientists and engineers.

Most of the biotechnology firms were set up as subsidiaries of research institutes or universities, and some are subsidiaries of foreign companies. Only a minority are entrepreneurial, established with venture capital. Most of them are based on technological knowledge and skills of a single academic researcher.

Most of these firms are in pharmaceuticals; 19 are in this area, of whom 10 produce diagnostic kits and 2 make materials used for diagnostic kits. Eight companies manufacture drugs, hormones and enzymes. In addition, three small firms produce materials used in research labs and in the biotechnology industry. Two companies are in the chemical industry and three are in agriculture.

According to the Nov. 1988 report of the Katzir Committee, set up to determine sectors in biotechnology that merit investment and development, six constraints limit development of this industry: lack of venture capital for establishing new firms; lack of venture capital and other forms of risk capital for existing companies; lack of academic research centers specializing in biotechnology; lack of trained manpower in biochemical engineering, production and management engineering; lack of technological infrastructure in existing drug and chemical companies that use traditional technology; and the small size of the local market in Israel for biogenetic products, coupled with the large distance from foreign markets.

In order to remedy some of these constraints, a National Biotechnology Program has been established, headed by Prof. Max Herzberg, President of Orgenics Ltd. (one of the companies in our survey).

In the biotechnology industry, diagnostic kits is the market "easiest to enter, with the shortest product life and highest risks" [*Biotechnology Europe*, Oct. 1989, p. 40]. Israeli firms in this industry mainly produce products for human and veterinary diagnosis, based on monoclonal antibodies. Our field survey of Israeli biodiagnostic firms was limited to companies that produce complete kits. We did not include companies that produced only components of such kits. Nor did we include companies that purchased foreign technology under licensing agreements, but only companies with proprietary technology used in developing their own unique products.

A total of 12 biodiagnostic companies were located, of which 8 complied with the above criteria. Senior managers in all of those 8 firms were interviewed, and supplementary material on each firm was collected. Managers were highly cooperative and gave generously of their time. A key part of the interview was a detailed questionnaire, eliciting information on the company and on technometric details of its products.

The nature of biodiagnostic companies in Israel:

Analysis of the data from our field survey revealed that half of the 8 firms are independent, while half are subsidiaries of foreign firms. Most of the companies are privately owned, while some are public companies whose stock is listed on stock exchanges. The companies owned by foreign firms largely began as independent firms but because of difficulties in raising capital or the need to penetrate new markets, were bought out by larger companies abroad. These companies became subsidiaries, but retain their independence in matters of product R&D.

Seven of the eight companies were established after 1980, while one was established during the 1970's. Despite their youth, all these companies have by 1990 succeeded in producing and marketing their own products. The transition from R&D to production and marketing was remarkably swift -- two years from the birth of the company. This contrasts sharply with the 7-10 years needed to develop and test new drugs, and the estimated \$50-\$100 million cost, as noted by the Katzir Committee. (According to the U.S.

Pharmaceutical Manufacturers Association, this cost has risen to $230 million in 1990 [Moran 1991]).

Average plant size is small; the eight plants employed a total of 182 workers of all kinds, an average of 23 per firm, with size ranging from 5 workers to 45. (In general, industrial firms in Israel are very small).

As expected, the proportion of workers in this industry comprising highly-skilled and scientific manpower is very high. According to a 1987 Manpower Survey conducted by the Ministry of Industry, biodiagnostics employs a high proportion of scientific personnel, even in comparison to other high-tech industries. (See Table 1).

Table 1. **Manpower Profile for Biodiagnostic Firms, High-Tech Firms and Industrial Firms in General in Israel (Per Cent)**

	Engineers & Scientists	Techni-cians	Skilled Workers	Unskilled Workers	Office Workers	Total
Biodiagnostic Firms	43.4	13.7	27.5	4.4	11.0	100
High-tech Firms	25.1	20.3	34.8	9.0	10.8	100
All Industrial Companies	9.6	7.7	50.1	22.4	10.2	100

R&D: Our survey revealed that fully a third of employees are engaged in R&D, at least part of the time. A third of the total outlays of the eight firms goes to R&D. This proportionately-heavy spending on R&D is fairly typical of young companies in science-based industries.

Sales and exports: All eight firms export at least part of their output. In aggregate, 75 per cent of the biodiagnostic firms' sales are exported. The heavy reliance on exports stems from the small size of the local market in Israel. Only two of the 8 firms rely principally on the local market; in the remainder, 90 per cent of total output is exported.

Europe is the main market. Two thirds of their exports goes to that market, while one third goes to other destinations. Half of the 8 firms export diagnostic kits to Germany, which absorbs between 10 per cent and 35 per cent of their exports. The United States is not a principal market for Israel-made diagnostic kits, except for the two firms that are wholly-owned subsidiaries of American companies. For the others, a maximum of 12 per cent of total exports go to the U.S. market. For one of the companies, Japan stands second in importance as an export market, next to Europe. Two firms export to Latin America and one company has a small amount of export sales to Africa.

The survey asked managers to forecast future export sales. Most of the companies predicted a rapid expansion in exports in the next five years, between threefold and sixfold growth.

Marketing and distribution: As in most high-tech products made in Israel, marketing is a major obstacle for biodiagnostic kits. Most of the firms we surveyed sell their products abroad through distributors, who acquire exclusive territorial rights. Some of those distributors belong to large foreign companies. This approach to distribution is one important way that Israeli biodiagnostic companies cooperate with foreign entities. One of the 8 companies reported setting up its own marketing firm abroad, in order to achieve greater control over distribution.

All the companies responded that their products are aimed at broad market niches where some competition exists. None of the products compete on the basis of low price, but rather value-added and quality.

Most of the managers interviewed in our survey emphasized marketing as the main difficulty they face, rather than finance, R&D or technology.

The Single European Market in 1992: All 8 companies reported preparing for the 1992 Euromarket. Two have already set up companies in Europe, and three said they intended to do so. Two other companies reported joint-venture agreements to this end with European firms. Most of the companies felt that the main difficulties facing Israeli biodiagnostic firms, in connection with the Euromarket, would come from product standards. The present situation, in which approval by Israel's Ministry of Health is recognized in, for instance, Germany, will not continue after 1992. It is therefore vital that Israel adopt standards that are consistent with, and comply with, those prevailing in Europe. {A major difficulty in doing this is that European standards in many areas have not yet been agreed upon -- which some see as a deliberate European strategy to hamper imports from other countries}.

III. Technometric Evaluation of Biodiagnostic Kits

Availability of technometric data on biodiagnostic kits for Germany, U.S. and Japan [Reiss, 1990] makes it possible to compare the relative technological quality of Israeli kits to those abroad.

Characteristics: Earlier studies of biodiagnostics [Reiss, 1990] showed that there are six main attributes of biodiagnostic materials, which together define the quality of those materials.

They are:

- **sensitivity**: the minimum amount of antibodies needed to product a chemical reaction, or the "threshold". Units of measurement are generally thousandths of a gram per milliliter.

- **intra-assay precision**: degree of internal (intra-assay) accuracy: if the same kit is used 100 times, how many times will it correctly diagnose the presence of a hormone or microorganism; expressed as the coefficient of variation.

- **inter-assay precision**: for a 100 randomly-selected kits, how many of them will give precisely the same diagnosis results; expressed as the coefficient of variation.

- **measurement**: range over which diagnosis is possible. Units of measurement are the same as with sensititivity.

- **test duration**: length of time needed for operating diagnostic test until result is obtained, in minutes.

- **handling**: number of steps required.

Diagnostic kits: Data enabled comparison of diagnostic kits for the following:

- *hormonal deficiencies related to the thyroid gland* (lack of hormones): FT-3 [free tri-iodothyronin], FT-4 [free thyroxin], T-4 [thyroxin], TSH - thyroid-stimulating hormone], and T-3 [tri-iodothyronin]),
- *the sex hormone* Prolactin;
- *infectious diseases*: - HIV-1 (AIDS virus), Rotavirus Ag, Chlamydia IgG and IgM.

The technometric values for hormonal deficiencies are shown in Table 2, and technometric profiles are drawn in Figures 2 and 3.

What emerges is that, as expected, the United States in general holds the lead in the quality of its diagnostic kits. The U.S. pioneered in the field of biotechnology, and still enjoys a technological advantage. This lead is especially pronounced for T-3, T-4, and FT-4. For TSH, Japan enjoys a slight advantage over the U.S. and Israel, with the Germany trailing. For prolactin, the German product is superior to that of Israel, with the U.S. in third place.

* **T-3 tri-iodothyronin**: The United States is far ahead of other countries in this diagnostic kit, leading substantially in all characteristics except test duration. Only for "sensitivity" does the Israeli product equal that of the United States. When the technometric specifications are aggregated (Fig. 3), the United States' substantial lead for T-3 kits is clear.

* **T-4 thyroxin**: The situation is similar to that for T-3, with the U.S. well ahead of Israel and Germany, but not Japan. (Data for Japan exist only for some of the six characteristics). For T-4 sensitivity, the value of "Kmin(min) (the global minimum of the technometric indicator) for all the kits included in the sample, and the Kmax for Germany, Israel and the United States, were all equal to one another. This indicates a weakness of the technometric approach, in cases where the "0" and "1" points of the [0,1] metric coincide.

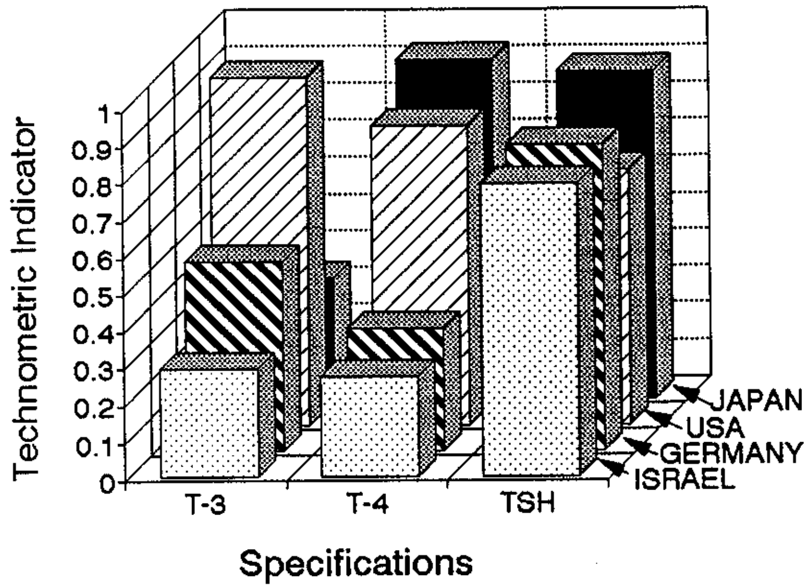
* **TSH thyroid-stimulating hormone**: for this kit, quality gaps among the four countries are smaller. Japan's product is superior overall, with Israel and Germany trailing slightly. The lower scores for both intra- and inter-assay precision for Israel's product, relative to the other countries, indicate a pressing need for improvement in accuracy, in order for Israel's kits to become fully competitive.

Table 2: Technometric Value for Hormonal Diagnostic Kits, Germany, the United States, Japan and Israel by Type and Specifications

Kits	Specifications	Technometric Value			
		Germany	USA	Japan	Israel
T-3	Sensitivity	0.99	1.00	0.00	1.00
	Intra-Assay Precision	0.89	1.00	0.44	0.00
	Inter-Assay Precision	0.00	1.00	m.v	0.43
	Measurement-range	0.00	1.00	m.v	0.03
	Test duration	0.68	0.68	1.00	0.00
	Average	0.51	0.94	0.48	0.29
T4	Sensitivity	0.00	0.00	1.00	0.00
	Intra-Assay Precision	0.25	1.00	0.75	0.11
	Inter-Assay Precision	0.75	1.00	m.v	0.00
	Measurement-range	0.28	1.00	m.v	0.03
	Test duration	0.68	0.85	1.00	0.68
	Handling	0.00	1.00	m.v	0.80
	Average	0.33	0.81	0.92	0.27
TSH	Sensitivity	1.00	1.00	1.00	1.00
	Intra-Assay Precision	1.00	0.82	0.90	0.54
	Inter-Assay Precision	0.89	0.89	1.00	0.62
	Measurement-range	0.97	0.42	0.56	1.00
	Test duration	0.70	1.00	0.90	0.79
	Handling	0.40	0.00	1.00	0.80
	Average	0.83	0.69	0.89	.0.79
FT-3	Sensitivity	0.00	0.88	m.v	1.00
	Intra-Assay Precision	0.60	1.00	m.v	0.00
	Inter-Assay Precision	1.00	0.00	m.v	1.00
	Measurement-range	1.00	0.00	m.v	0.00
	Test duration	0.33	0.00	m.v	1.00
	Handling	0.00	0.00	m.v	1.00
	Average	0.49	0.31	m.v	0.67
FT-4	Sensitivity	0.00	1.00	m.v	0.78
	Intra-Assay Precision	1.00	0.88	m.v	0.56
	Inter-Assay Precision	1.00	0.86	m.v	0.60
	Measurement-range	0.00	1.00	m.v	0.41
	Test duration	0.61	1.00	m.v	0.61
	Handling	0.17	1.00	m.v	0.83
	Average	0.46	0.96	m.v	0.63
PROLACTIN	Sensitivity	0.67	0.58	m.v	1.00
	Intra-Assay Precision	1.00	0.74	m.v	0.48
	Inter-Assay Precision	1.00	0.69	m.v	0.60
	Measurement-range	1.00	0.00	m.v	0.34
	Test duration	1.00	0.62	m.v	0.35
	Handling	0.40	0.60	m.v	1.00
	Average	0.85	0.54	m.v	0.63

v.m=missing value

Figure 2: Aggregated Technometric Profile for Hormonal Diagnosis Kits - Germany, the United States, Japan and Israel, by Types



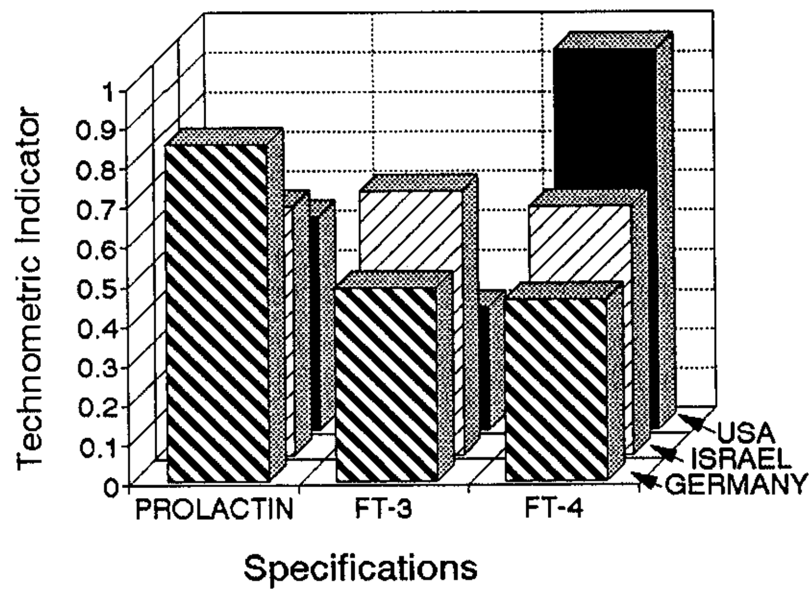
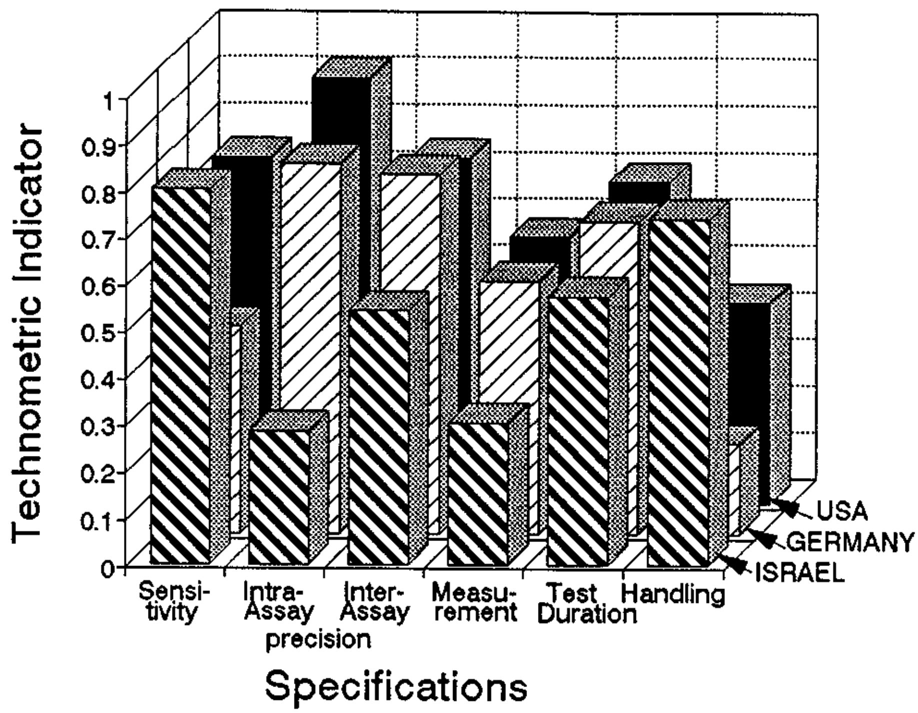


Figure 3: Aggrgated Technometric Profile for Hormonal Diagnostic Kits - Germany the United states, Japan and Israel, by Specifications



* **FT-3 free tri-iodothyronin**: Israel leads Germany and the United States. Israel's kit is highly automated, leading to high technometric scores for test duration and handling. Germany's strength here lies in its wide range of measurement.

* **FT-4 free thyroxin**: The U.S. product has a clear technological edge, with Israel second and Germany third, trailing in sensitivity, measurement range and handling.

* **Prolactin**: Here, Germany leads, with clear technological superiority in all characteristics except sensitivity and handling. Except for those two characteristics, in which Israel leads, the Israeli kit is mediocre compared to its rivals.

Aggregated over the six diagnostic kits, the United States has an overall technometric lead; its "score" is 0.72, compared with 0.58 for Germany and 0.52 for Israel. The German products trail largely because of lower scores in sensitivity and handling, characteristics that could stand improvement. Israeli kits are outstanding in sensitivity and handling.

Some statistical incoherencies might occur because data collection for the U.S. and Germany was completed in mid-1989, while Israeli data were collected in 1990. Nonetheless, Israel's relatively small number of biodiagnostic firms, compared to the U.S., the relatively short period of time in which these firms have been active in the industry, and their short time-to-market, points to a notable, and somewhat surprising, technological achievement for that country.

The attribute most in need of improvement in the Israeli kits is intra-assay precision, and to a lesser extent inter-assay precision. Precision is apparently a characteristic that laboratories place great weight upon in their decision which diagnostic kit to buy. For this reason, we believe that if the technometric characteristics were weighted according to market preferences, the gap between Israel and the U.S. might be even larger than shown in Figure 3.

Table 3 presents technometric values for diagnostic kits for the detection of several infectious diseases: HIV-1 (AIDS virus), CMV, [Cytomegalovirus], Rotaviruses [a virus that attacks the intestinal tract] and Chlamydia IgG and IgM (a venereal disease common in the West), for Israel and Germany. It should be emphasized that for Israel, the technometric values are for kits produced by a single producer, while for Germany there are in most cases more than one.

The technometric indicators for almost all of the kits include: Sensitivity, Specificity, Inter-Assay Precision and Intra-Assay Precision. For all of them, the units of measurement are per cent. One hundred per cent sensitivity means that all the infected sample tested will yield a positive result. (Sensitivity is for obvious reasons a highly important attribute, when the presence of infectious diseases is being tested). One hundred per cent specificity means that all of the samples that are not infected do not test positive. Sensitivity and specificity correspond to what is known in statistics as Type I and Type II error (rejecting true hypotheses, and accepting false ones, respectively).

* **AIDS detection [HIV-1]** -- this market amounts to hundreds of millions of dollars and is certain to grow rapidly as the illness itself spreads. Data exist for only two parameters -- specificity and sensitivity. Kits made in Germany, Japan and Israel are essentially equivalent in quality.

Table 3: Technometric Value for Infectious-Disease Diagnostic Kits, Germany the United States and Israel by Type and Specifications

Kits	Specifications	Technometric Value		
		Germany	USA	Israel
HIV-1	Sensitivity	1.00	1.00	1.00
	Specificity	0.87	1.00	0.84
	Average	0.94	1.00	0.92
Chlamydia Trachom. IgG	Sensitivity	0.76	m.v	1.00
	Specificity	0.00	m.v	1.00
	Intra-Assay Precision	1.00	m.v	0.78
	Inter-Assay Precision	0.59	m.v	1.00
	Average	0.59	m.v	0.95
Chlamydia Trachom. IgM	Sensitivity	1.00	m.v	0.67
	Specificity	0.00	m.v	1.00
	Intra-Assay Precision	1.00	m.v	0.80
	Inter-Assay Precision	0.65	m.v	1.00
	Average	0.66	m.v	0.87
Rotavirus Ag	Sensitivity	1.00	m.v	1.00
	Specificity	0.00	m.v	1.00
	Intra-Assay Precision	1.00	m.v	0.00
	Inter-Assay Precision	0.00	m.v	1.00
	Test Duration	0.00	m.v	1.00
	Average	0.40	m.v	0.80
CMV IgM	Sensitivity	1.00	m.v	1.00
	Specificity	0.85	m.v	1.00
	Intra-Assay Precision	0.58	m.v	1.00
	Inter-Assay Precision	0.43	m.v	1.00
	Average	0.72	m.v	1.00
CMV IgG	Sensitivity	0.50	0.17	1.00
	Specificity	0.72	1.00	0.98
	Intra-Assay Precision	1.00	m.v	0.75
	Inter-Assay Precision	0.83	m.v	1.00
	Average	0.76	0.59	0.93

v.m=missing value

- **Rotavirus**: while Israel appears to enjoy a technological lead over Germany in this area, the technometric index in this case somewhat exaggerates the technological gap between them; the Israeli kit enjoys a small advantage in "specificity" over Germany, but the arithmetic of the {0,1} metric makes it seem bigger. In inter-assay precision and test duration, the Israeli product does have a substantial lead.

- **Chlamydia**: Israeli kits lead, with demonstrable superiority in nearly all the key parameters. We note, however, that the German kit is represented in this case by a single product, and it is possible our survey failed to discover other kits of this sort made by German producers.

- **CMV**: Israeli kits lead those of Germany and the U.S. (For CMV IgG, we had only partial results for the United States). The German products trail, particularly in intra-assay and inter-assay precision. The American kit for CMV IgG led in specificity, but trailed in sensitivity.

Figure 4 shows the comparative aggregated technometric profile for the six infectious diseases diagnostic kits, by type.

Figure 4: **Comparative Aggregate Technometric Profile of Selected Kits Connected with the Diagnosis of the Infectious Diseases, by Type (CMV, Rotavirus, and Chlamydia), Germany and Israel**

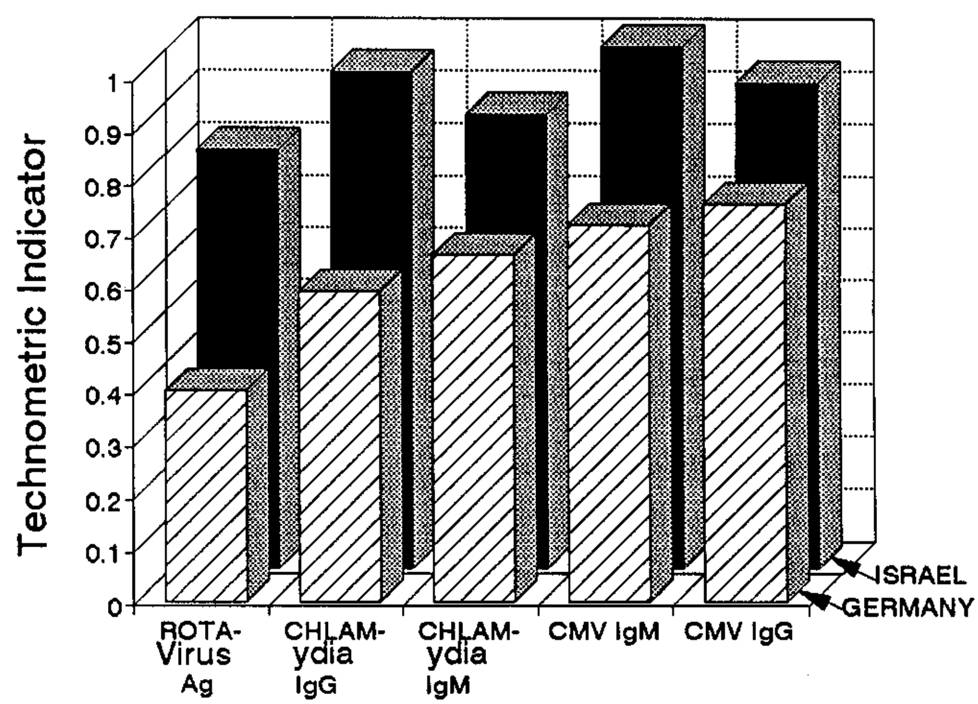
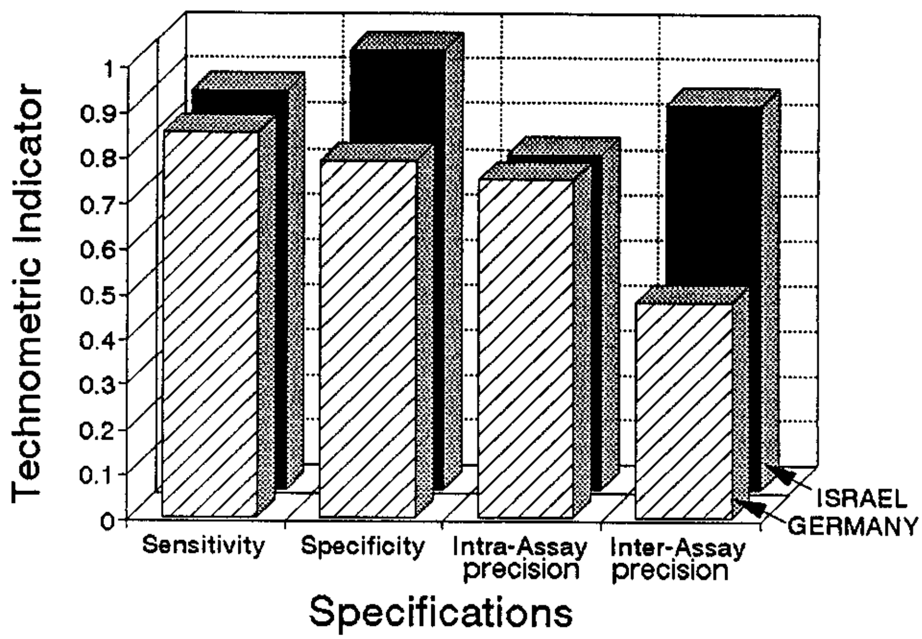


Figure 5 shows the aggregate technometric profile for all six infectious-disease diagnostic kits averages the technometric scores for each of four key parameters, for which data are available -- sensitivity, specificity, and intra-and inter-assay precision. The profile indicates that Israel enjoys a small but notable lead. Again, we note the fact that the Israeli kits appeared on the market for the first time as late as 1988. Our interviews with top management of the Israeli firms revealed the belief that sales will expand rapidly in future years, and second-generation products are likely to appear soon.

Figure 5: **Aggregate Technometric Profile for Six Infectious Disease Diagnostic Kits: Germany and Israel, by specification**



Prices & "Voice of the Market":

Noteworth by its absence from our analysis, and from the technometric approach in general, is data on prices and consumer preferences. Prices are not in general included as a product or process attribute in technometrics, since the objective is largely to assess data that measure product quality and relate that quality to its price; technometric specifications, thus, are in a sense one input in a study of the determinants of price. For example, in the "hedonic price index" approach, technometric scores can be used as explanatory variables in regression equations that try to explain product prices by variables measuring, among other things, quality. (See, for instance, Frenkel, Harel, Maital, Grupp and Koschatzky, [1993] for a study of identifying the source of market value for industrial sensors).

Consumer preferences can play a role, in providing information on the relative importance of various technometric attributes. While in this study we have simply taken the simple average of technometric scores, in aggregating, in some instances it is preferable to use weights elicited from surveys of product buyers. We note that in general, weighted averages are not very sensitive to small changes in weights; when only the most important technometric attributes are chosen from the outset -- a condition inherent in the method itself -- our experience has been that altering the weights of the specification, during aggregation, has not altered the overall technometric score significantly.

IV. Conclusions and Implications

These results suggest that for biodiagnostic products, Israel is in some cases at the frontier of technological excellence, according to the technometric index, and in other cases is close to it. This has occurred despite the fact that far less resources have been invested in biotechnology in Israel, compared to the other countries in the survey, Japan, Germany and the United States.

There is reason for concern that this area of proven technological excellence will not be translated into market share and export sales for Israel. The eight participating firms in our survey report a lack of risk capital, and difficulty in marketing and distributing their products. Four of the eight firms are wholly-owned subsidiaries of foreign companies, suggesting that much of the benefits of excellence at the R&D stage will accrue abroad.

Moreover, Israel's industrial and R&D policy has been slow to implement many of the Katzir Committee recommendations and to support biotechnology, and biodiagnostics in particular, as a promising area of excellence.

A primary reason for the failure of government ministries to provide adequate support for this product area is that biotechnology companies are small, and the current size of their export sales is also small, relative to other industrial branches. Ministries prefer dealing with large companies -- even when small science-based firms meet the key criterion of exporting a large fraction of their output.

Thus, the field of biotechnology is a particular case of a more general problem in Israel -- severe constraints facing nearly all high-tech startups as they make the difficult transition from successful R&D projects to producing, marketing and distributing products and processes in distant markets. There is a danger that Israeli expertise in this area will be recognized by foreign firms , who will then purchase it, causing the employment, exports and profits to accrue outside of Israel. Israel has already experienced a sizeable export of its knowhow -- in the area of agricultural technology, for example -- and later found its products were competing with foreign ones built with original Israeli design and technology.

Policy issues in biodiagnostics, revealed in part by the technometric indexes, have also appeared in other Israeli industries, including for example the plastics industry. This industrial sector, studied by the S. Neaman Institute (see H.D. Frenkel, 1990) is characterized by numerous small firms, which are secretive about their products and technologies (for understandable reasons), and the firms in it are highly competitive in their business strategies. Yet ironically, in order to compete abroad it is vital for them to cooperate with their competitors, because few of them can alone mount successful marketing and distribution efforts in distant foreign markets. {See Maital [1991] for a discussion of the role of joint ventures}.

This is where government policy can play a major role, as mediator, initiator and peacemaker. Joint marketing ventures could be established, in cases where technometric and other quantitative indexes reveal favorable prospects for competing abroad. Investment in such efforts are no less important than supporting Research and Development and providing venture capital. Yet repeatedly, fruitful public investments and support at the initial stage of the innovation cycle are frustrated by the lack of timely investments at the later stages, production and especially marketing.

There is widespread awareness in Israel of her deficiencies in marketing skill, which result in shares of world markets far below what the technological quality of Israeli products otherwise would merit. That awareness has not yet led to decisive action or sizeable allocation of resources to solve it.

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The Relation Between the Average Complexity of High-Tech Products and Their Diversity:

An Empirical Test of Evolutionary Models

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Abstract

What is the relation between the average level of complexity that characterizes a product's technology, and the degree of diversity of that technology across rival firms? Evolutionary theories of innovation and technical advance are consistent with either a direct or an inverse relation. The issue thus becomes an empirical one.

This paper uses a unique database containing detailed quantitative data on the specifications of 12 high-tech product groups for the U.S., Japan and selected European countries, for 1982, for both products and processes. It is found that the more complex the technology, the less diverse is the technology of rival firms that produce the product. This is consistent with the following evolutionary process: Economies of scale and scope inherent in high-level technologies require firms who adopt them to dispose entirely of older technologies, in order to remain competitive; at the same time, older, simpler technologies continue to exist and permit wide diversities among firms who pursue "niche" market strategies.

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Introduction

For rival firms within a given industry or product-group, are product and process technologies uniform in their level of complexity? Or in contrast, are such technologies highly diverse?

Evolutionary theories of innovation are consistent both with models in which variations in technological quality diminish as the technology ages -- through a kind of competitive 'natural selection' -- or with models in which such variations increase, as conservative firms manage to co-exist with more innovative ones. The issue thus becomes an empirical one.

This study proposes a new measure for the diversity of technology, based on the technometric indexes of Grupp [Grupp, 1991, 1993; Grupp and Hohmeyer, 1985, 1988], and applies that measure to the estimation and comparison of the relation between the average level of complexity in technology, and its diversity across firms, principally those in the United States and Japan. Use is made of a unique Japanese database that provides detailed cross-country quantitative data on product and process specifications for 12 high-tech product groups.

The structure of this paper is as follows. Part 1 surveys the relevant evolutionary theories of innovation. Part 2 defines the technometric indexes that are used to measure the level and diversity of technology. Part 3 describes the database that permits us to generate empirical estimates of those indexes for the U.S., Japan and some European countries. Part 4 presents the main empirical results and examines their implications. The concluding section suggests some directions for future research.

1. Evolutionary Theories of Innovation

One of the most powerful paradigms for technological advance is Schumpeter's model of the evolutionary process [Schumpeter, 1939, 1950, 1961] and the related interpretations and extensions of the model [Nelson and Winter, 1982]. According to this model, ideas, innovations and technologies compete for resources in a market environment. Basic and applied research, like mutations, generate variations within "species" of products and processes. These variations are then sorted by a process of "natural selection" -- in economics, competitive rivalry for profits and market share. Ultimately, the technology of products and processes most suited to the existing market conditions triumphs. This evolutionary process may be long, time-consuming and somewhat inefficient in the short run.

Schumpeter perceived this dynamic process as the very essence of capitalism. He wrote:

> "In dealing with capitalism, we are dealing with an evolutionary process...The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates. ...The opening up of new markets, foreign or domestic, and the organizational development from the craft shop and factory to such concerns as U.S. Steel illustrate the same process of industrial mutation -- if I may use that biological term -- that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in." (Schumpeter, 1950, pp. 82-83).

In his books and articles, Schumpeter repeatedly cautioned against embracing biological evolution and natural selection in its entirety as a model for innovation. Nelson, too, has noted that there are major differences between the biology of evolution and the evolution of technology:

> "...the feature that most sharply distinguishes the evolutionary process through which technology advances, from biological evolution, is that new findings, understandings, generally useful ways of doing things, do not adhere strictly to their finder or creator but are shared, at least to some extent. In many cases, the sharing is intentional, in others despite efforts to keep findings privy." [Nelson, 1990, p. 194].

One major difference between biological and economic evolution, as Nelson observes, lies in learning and imitation. Economies, unlike ecologies, evolve in part when "firms watch other firms and try to learn from their experience", Nelson wrote [1990, p. 211].

A somewhat different evolutionary theory, associated with Utterback, suggests that a wide range of technological innovations ultimately leads to a *dominant product design* -- a new product with a fairly standard, common set of features -- that enforces or encourages standardization, and narrows the variety of possible new products down to a few "species" or standard products. [Utterback and Abernathy, 1975].

Some of these Schumpeterian "learning" models posit that as a technology design configuration ages, more and more firms gain the opportunity to learn and use it, as they observe other firms and adapt and acquire their technology. This suggest the following hypothesis:

> **"Firms learn with time"**: *the older (and presumably, less complex) a technology is, the smaller should be the degree of diversity in the level of technology across rival firms.*

However, while learning, diffusion and market forces operate to narrow technological diversity over time, a different and opposing evolutionary force -- one that works to *broaden* diversity in technological complexity and leads to product differentiation. In order to meet customer wants, product differentiation often presents a do-or-die decision -- either adopt costly new technologies and replace existing plants with new ones, [because the new technology is optimally efficient at such high levels of output that it does not pay to run old product variants and new ones in parallel] or remain solely with the old plant and equipment. Once firms do begin adopting the new level of quality and complexity, it is often so cost-effective or high-quality that competing firms face another fateful either-or choice: Either adopt the new technologies that competitors have implemented, or leave the industry entirely.

In his book *Scale and Scope*, business historian Alfred Chandler notes two examples in which powerful economies of scale and scope led major companies to dominate their industries through new technologies, in a very short space of time. In the U.S. in the 1880's, the Standard Oil trust built massive a massive new kerosene plant, whose economies of scale slashed production costs by an order of magnitude and generated large profits. In Germany, at the same time, Bayer, Hoechst and BASF built huge new chemical plants capable of producing a large number of different dyes on the same chemical base. The resulting economies of scope reduce production costs dramatically and gave the three above-mentioned firms a dominant position in the market.

This particular evolutionary process, in which dramatic economies of scale and scope make it imperitive to adopt new technologies, implies:

> **Do-or-Die Decision**: *the newer and more complex the technology, the smaller the degree of diversity across different firms.* Firms must either adopt the new technology quickly, or "die" (leave the industry). Over time, diversity in technology increases, as firms find "niche" strategies and exploit market segments that larger, more technologically-advanced firms ignore.

The two contradictory hypotheses cannot in fairness be labelled "Schumpeter vs. Chandler", because Schumpeter's views themselves were somewhat ambiguous, and changed and evolved over time.

As Heertje (1992) points out, Schumpeter's earlier writings emphasize the key role played by small, new firms who act as technology pioneers. Thus, Schumpeter wrote in 1939 that "even in the world of giant firms, new ones rise and others fall into the background. Innovations still emerge primarily with the "young" ones, and the "old" ones display as a rule symptoms of what is euphemistically called conservatism.... [our model] explains why innovations are not carried into effect simultaneously and as a matter of course ...by all firms" [1939, p. 97]. This is "firms learn with time".

But in *Capitalism, Socialism and Democracy*, Heertje notes that Schumpeter "seems to have lost sight of the relative importance of new, often small firms as the carriers of minor and sometimes major innovations, not to speak of their role in the process of invention" (Heertje, 1992, p. 10). There, the emphasis is on scale, and on "do-or-die".

In this sense, both hypotheses may be viewed as Schumpeterian. The evolutionary model of innovation in capitalist development is thus consistent with either: a) diminishing diversity in technological quality, as the technology ages, or b) increasing diversity. The issue then becomes an empirical one -- appealing to data and facts to determine which hypothesis is valid.

It is possible to point to specific technologies that fit either the "firms learn with time" or the "do-or-die" hypothesis. For instance, Ray [1989] describes four process technologies, for which the equipment incorporating them "is usually of large capacity, often large enough to make the older technique wholly redundant...when built, the new plant takes over huge quantities of output, in large indivisible chunks, from the earlier technology. Thus diffusion is swift."

These four technologies are: oxygen steelmaking, continuous casting, the tunnel kiln and the float glass process. Two newer technologies also belong in this category, he believes: robots and automatic-flexible manufacturing systems.

Here, firms face all-or-nothing decisions. Those that adopt the technologies must replace older ones completely. Those that will not, or cannot afford to, may quickly disappear. This type of new technology does not leave much room or much time for differentiation in technology or for "varieties of species".

But not all technologies are of this sort. There are some more "divisible" technologies. Ray cites as examples shuttle looms and numerically-controlled machine tools. In Europe, about two-thirds of all cotton-type looms are shuttle looms of older vintage and shuttleless looms, Ray observes; and the share of numerically-controlled machine tools is far lower. Here, new and old technologies co-exist, leaving a wide variance or range across firms in the level of technological advance.

The precise nature of the process through which technology diffuses through an economy and from one economy to another --and through which one firm learns from another -- is very important, because it is a crucial determinant of competitive advantage. It has been widely claimed and believed that the Japanese efficiency in exploiting and diffusing existing technology gives that country an advantage over slower-moving competitors. Nelson has argued that "the Japanese system is not of fundamentally different design from the American but rather is a different and perhaps more effective model in the same broad class" [1990, p. 211]. Attaining a better understanding of the technology diffusion process, in general, and empirically testing which of the above two hypotheses is correct, may have important policy implications.

Empirical studies of evolutionary models in general, and the diffusion of technology in particular, face severe measurement problems. Ray's studies of the life-cycle of several technologies [1989] measure diffusion by "the proportion of the new machines [embodying a new technology] in the total stock of productive equipment." Ray notes that "lack of data prevents measuring diffusion in another, perhaps more informative manner, namely the *contribution of the new technology to total production*".

The next section suggests a new, operational technique for measuring both the level of best-practice technology and its degree of diversity across firms.

2. The Technometric Approach to Measuring Technological Quality and Complexity

A technometric index of product and process quality has been developed by Grupp and Hohmeyer (1985; 1988). Technometrics begins by observing that every product or process has a set of key attributes that define its performance, value or ability to satisfy customer wants. Most of these attributes can be quantified - for instance, in the case of solar cells, such attributes as intrinsic cell efficiency, flash current, standard power, voltage, bulk factor, module efficiency, power per unit of area, power per unit of weight, and warranty time can all be defined and measured in physical units.

Each of these attributes has a different unit of measurement. Problems then arise in aggregating attributes to build a single quality index. The technometric indicator surmounts this difficulty by converting each measured attribute into a [0,1] metric, enabling construction of weighted averages, etc., and permitting comparisons across products, firms, industries and countries.

Formally, let subscripts f, i, j and k represent firms, products, product attributes or characteristics, and subgroup (industry or country), respectively. (For our purposes here, the subscript "k" will represent different countries -- namely, the U.S., Japan, or selected European countries). Let $K_f(i,j,k)$ represent the measurement of an attribute for given f, i, j and k.

The technometric indicator, K* , is defined, on the (0,1) metric, as the maximum national performance of attribute j, product group i :

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

where:

$K_{max}(i,j,k)$ = the highest value of product characteristic "j" for product "i", for country k, achieved by some firm in that country.

$K_{min}(i,j,k_{min})$ = the **lowest** value of product characteristic "j", among **all** countries k, produced by some firm in country kmin.

$K_{max}(i,j,k_{max})$ = the **highest** value of product characteristic "j", among **all** members of country k, produced by some firm in country k_{max}.

It is possible to aggregate K* across all key attributes of a product or process, in order to achieve an aggregate K* measure for the product or group of products. This aggregate technometric measure can then be correlated with other variables to determine the link between technological excellence and, for instance, market success. K* can also contribute to policymaking, indicating products or sectors where a country has a competitive advantage, technologically, and hence worthy of investment to advance marketing and sales efforts in foreign markets and to further improve R&D and production efficiency at home.

Constructing technometric indexes, especially for cross-country comparisons, is costly and highly data-intensive. Fortunately, a database exists containing technometric specifications for some 42 different product groups and processes. The data were compiled in 1982 in Japan. [Agency for Industrial Science & Technology, 1982].

We shall now describe these data and then use them to test our two hypotheses. (Unfortunately, like so many costly databases, this one was not updated; like an unsuccessful mutation, its brief but useful lifetime begins and ends with 1982).

3. The JATES/AIST database

In a survey sponsored and funded by the Japanese Agency for Industrial Science and Technology, Japanese experts were asked in 1982 to evaluate specifications for 42 different product groups, for the United States, Japan, and selected European countries. (For an early analysis of these data, see Grupp and Hohmeyer, 1986). These product groups included high-technology, medium-technology and low-technology products. The data include 984 specification items and 5,584 data points -- experts were asked to estimate maximum, minimum, and model values for each specification, for Japan and the United States, and for some foreign countries as well.

Of the 42 product-groups, twelve were in the high-tech realm. High-tech was defined as a product group within a 3-digit industry (according to the Standard Industrial Classification) characterized by Research and Development expenditures amounting to at least 3.5 per cent of sales turnover. The twelve high-tech product-groups selected for study were: 1. optic fibers. 2. industrial assembly robots. 3. ultra-high-tension transformers. 4. video tape recorders. 5. large computers. 6. digital x-ray equipment 7. LSI memory 8. semi-conductor lasers. 9. passenger cars. 10. general ships. 11. civilian aircraft. 12. LSI probers (large-scale integrated circuit probers, or sensor, designed to determine whether LSI microchips are defective).

The experts provided their quantitative estimates of technical specifications $K_f(i,j,k)$, including, for each, K_{max}, K_{min}, and K_{mode} (the modal value of $K_{i,j,k}$ for each specification, for firms in each country). They also indicated whether the specification was "standard" (coded S, in column D), or "key" (coded K, in column D), meaning of major future importance.

Detailed descriptions of a sample of the raw data (for optic fibers), and the manner in which K*range and K*mode were computed, are shown in Table 1. All told, we extracted and analyzed 844 data points.

K_{mode} was converted to the [0,1] technometric index K^*_{mode} through:

$$[2] \quad K^*_{mode}(i,j,k) = [K_{mode}(i,j,k) - K_{min}(i,j,k_{min})]/[K_{max}(i,j,k_{max}) - K_{min}(i,j,k_{min})]$$

That is, K^*_{mode} was put into the [0,1] metric for each country by expressing it as a fraction of the difference between the global state-of-the-art value (the highest value of the specification available anywhere) and the value for the lowest-performing (and presumably, least costly) specification anywhere.

The measure of the degree of diversity in technological specifications across firms in the same product-group and country, K_{range}, was taken as the difference in the K value across firms in the same country, $K_{max}(i,j,k) - K_{min}(i,j,k)$, expressed as a fraction of the global range in the K value for all countries, within the given product specification:

$$[3] \qquad K^*_{range}(i,j,k) = \frac{K_{max}(i,j,k) - K_{min}(i,j,k_{min})}{K_{max}(i,j,k_{max}) - K_{min}(i,j,k_{min})}$$

The two competing hypotheses could then be tested statistically by examining whether the relation between K^*_{range} and K^*_{mode} is direct or inverse, for the 12 product groups, for the U.S., Japan, and such European countries as the U.K. and Germany.

Table1. Data on product and process specifications, optic fibers, for U.S., Japan and Great Britain, 1982
Source: Agency for Industrial Science and Technology (1982).

Specifications	Units	Type	Product Key	Expert weight	Agg-regate weight	Max Japan	Min Japan	Mode Japan	Max USA	Min USA	Mode USA
A	B	C	D	E	F	G	H	I	J	K	L
Attenuation(.85μm)	db/km	product	S*	0.505	0.039	3.00	2.40	2.50	3.50	2.50	3.00
Attenuation(1.3μm)	db/km	product	S	0.693	0.053	1.00	0.40	0.70	1.00	0.50	0.70
Attenaution (1.3μm)	db/km	product	S	0.815	0.063	0.50	0.40	0.50	0.70	0.60	0.40
Bandwidth (6db. 0.85μm)	MHz/km	product	S	0.725	0.056	1000.00	500.00	1000.00	1000.00	500.00	800.00
Bandwidth (6db. 1.3μm)	Mhz/km	product	S	0.845	0.065	2000.00	100.00	1500.00	1300.00	80.00	1000.00
Transmission range(100mbits)	km	product	S	0.690	0.053	300.00	15.00	15.00	25.00	10.00	15.00
Transmission range(400mbits)	km	product	S	0.690	0.053	40.00	20.00	20.00	30.00	20.00	20.00
Power loss (0.85 μm)	db/km	product	S	0.560	0.043	0.20	0.10	0.10	0.20	0.10	0.10
Breakdown force (50%,1.25μm)	kg/mm2	product	S	0.715	0.055	600.00	500.00	550.00	600.00	500.00	500.00
Lifetime (standard conditions)	years	product	S	0.690	0.053	100.00	30.00	50.00	100.00	50.00	50.00
Purity	ppb***	process	K**	0.435	0.034	3.00	0.00	1.00	1.00	0.00	0.20
De-Off process (water quantity)	ppb*	process	K	0.930	0.072	20.00	0.20	1.00	15.00	1.00	10.00
Control of refraction	.01%	process	K	1.000	0.077	13.30	0.10	1.00	1.00	1.00	1.00
Control of diameter (1.25μm)	μm	process	K	0.505	0.039	2.00	0.50	1.00	2.00	0.50	1.00
Control of diameter (50μm)	μm	process	K	0.505	0.039	2.00	1.00	1.00	2.00	1.00	2.00
Loss from nonhomogeneity	db/km	process	K	0.780	0.060	0.20	0.05	0.10	0.10	0.10	0.10
Control of temp. gradients	indexed	process	K	0.780	0.060	100.00	100.00	100.00	100.00	90.00	90.00
Control of impurities	indexed	process	K	0.430	0.033	100.00	100.00	100.00	100.00	90.00	100.00
Flame Method	indexed	process	K	0.360	0.028	100.00	100.00	100.00	100.00	100.00	100.00
Etching	indexed	process	K	0.215	0.017	100.00	100.00	100.00	100.00	100.00	100.00
Color coating	indexed	process	K	0.360	0.028	100.00	100.00	100.00	100.00	80.00	100.00
Control of micro-marginal losses	indexed	process	K	0.425	0.033	100.00	90.00	100.00	100.00	80.00	90.00

*S - Standard; **K - Key; *** parts per billion

Table1. Data on product and process specifications, optic fibers, for U.S., Japan and Great Britain, 1982
Source: Agency for Industrial Science and Technology (1982) - continued

Specifications A	Max GBR M	Min GBR N	Mode GBR O	Max Max P	Min Min Q	Range Japan R	Range USA S	Range GBR T
Attenuation(.85μm)	4.00	2.50	3.00	4.00	2.40	0.60	1.00	1.50
Attenuation(1.3μm)	1.00	0.70	1.00	1.00	0.40	0.60	0.50	0.30
Attenaution (1.3μm)	0.60	0.40	0.50	0.70	0.40	0.10	0.10	0.20
Bandwidth (6db. 0.85μm)	1000.00	400.00	500.00	1000.00	400.00	500.00	500.00	600.00
Bandwidth (6db. 1.3μm)	1300.00	1000.00	1000.00	2000.00	80.00	1900.00	1220.00	300.00
Transmission range(100mbits)	30.00	15.00	20.00	30.00	10.00	15.00	10.00	15.00
Transmission range(400mbits)	30.00	20.00	20.00	40.00	20.00	20.00	10.00	10.00
Power loss (0.85 μm)	0.20	0.10	0.10	0.20	0.10	0.10	0.10	0.10
Breakdown force (50%,1.25μm)	550.00	500.00	500.00	600.00	500.00	100.00	100.00	50.00
Lifetime (standard conditions)	100.00	50.00	50.00	100.00	30.00	70.00	50.00	50.00
Purity	1.00	0.00	0.20	3.00	0.00	3.00	1.00	1.00
De-Off process (water quantity)	18.00	1.00	10.00	20.00	0.20	19.80	14.00	17.00
Control of refraction	1.00	1.00	1.00	13.30	0.10	13.20	0.00	0.00
Control of diameter (1.25μm)	2.00	0.50	2.00	2.00	0.50	1.50	1.50	1.50
Control of diameter (50μm)	2.00	1.00	2.00	2.00	1.00	1.00	1.00	1.00
Loss from nonhomogeneity	0.10	0.10	0.10	0.20	0.05	0.15	0.00	0.00
Control of temp. gradients	100.00	90.00	100.00	100.00	90.00	0.00	10.00	10.00
Control of impurities	100.00	90.00	100.00	100.00	90.00	0.00	10.00	10.00
Flame Method	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00
Etching	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00
Color coating	100.00	80.00	90.00	100.00	80.00	10.00	20.00	10.00
Control of micro-marginal losses	90.00	80.00	90.00	100.00	80.00	10.00	20.00	10.00

P = MAX(G,J,M)   Q - MIN(H,K,N)   R = G-K   S = J-K   T = M-N

If "firms learn with time" is valid, then K^*_{range} should vary inversely with K^*_{mode}. If "do-or-die" is valid, then K^*_{range} should vary directly with K^*_{mode}.

All told, the part of the database we extracted, for the 12 high-tech products, comprised data points including a value for K^*_{range} and K^*_{mode}, for each particular specification, for the twelve abovementioned product groups.

Thus, for each product group, and each country, a value of K^*_{range} and K^*_{mode} was computed, by taking the simple average of K^*_{range} and K^*_{mode} values for all of the specifications given for the specific product group. (It was found that weighting each specification by a coefficient indicating its relative importance did not affect the results, but simply added more complexity; we therefore used a simple average).

The data for K^*_{range} and K^*_{mode} are shown below, in Table 2.

In addition to K^*_{range} and K^*_{mode}, we extracted from the database five additional variables that characterized each specification:

1. **the product group**, described with a 2-digit code, from 1 to 12;
2. **product or process** specification;
3. **future importance of the specification**: yes, if judged by experts to be of likely future importance, coded K; no, coded S;
4. **the relative importance of the specification** (a weight, given by the experts, normalized to add to one). (As noted above, these weights were found to have virtually no effect on the empirical results, and hence were not used for the final computations as presented here; aggregation was done by taking simple arithmetic averages).

Table 2. Values of K*range and K*mode, 12 Technology-Intensive Product Groups, U.S., Japan and other Countries, 1982

Product	All range	All mode	Japan range	Japan mode	U.S. range	U.S. mode	Other range	Other mode	No. of experts	No. of Specs
Optic fibers	0.638	0.553	0.668	0.575	0.644	0.534	0.603	0.55	9	22
Indust. robots	0.284	0.56	0.669	0.521	0.095	0.739	0.089	0.422	5	8
Ultra High-tension transformers	0.288	0.788	0.232	0.855	0.25	0.743	0.381	0.766	8	15
video tape recorders	0.517	0.517	0.537	0.697			0.497	0.338	7	19
large computers	0.443	0.527	0.514	0.573	0.372	0.481			5	16
digital radiography	0.259	0.644	0.234	0.522	0.264	0.825	0.277	0.584	3	20
LSI memory	0.566	0.464	0.668	0.46	0.463	0.469			5	44
Semiconductor lasers	0.457	0.53	0.537	0.666	0.457	0.53	0.46	0.45	5	46
Cars	0.444	0.577	0.453	0.717	0.429	0.513	0.453	0.5	6	35
Ships	0.352	0.712	0.401	0.857	0.356	0.746	0.298	0.534	7	23
Civ. aircraft	0.449	0.627	0.59	0.366	0.221	0.883	0.534	0.631	11	36
LSI probers	0.383	0.58	0.638	0.456	0.128	0.703			6	21

Source: A.I.S.T. (1982) and own calculations (see table 1)

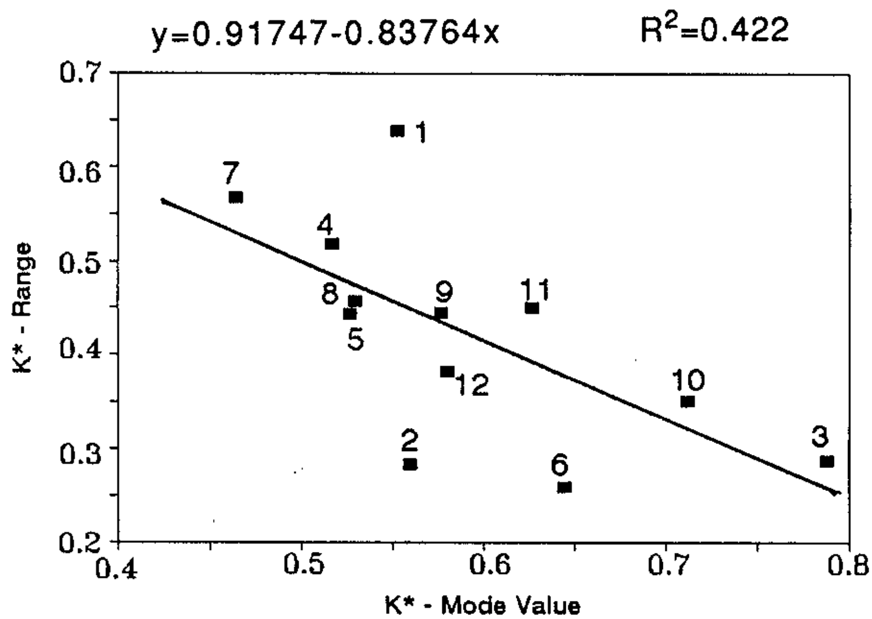
4. Empirical Results

Figures 1, 2 and 3 plot K^*_{range} against K^*_{mode} for the U.S., Japan and selected European countries; Japan alone; and the United States alone, respectively. Figure 1 shows a statistically-significant negative relation between the level of technology and its range or variance, for all of the countries in the database taken together.

This result is replicated when Japan (Figure 2) and the United States (Figure 3) are examined in isolation.

This suggests that the "do-or-die" (economies of scale and scope) hypothesis is more compatible with the data than the "firms- learn- over-time" hypothesis. That is, the higher the modal level of technological excellence across firms, the less likely it is that firms will differ widely. This appears to be the case in all the countries included in the database.

Figure 1
Relation between Average Complexity of Technology, and its Diversity, U.S., Japan, Europe: 12 High-Tech Products, 1982



1. optic fibers. 2. industrial assembly robots. 3. ultra-high-tension transformers. 4. video tape recorders. 5. large computers. 6. digital radiography 7. LSI memory 8. semiconductor lasers. 9. passenger cars. 10. general ships. 11. civilian aircraft. 12. LSI probers

Figure 2
Model Level of Technology vs. Diversity, 12 High-Tech Products, 1982
United States

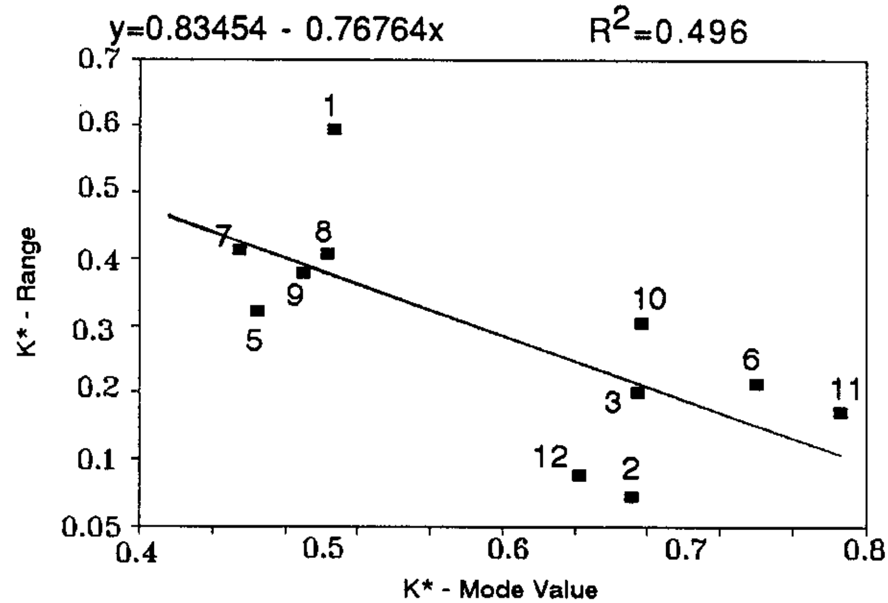
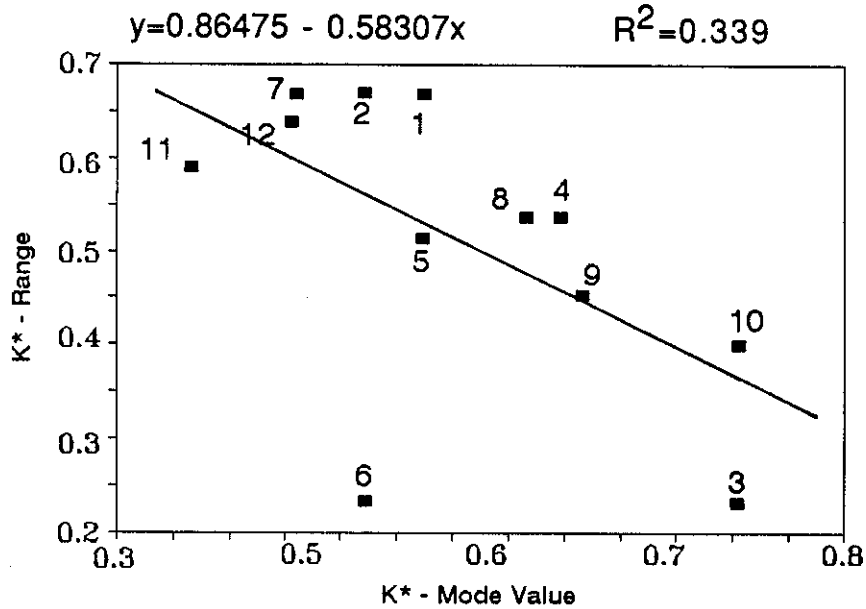


Figure 3
Modal Level of Technology vs. Diversity, 12 High-Tech Products, 1982
Japan



1. optic fibers. 2. industrial assembly robots. 3. ultra-high-tension transformers. 4. video tape recorders. 5. large computers. 6. digital radiography 7. LSI memory 8. semiconductor lasers. 9. passenger cars. 10. general ships. 11. civilian aircraft. 12. LSI probers

Process vs. Product:

We performed a t-test on the average values of both K^*_{range} and K^*_{mode}, for *product* specifications vis a vis *process* specifications, to see whether there were significant differences across the whole database (i.e. all 844 data points, divided into 657 product specifications and 187 process specifications):

MEAN VALUES of K^*_{mode} and K^*_{range}

	K^*_{mode} product	K^*_{mode} process	K^*_{range} product	K^*_{range} process
	.585	.618	.410	.500 *
N =	657	187	657	187

* significant at $p < 0.01$

For the whole sample, while the modal *level* of technologies did not differ significantly for products compared with processes, the technometric range across firms did differ significantly, with substantially higher variation existing for processes than for products.

Interestingly, the inverse relation between K^*_{mode} and K^*_{range} noted above in Figures 1-3 held well for *product* specifications, but not for *process* specifications, as shown in the two regression equations below (the t-values of slope coefficients are shown in brackets below the coefficient):

PRODUCTS (N = 657 specifications):

$$K^*_{range} = 0.497 - \underset{(3.88)}{0.150}\ K^*_{mode}, \qquad R^2 \text{ adj.} = 0.021$$

PROCESSES (187 specifications)

K^*_{range} = 0.550 - 0.077 K^*_{mode}, R^2 adj. = 0.006

(1.05)

While the coefficient of K^*_{mode}, was statistically significant for the "product" regression, it was not statistically significant for the "process" regression. This implies that the "either-or" hypothesis holds more strongly for product technology than for process technology, where presumably "firms-learn-with-time" dominates.

Future importance:

Another t-test comparison was conducted for specifications judged to be of future importance, against those which the experts thought would not be important in the future. The difference in K^*_{range} between the two groups was *not* statistically significant -- implying the experts foresaw no substantial rise in the degree of variation across firms.

However, expectedly, there *was* a statistically significant difference in K^*_{mode}, with specifications perceived to have future importance being technologically more advanced than those thought important now but less important in future:

MEAN VALUES of K^*_{mode} and K^*_{range}

	K_{mode}		K_{range}	
Future importance?:	NO	YES	NO	YES
	.454	.687*	.403	.448

* significant at p<.01

We then chose to regress K^*_{range} on K^*_{mode}, first for the 344 specifications adjudged "important now but not likely to be important in future", and then on the 500 specifications adjusted "important now and in future".

For the first "unimportant in future" group, there was no significant correlation between K^*_{range} and K^*_{mode}. But for the second, "important in future" group, the slope coefficient was negative and strongly significant statistically (t-value in brackets):

$$K^*_{range} = .60753 - (0.20576)\ K^*_{mode}, \quad R^2(adj) = .040;$$
$$(4.69) \qquad N=500$$

This result suggests that much of the inverse relation between the range and modal value of technological quality stems from "forward- looking" specifications -- those which are likely newer, more technologically-advanced, and hence have had less time for evolutionary processes to work themselves out.

In a sense, then, the data support *both* seemingly-contradictory hypotheses. The "do-or-die" hypothesis is supported by the inverse relation between K^*_{range} and K^*_{mode}; but the "firms learn with time" hypothesis is supported by the fact that the inverse relation holds only for "future-important" specifications, not for those unlikely to be important in the future.

Japan vs. the U.S.:

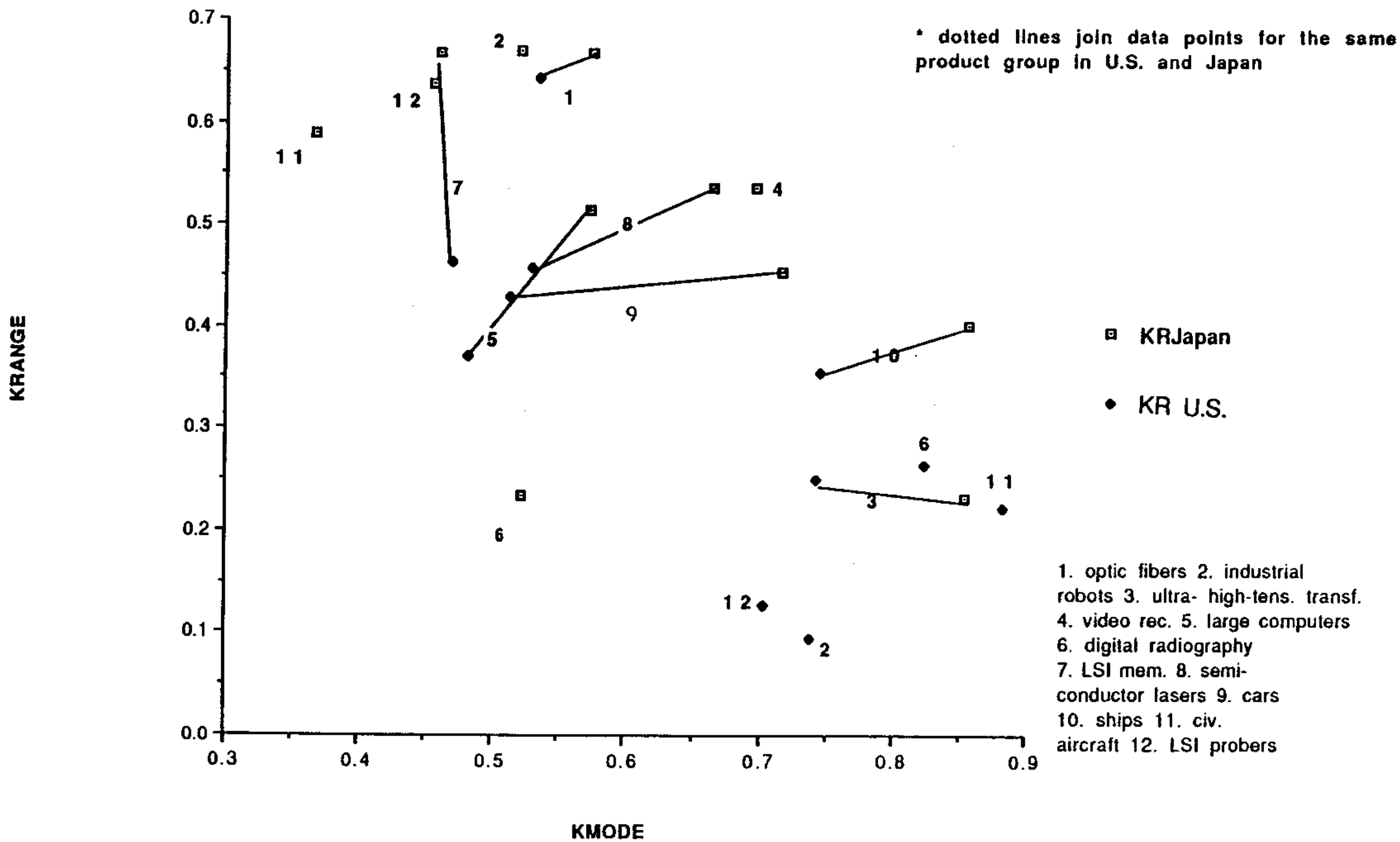
An interesting result is obtained when the diagram for Japan is overlaid on the diagram for the United States. (See Figure 4). This indicates that:

a) in 1982, for the dozen high-tech product groups, the United States appears to enjoy technological parity with Japan, in the sense that the values of K^*_{mode} for the U.S. and Japan seem roughly equal; and

b) the values of K^*_{range} in technological specifications across firms appeared to be significnatly *higher* for Japan than for the United States.

To test this statistically, a t-test comparison was done for Japan and the U.S., for the whole sample of 844 specifications. K^*_{mode} did not differ significantly for Japan vs. the

Fig. 4. Relation Between Level of Technology and its Diversity, U.S. vs. Japan, 1982, 12 High-tech groups



U.S. However, K^*_{range} (technometric range) for Japan was significantly greater than that for the United States -- which runs counter to impressions of Japan's allegedly ubiquitous high-quality technology:

MEAN VALUES of K^*_{mode} and K^*_{range}

K_{mode}		K_{range}	
Japan	United States	Japan	United States
.600	.624	.529	.356 *

* significant at $p < .01$

Between 1982 and 1990, Japan experienced rapidly growing trade surpluses with the United States. Though it is likely that Japan's technological deficit with respect to the U.S. narrowed during this period -- for instance, in industrial robots -- nonetheless the data appear to confirm the well-known conclusion that Japanese skill in marketing and distribution explains more of that country's export success than underlying technological excellence.

At the same time, Figure 4 reveals an interesting fact about the structure of Japanese industry. Many large Japanese manufacturing firms -- especially those in the automobile industry -- rely on a large network of small-scale parts suppliers. While these suppliers are held to rigorous quality standards, they are often not technologically advanced. This may in part explain the larger across-firm range of technological excellence in Japan than in the United States, even though the American economy is more than twice the size of Japan's, and has more than twice the number of firms.

Spurious correlation?

The Japanese database was constructed by canvassing experts, and asking each to supply values for specifications, for each product group, including their modal values, and maximum and minimum levels. The number of experts varied across the 12 different product groups, from 5 for product groups 2, 5, 7 and 8, to 11 for product group 13. (See Table 1). It could be argued that a product group with a larger number of experts supplying data would naturally have a larger range or variance in those estimates -- the more persons supplying responses, the greater the likelihood of extreme values.

To test for this source of bias, we correlated the K^*_{range} with the number of experts, for all countries, for the U.S. and for Japan. In each case, the correlation was very close to zero and, of course, statistically insignificant. This implies that there was no systematic relation between the number of experts for each product group and the size of diversity for that group.

5. Conclusion

Our main finding is this: For a dozen high-tech product groups, there is a consistent, inverse relation between the *level* of technological quality -- measured quantitatively by product attributes --and its *diversity*, measured by the range of values those attributes take on, across firms. This relation exists both in Japan and in the United States. The degree of diversity of technology in Japan is as great as, or greater than, that of the United States.

This inverse relation is consistent with the evolutionary view of technical change that emphasizes the economies of scale and scope inherent in new, costly technology, and which downplays the importance of learning effects through which firms become more homogeneous in their technologies over time, at least with regard to significant future technologies. T hus, our results support the variant of the evolutionary model of technical progress that is based on the "do-or-die" notion of technology adoption.

The policy implications of this result are unclear. One might conjecture that in some sense, a larger "variety of species" in technology may be preferable to a larger degree of uniformity among firms. The market is thus provided with a greater degree of choice between costly state-of-the-art products and simpler, cheaper ones. The marketplace itself can then "vote" for different technologies, as they compete for survival, and work efficiently to ensure the "survival of the fittest". What becomes significant, then, for industrial policy, is not that there exist plants that are relatively backward, technologically, but whether there are at the same time plants that are at the global, state-of-the-art frontier. Encouragement of technological excellence may work to increase the range of technological excellence across firms, because many firms may choose not to strive for the frontier but rather remain in the relatively cheap and safe hinterland. This heterogeneity may in fact be desirable, just as the wide variety of species serves a function in biology by efficiently filling all the available biological spaces and niches.

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Exporting Goods ... or Knowhow

An Empirical Comparison of the Relation between Scientific and Technological Excellence and Export Performance for Israel and European Community Countries

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Working Paper

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Abstract

A two-stage model of innovation is presented, in which: I. economic inputs (such as R&D spending) generate science and technology outputs (such as publications, citations, and patents), and II. these science and technology outputs in turn serve as inputs, that generate knowledge-based exports. An integrated system of science and technology indicators, built on a "stages" model of the innovation process developed by Grupp (1992b), is used to measure and compare Israel's efficiency in: a) utilizing R&D resources to generate scientific and technological "outputs" (citations, patents, and publications), and b) employing these scientific outputs to generate export sales, relative to the leading European countries. It is shown that Israel is more efficient than Europe in producing scientific and technological outputs, but far less efficient in utilizing its excellence in scientific and technological outputs to generate science-based exports. In the so-called "value-added chain" in high-technology products -- R&D, production, marketing, distribution -- the farther one moves along the chain toward final output, the greater are the economic benefits in terms of export sales revenue, employment, and market share. An inverse empirical relationship emerges between Israel's relative performance in each stage of innovation, compared to European countries, and the economic benefits that stage confers. It is argued that Israel must adopt policy measures, both at the micro- and macroeconomic level, to transform scientific excellence in R&D and innovation into export performance in the later stages.

Introduction

The purpose of this paper is to utilize quantitative indicators of scientific and technology performance, available for a number of European countries as well as for Israel, to examine empirically the link between scientific and technological excellence and export performance. Specifically, we propose to analyze (a) whether Israel's investment of resources in applied and basic research -- as measured by spending on Research and Development -- are as productive as similar investments in European countries, in terms of their technological and scientific "output", and (b) whether Israel's scientific "output" is as productive in generating exports as in comparable European countries.

The structure of our paper is as follows. The first section presents a "stages" model of innovation, together with an operational, integrated network of indicators that serve to quantify each stage. In the next section, we construct a two-stage model of comparative advantage, in which two types of types of efficiency are defined: Stage I, *efficiency in translating R&D resources into scientific output*, and Stage II, *efficiency in translating technological and scientific output into export sales of R&D-intensive products.* In section 3, we define and describe our data set. Section 4 presents our regression results, and in Section 5, we conclude and summarize, and list some policy implications of our findings.

1. A "Stages" Model of Innovation

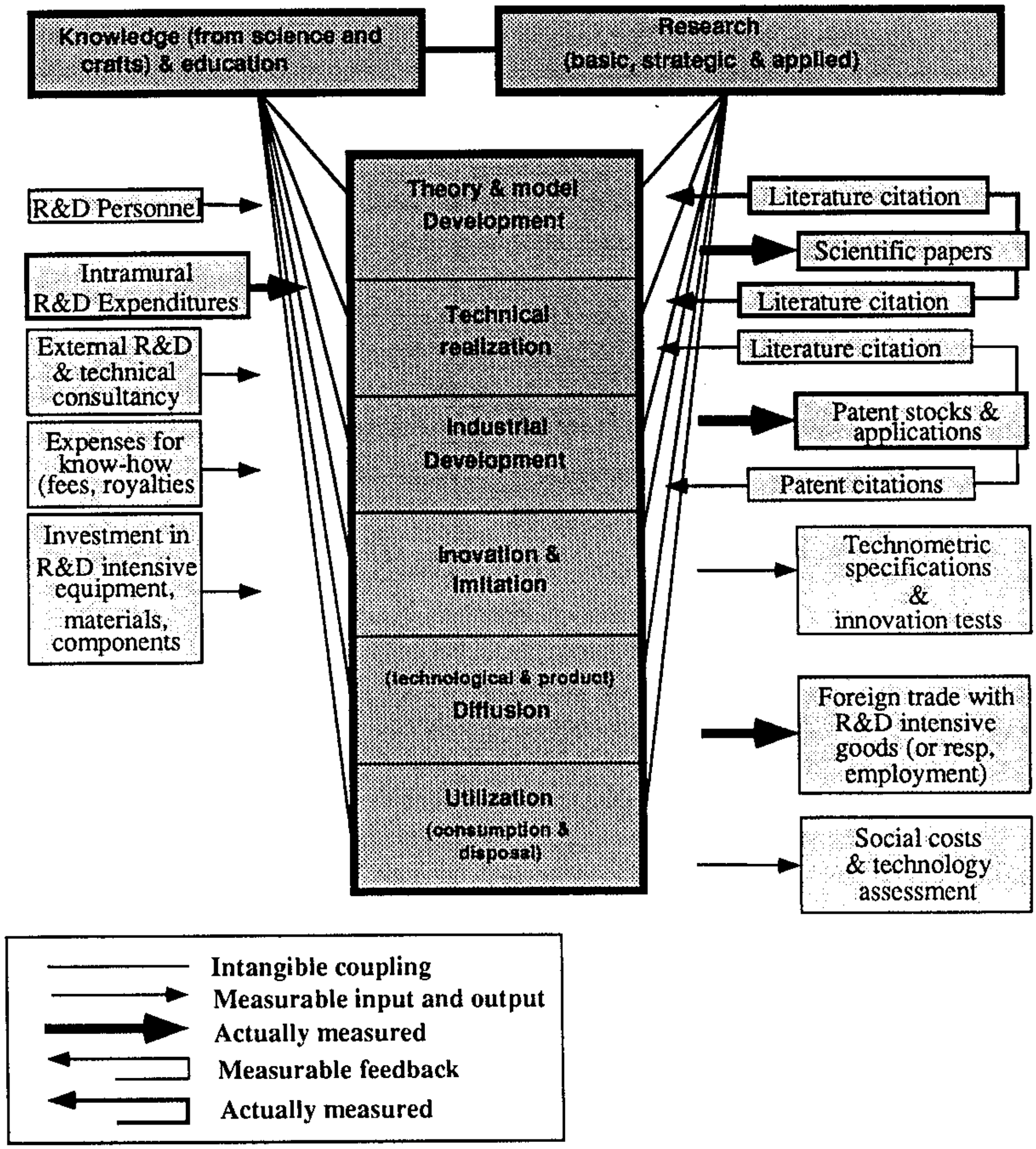
Grupp et al. (1992a) have constructed a "stages" model of the innovation process, in which six different phases or functions are defined: theory and model development, technical realization, industrial development, innovation and imitation, diffusion, and finally utilization. The model is accompanied by a comprehensive, operational set of indicators that quantify each stage and enable researchers to examine its relation with succeeding and preceding stages. (See Table 1). While, as Grupp noted, "...the well-known approach by indicators...grasps only parts of the complex and cyclical (feedback) innovation-oriented processes", nonetheless, such indicators "offer an opportunity to speak a common language in science and innovation research."

The model takes a somewhat "economic" perspective, in the sense that each of the stages is characterized by "inputs" and "outputs". The model is highly recursive, or "feedback", in nature, because the outputs of one stage become the inputs of succeeding stages.

As Grupp (1992a) notes,

> "..the description of the knowledge transfer between science and technology and within technology seems to be quitecomplex so that the definition of simple quantitative procedures is not possible. Nonetheless, a network of indicators, which are based partly on sample patents, partly on the respective references, can be established, giving an interesting insight into the interface processes. " (p. 39).

Table 1. Stages of Research, Development and Innovation, and corresponding Science and Technology indicators



The initial stage, theory and model development, uses R&D spending as its inputs or resources, and generates scientific outputs: publications, and citations of publications. The field of scientometrics -- the quantitative measurement of scientific output -- is by now well developed, and comprehensive databases of publications and citations, by subfield, are now widely accessible. The second and third stages of the innovation process build on scientific expertise, as expressed in publications and citations, to generate patent applications, citations and stocks of patents. Here, too, data are widely available for a wide range of products, services and processes. At the innovation and imitation stage, technology -- as expressed in patents -- is used to generate products, processes and services, whose quality or level of sophistication can be measured by the "technometric" approach (Grupp, 1990). In the technological diffusion stage, product and process quality is transformed into export sales and global market share. Detailed data are available on exports, according to standard industrial product classifications, by country of origin and by country of destination.

It should be emphasized that this model is not necessarily linear or rigidly sequential; for some products and processes, some stages may be skipped, while for others, the precise sequence may differ from that in Table 1 (for instance, patents may precede publications and citations).

Since each stage of the innovation process is characterized by empirical indicators, the "integrated network model" is an operational one; using it, it is possible to test hypotheses and to conduct cross-country comparisons.

The focus of this paper is on the extent to which inputs are used efficiently to generate outputs. In order to examine this important issue, it is first necessary to model the process through which nations acquire comparative advantage in high-technology products, and then utilize that comparative advantage in achieving high levels of exports and export market share. This is the task of the next section.

2. A Two-Stage Model of Comparative Advantage

A nation's export value-added can be partitioned according to the sources of that value added: Research and Development -- value added accruing from R&D spending, leading to goods and services that perform well in global markets; production of those goods and services, at minimum cost and maximum quality; and marketing and distribution. This is the so-called "value-added chain", used effectively by Porter (1980).

It is possible to model the innovation process as a two-stage one. In the first stage, economic resources -- physical and financial capital, and skilled manpower -- expressed as Research and Development spending are invested, in order to generate scientific and technological outputs (publications, citations, patents, etc.). In the second stage, the scientific and technological outputs become inputs, that generate new products and processes, of which some are exported. Presumably, comparative advantage in high-technology products (where science and technology play important roles) can arise either from excellence in generating scientific outputs (stage one), or from excellence in utilizing scientific outputs, or both.

Stage One:

Let X be a vector of variables $x_1, x_2, ..., x_n$, measuring the magnitude of resources invested in R&D, and let Y be a vector of variables $y_1, y_2, ..., y_n$ measuring the resulting scientific and technological outputs (citations, publications, patents, etc.). Then there exists a "production function" F( ), that maps from R&D inputs X to scientific output Y:

[1] $$Y = F(X)$$

This production function can be subjected to the same types of economic analyses as conventional production functions, that map from, say, labor and capital, into value-added. In particular, the efficiency of translating R&D resources into scientific outputs can be measured. Grupp, Maital, Koschatzky, and Frenkel, 1991, for example, adopt a linear-programming approach to measuring efficiency in transforming scientific excellence into exports. Or, alternately, using regression analysis, the empirical relation of Y and X can be examined, and individual countries' performance compared with the trend line -- an approach that we take here.

Equation [1] is a measure of Stage I efficiency -- the degree to which resources invested in research are efficiently utilized to achieve scientific excellence.

Stage Two:

The second stage in the export process involves the translation of scientific excellence into R&D-intensive goods and services that capture export sales. This stage encompasses the production, marketing and distribution components of the value-added chain.

Let Z be a measure of export performance, and Y be, as above, the measure of scientific excellence. Then a production function G( ) exists that maps from scientific excellence to export performance:

[2] $Z = G(Y)$

As with F( ), G( ) can also be analyzed empirically, and used for comparing various countries with one another.

Availability of adequate data for X, Y and Z makes it possible to study Stage I and Stage II efficiency for a sample of countries. Such analysis makes it possible to partition causes of superior or inferior export performance between Stages I and II, and as a result, to construct policies for stimulating exports that attack the root of the problem.

For many years, it has been argued that Israel has indeed achieved a high degree of excellence in its scientific and technological capabilities, but that it has not been efficient in translating that capability into strong export sales of science-based products.

We propose to test this hypothesis, using data for X, Y and Z that include 12 EC countries as well as Israel. Before presenting our empirical results, we first describe the extensive data set itself.

3. Scientometric and Economic Indicators

The variables used in this study are listed below, together with a description of their nature and their sources. For our purposes, high-technology products are defined as those with R&D spending above 3.5 per cent of sales. A complete list of high-tech product groups according to the three-digit SITC code is given in Appendix 2.

A. "X" Variables:

GERD: Gross R&D Spending, annual average for 1981-85; converted to U.S. dollars using Purchasing Power Parity index of O.E.C.D.; $ billion. Source: O.E.C.D., scientific indicators. For Israel: R&D data are taken from the Central Statistical Bureau's *Statistical Yearbook*.

GDP 81/85: Gross Domestic Product, average for 1981-85, $ billion, converted to U.S. $ using Purchasing Power Parity index as for variable 1.

GERD/GDP: ratio of GERD to GDP, as per cent.

B. "Y" Variables:

For our measures of scientific excellence, we used indicators in three different areas: patents, citations, and publications.

a) Patent Indicators:

For patents, we measured the number of patents granted, for the 12 EC countries, at the United States Patent and Trademark Office (USPTO), as a measure of a country's aggressiveness in seeking global protection for its intellectual property. We computed the sum total of patents invented in 1977-86, as an expression of cumulative patent activity, at the USPTO, and expressed them as a fraction of GDP for each country.[1]

PAT - number of patents, matched to product groups, USPTO, 1984-86

PAT/GDP - PAT, as a ratio to GDP.

PATPOT - cumulative no. of patents, USPTO, 1977-86.

PATPOT/GDP - PATPOT as a fraction of GDP.

b) Publications and Citations:

These indicators measure, for each country, the number of scientific publications by scholars who cite that country as their primary address in their publications, as listed by the databases of the Institute for Scientific Information (I.S.I.), in Philadelphia, Pa. The publications are for articles in scientific and engineering journals. Citations are similarly drawn from the I.S.I. databases.

For publications, we used the listings of the Science Citation Index, for engineering and science journals separately, and then added the two. We also expressed this indicator as a fraction of GDP.

For citations, we used similar listings from the Science Citation index, also divided between engineering and scientific periodicals and then summed, and also expressed as a fraction of GDP.

PUBSCIENG: number of publications in both scientific and engineering publications. (not including Life Science publications), 1981-85.

PUBSCIENG/GDP - PUBSCIENG as a fraction of GDP.

CITSCIENG - number of citations in both scientific and engineering periodicals, 1981-85.

CITSCIENG/GDP - CITSCIENG as a fraction of GDP.

C. "Z" Variables:

EXPHI - Science-based (high technology) exports, total $, 1988; for 2-digit industrial branches included, see Appendix 2

TOTEXP - total manufactures exports, $, 1988.

EXPHI/TOTEXP - high-tech exports as % of total manufactures exports, 1988.

The data based on trade figures were derived from Grupp and Legler (1991), for EC countries, and for Israel, from Israel's Statistical Yearbook. It is important to note that high-tech exports are compared to total exports (and imports) of *manufactured goods* only. Hence, Israel's relatively large imports of raw materials, and exports of agricultural products, do not figure in the calculations. The trade variables therefore serve as a measure of the extent to which trade in *manufactured products* is high-tech. (See Grupp, 1990, and Grupp and Legler, 1991.)

The data themselves are given in Appendix 1.

4. Empirical Results

Regression equation estimates for the Stage 1 Model are shown in Table 2. For purposes of this analysis, we chose to combine the "leading-edge" and "high-level" products. Disaggregation does not substantively alter our conclusions. In general, the level of government intervention in leading-edge products is much greater, and hence exports of such products are less influenced by pure market forces.[2]

a) Stage I: translating R&D into scientific excellence:

Figures 1, 2, 3 and 4 show the relation between four measures of scientific output -- publications, citations, patents, and cumulated patents -- expressed as a fraction of GDP, and Gross R&D spending, also as a fraction of GDP, for 12 European countries and Israel.

The European countries chosen are: Germany, France, UK, Netherlands, Belgium/ Luxemburg, Denmark, Ireland, Spain, Italy, Greece, Portugal.

For each Figure, the regression line for the "Y" (dependent) variable regressed on the "X" (independent) variable is shown.

In general, the results confirm our basic hypothesis that international commercial success in high-technology products exports is basically determined by R&D spending as a fraction of GDP, and by the resulting outputs of scientific and technical knowledge and patents.

Table 2.
Regression Equations for "Stage 1" Model:
Israel and Selected European Countries
Scientific and Technological Output Indicators as a Function of Gross R&D Spending/GDP:
(Independent Variable: Gross R&D Spending As % of GDP)

Dependent Variable	Intercept	Coefficient of Independent Variable (GERD/GDP)*	R^2 adj	P	N
PUBSCIENG/GDP	-10.41	63.379 (19.61)	0.46	0.009	12
CITSCIENG/GDP	-71.77	211.344 (56.41)	0.54	0.004	12
PAT/GDP	-1.66	5.053 (0.70)	0.82	0.000	12
PATPOT/GDP	-5.72	16.879 (2.63)	0.79	0.0007	12

* (standard error of slope coefficients in brackets)

These results show that for Publications and Citations, Israel is substantially more efficient than the 12 European Community countries in generating scientific outputs from R&D resources; for these indicators, Israel falls consistently above the trend line for Y regressed on X.

The slope of the two regression lines can be interpreted as:

$$\frac{d(PUBSCIENG / GDP)}{d(GERD / GDP)} \text{ and } \frac{d(CITSCIENG / GDP)}{d(GERD / GDP)}$$

meaning, the increase in publications and citations, respectively, normalized by GDP, for a one per cent increase in R&D spending (as a percentage of GDP). The respective slopes are, approx., 67 and 220.

For recent patents, Israel falls right on the regression trend line. (See Figure 3). And for Cumulative Patents, Israel falls somewhat below the trend line (though the gap is not statistically significant). (See Figure 4).

This result obtains, despite the fact that for Israel's R&D spending of nearly 3 per cent of GDP, a substantial portion of it is military in nature and therefore less likely to result in patent applications, or in publications or citations (limited for reasons of national security).

This result confirms the general view that despite its small size, Israel has attained a notable position in the scientific world, and that in proportion to its size, its base of science and technology is equal to or perhaps even superior to that of the European Community countries.

Stage Ib: Translating Publications into Patents: Our empirical analysis suggested to us that Stage I -- transforming R&D resources into scientific and technological "intellectual property" --is really comprised of two substages: Ia -- use of R&D resources to generate research results, expressed as publications and citations; and Ib -- use of scientific and technological knowledge (which find expression in publications and citations) in order to generate patentable inventions.

To test this hypothesis, we computed two additional statistical regression lines, in which Patents/GDP was the dependent variable, and Citations/GDP and Publications/GDP each served as the independent variables, respectively. The results are shown below in Table 3, and in Figures 5 and 6.

Figure 1

Publications in Science & Eng. per GDP As a Function of Gross R&D Spending (as % of GDP 1981-85) in 12 EC Countries and Israel

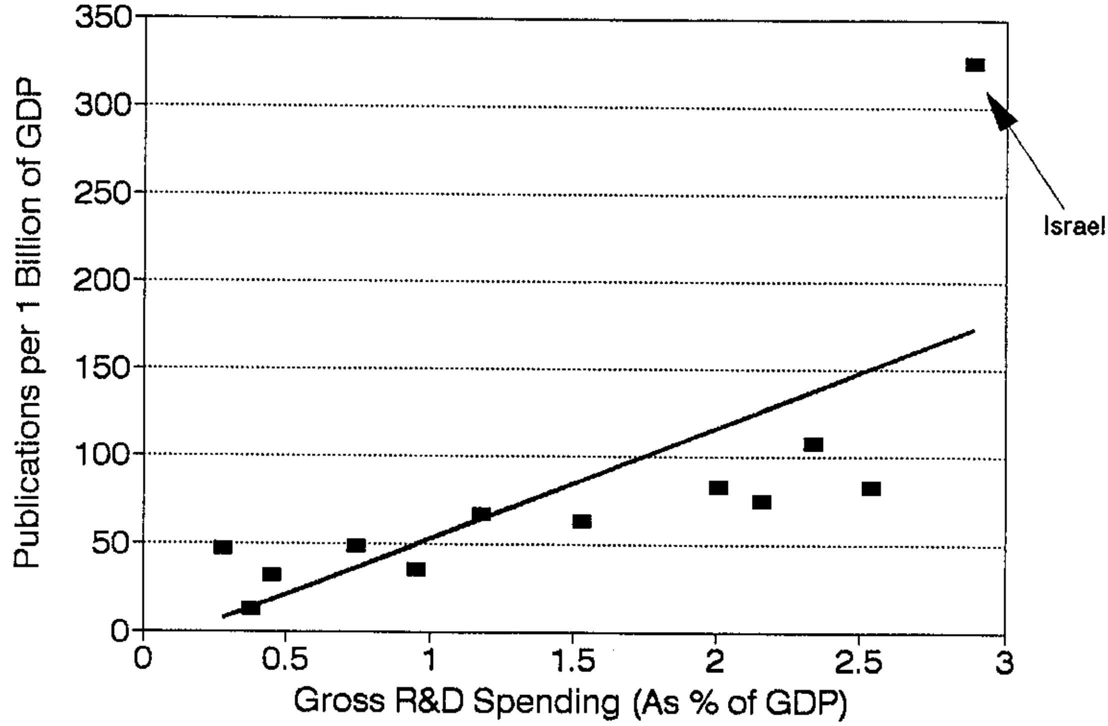


Figure 2

Citations in Science & Eng. per GDP, As Function of Gross R&D Spending (as % of GDP 1981-85) in 12 EC Countries and Israel

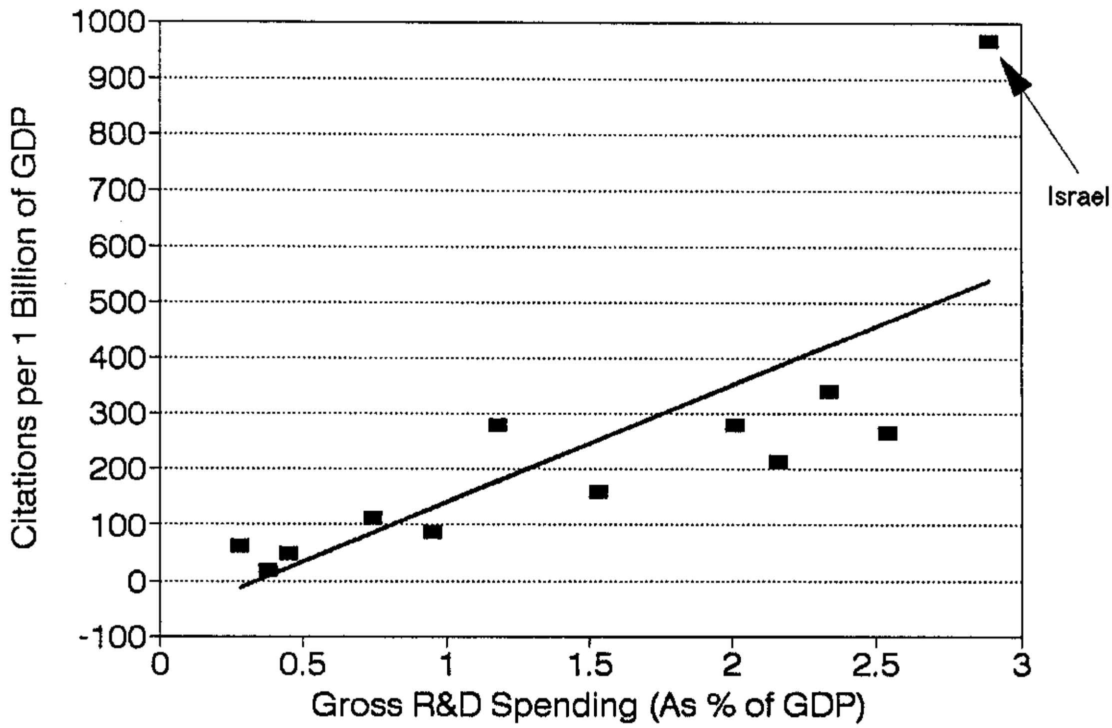


Figure 3
Patents Per GDP (At USPTO 1984-86) as a Function of Gross R&D Spending (as % of GDP 1981-85), in 12 EC Countries and Israel

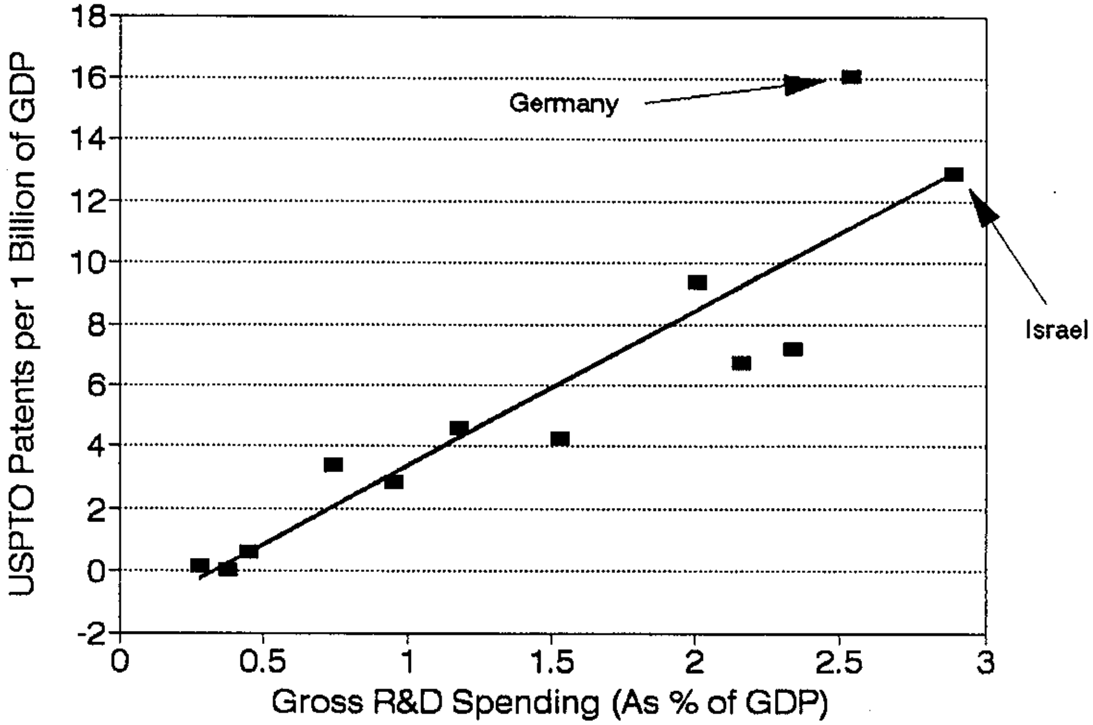
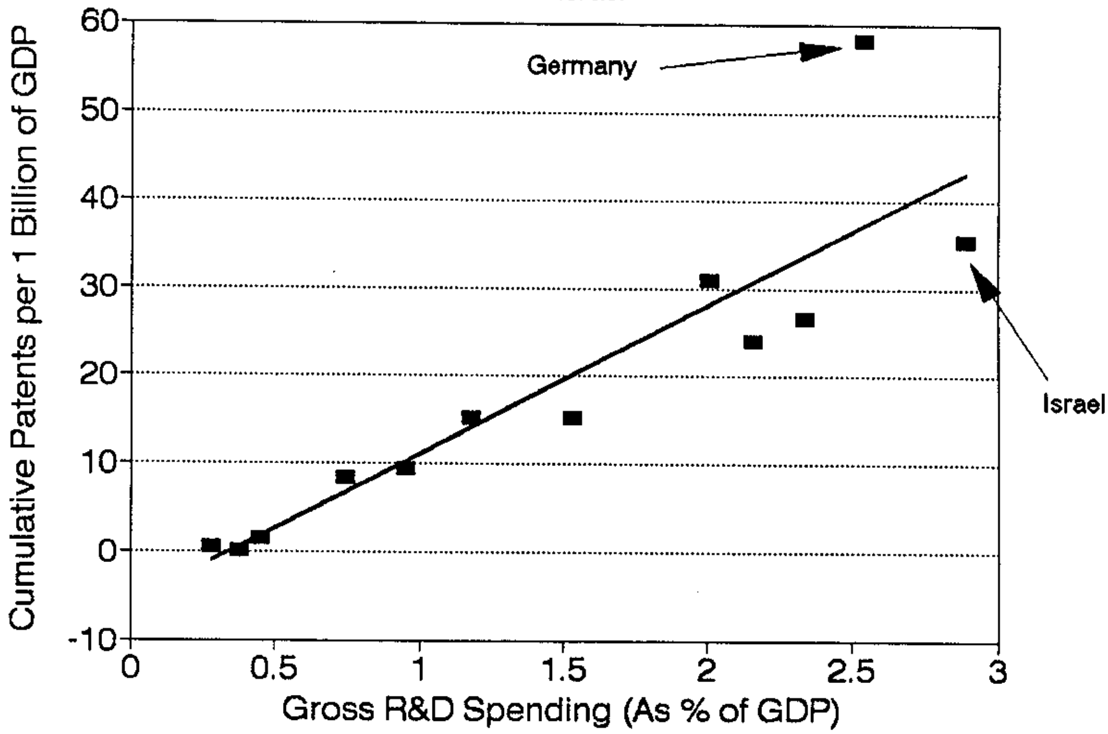


Figure 4
Cumulative Patents Per GDP (At USPTO 1977-86) as a Function of Gross R&D Spending (as % of GDP 1981-85), in 12 EC Countries and Israel



The results clearly indicate a) that there is a strong trend line between patents/GDP and citations and publications; and b) that Israel's patent efforts in the U.S. fall somewhat below the trend line that characterizes the dozen countries taken together. However, the extent to which Israel's Patent/GDP ratio falls below the trend line appears to be neither statistically significant, nor practically significant (in terms of its magnitude). Anticipating our later results, this suggests that Israel's weak export performance, relative to her scientific and technological expertise, is only in small part due to weakness in patenting activity abroad.

Table 3

Regression Equations for Stage "Ib" PAT/GDP as a Function of CITSCIENG/GDP and PUBSCIENG/GDP 12 European Countries and Israel

Independent Variable	Intercept	Slope*	R^2 adj	P	N
CITSCIENG/GDP	2.43	0.014 (0.00)	0.43	0.013	13
PUBSCIENG/GDP	2.43	0.039 (0.020)	0.35	0.025	13

* (standard error of slope coefficients in brackets).

Figure 5

Patents Per GDP (At USPTO 1984-86) as a Function of Citations in Science & Eng. per GDP 1981-85, in 12 EC countries and Israel

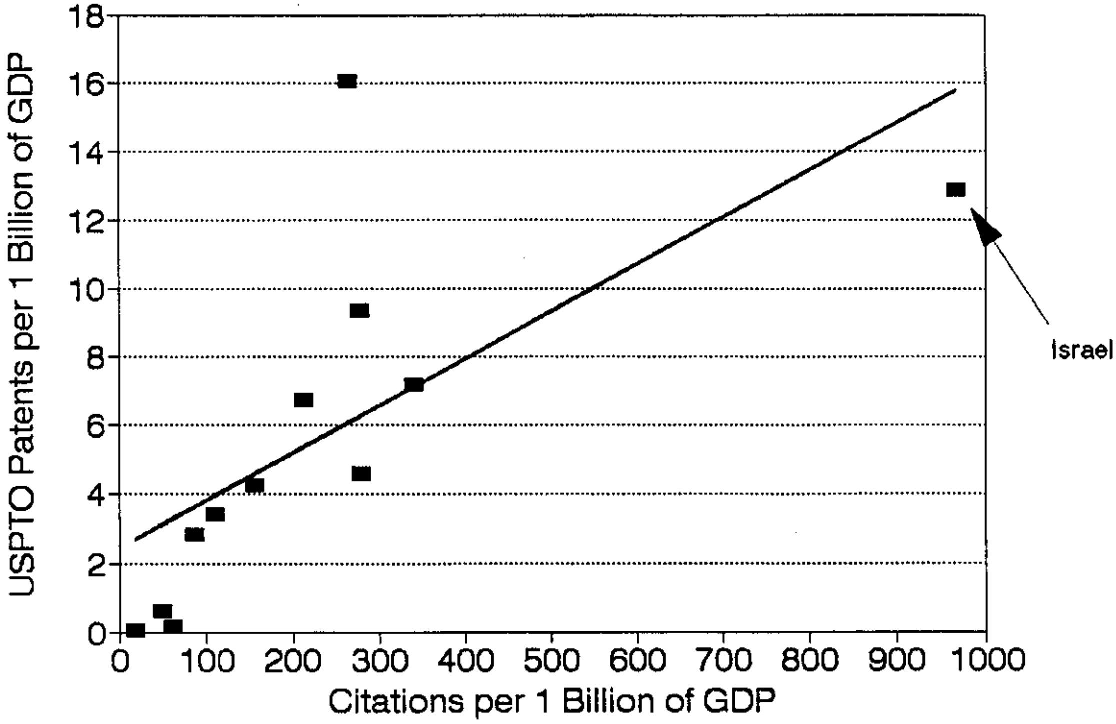
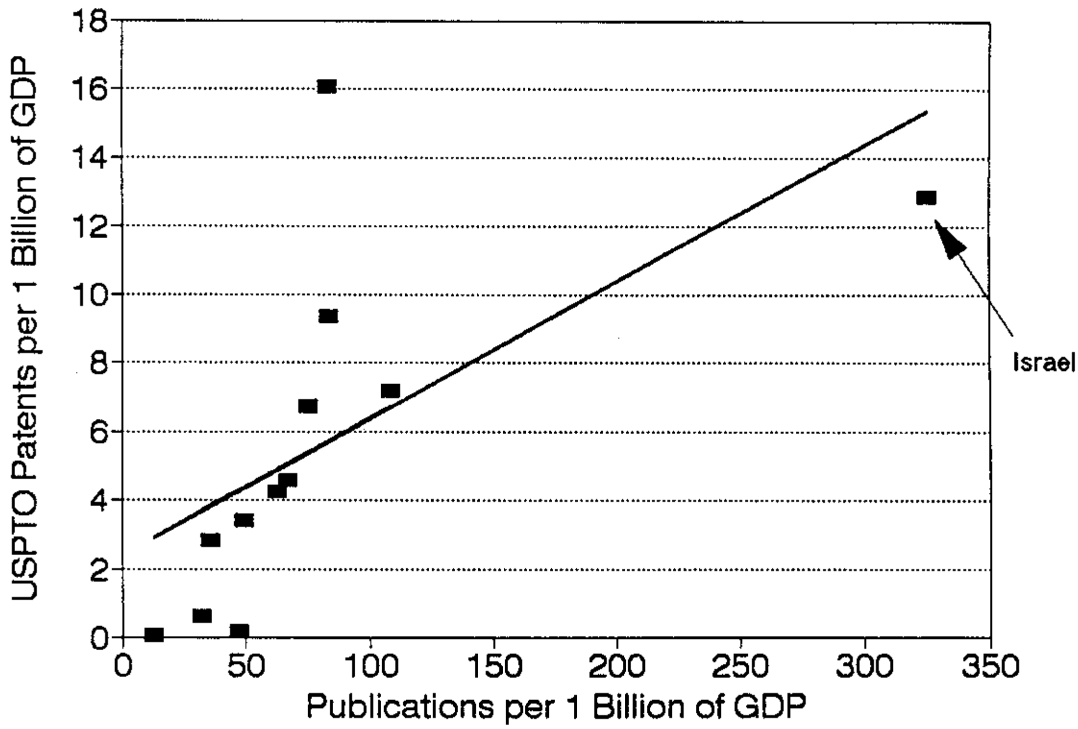


Figure 6

Patents Per GDP(At USPTO 1984-86) as a Function of Publications in Science & Eng. per GDP 1981-85, in 12 EC countries and Israel



b) Stage II: translating scientific excellence into export sales.

Figures 7 and 8, and Table 4, show regressions of our export performance measure, EXPHI/TOTEXP, on Patents/GDP and Cumulative Patents/GDP.

The results indicate that Israel performs substantially more poorly in transforming its technical skills, as expressed in current patents and in cumulative patents, into comparative advantage in export markets. For both measures, Israel falls substantially below the trend line that forms the basis of comparison.

Table 4

Regression Equations for Stage II (Dependent Variable: EXPHI/TOTEXP)

Independent Variable	Intercept	Slope*	R^2 adj	P	N
PAT/GDP	24.7	1.31 (.607)	0.249	.056	12
PATPOT/GDP	24.6	0.399 (0.175)	0.276	.046	12

* (standard error of slope coefficients in brackets)

Figure 7

High-Tech Export as % of Total Mfg. Export 1988, as a Function of Patents per GDP (at USPTO 1984-86), in 12 EC Countries and Israel

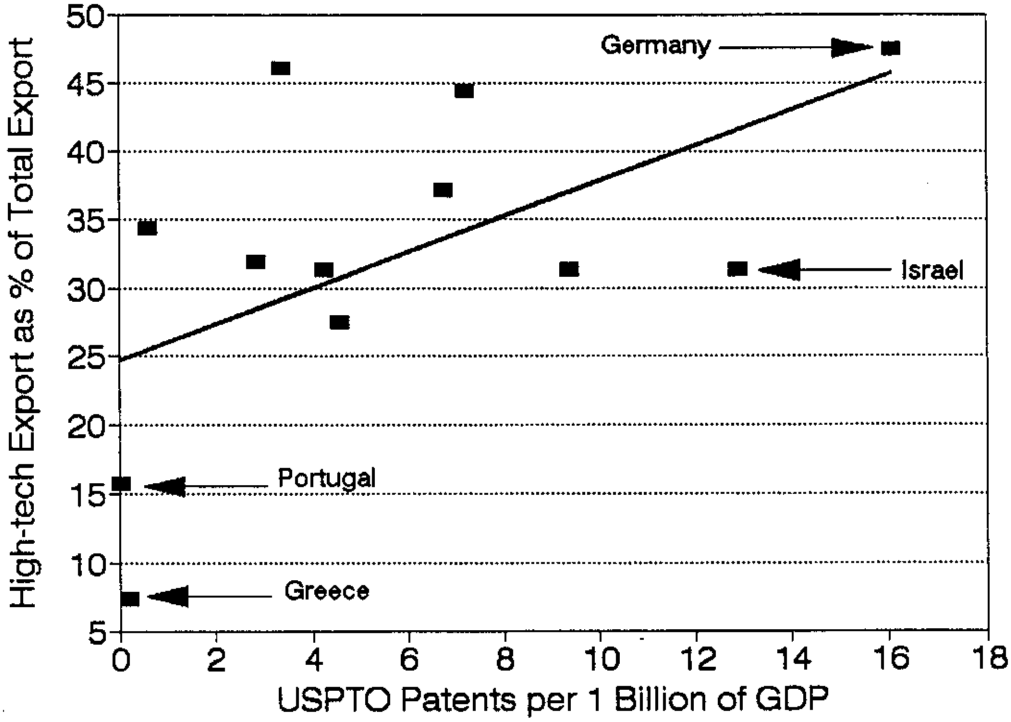
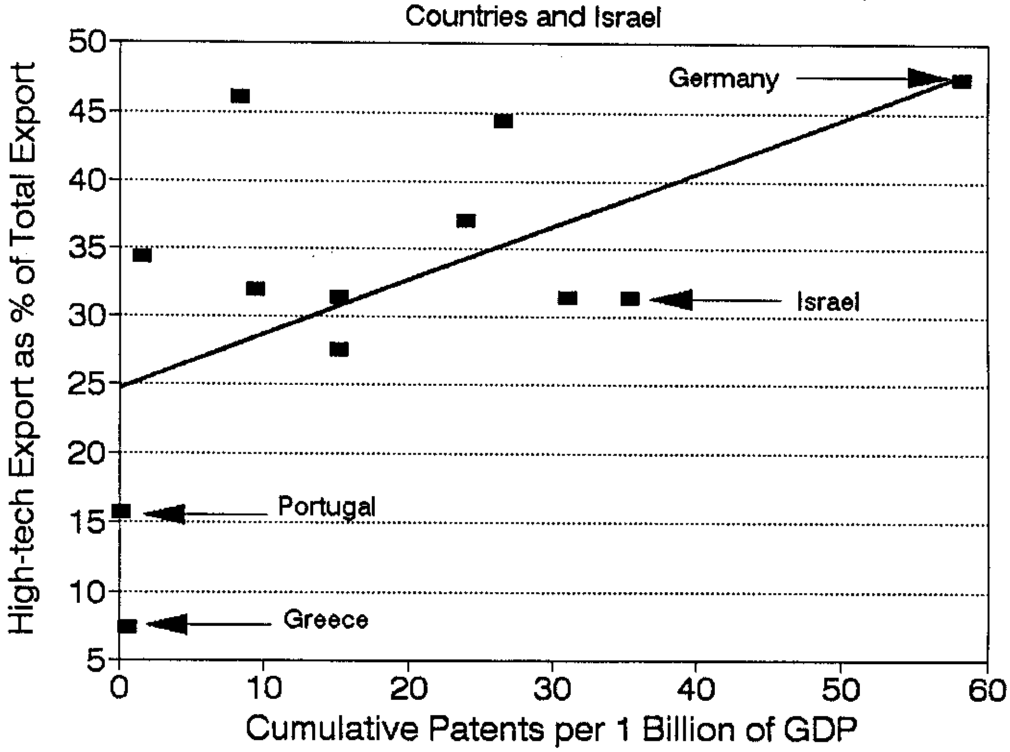


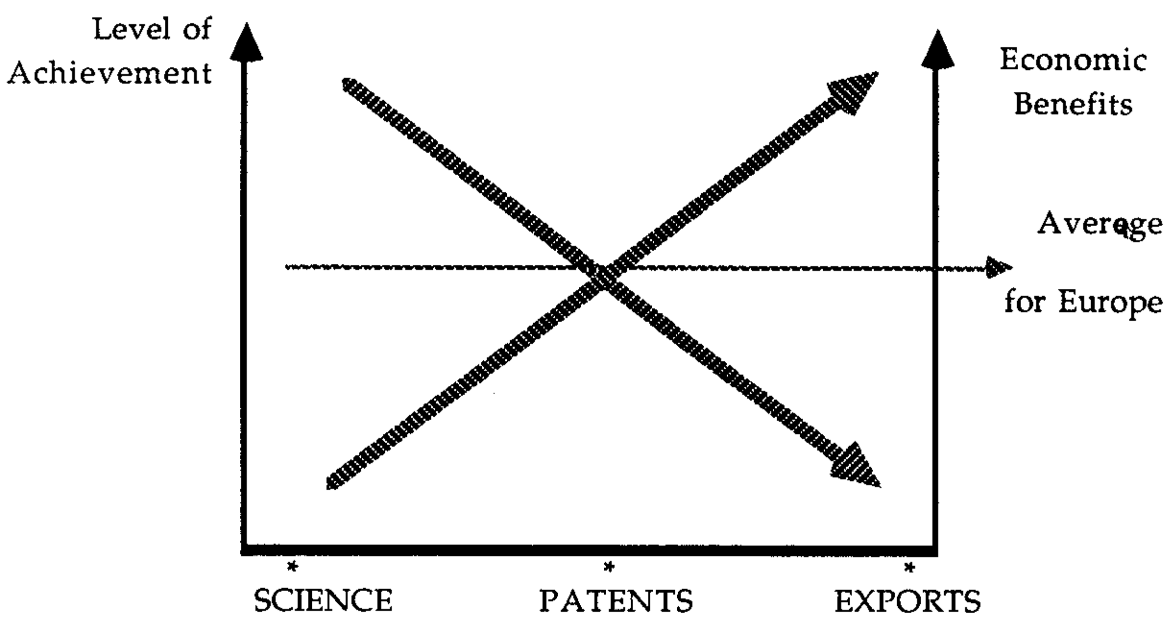
Figure 8

High-Tech Export as % of Total Mfg. Export 1988, as a Function of Cumulative Patents per GDP (at USPTO 1984-86), in 12 EC Countries and Israel



In general, the farther along the innovation stages one moves, the less efficient Israel becomes in exploiting the relevant inputs and converting them into export performance. (See Figure 9). At the same time, the main economic benefits conferred by innovation accrue mainly toward the end of the value-added chain, in the production, marketing and distribution stages. There is relatively little macroeconomic benefit to the national economy of Israel, when superior products and processes are conceived and designed in Israel and then taken elsewhere to be produced. The result is that jobs, income, profits and investment, stemming from Israeli scientific knowhow, accrue largely to foreign lands.

Figure 9: **Israel's Achievement Level in Basic Science, Patents and Exports Relative to European Countries; and the relative economic benefits each stage confers (This is a schematic, rather than empirical diagram)**



5. Conclusions and Policy Implications

The above results, while they will come as no surprise to anyone familiar with Israel's science base and economy, perhaps show more quantitatively than before -- with the aid of scientometric indicators -- the extent to which Israel has failed to fully convert its scientific achievements in export-led growth. In proportion to its Gross Domestic Product, Israel outpaced European countries in patents, publications and citations, yet lagged in R&D-intensive exports.

A vivid illustration of this result is the eagerness of global high-tech companies to locate R&D and design centers in Israel -- including DEC, IBM, National Semiconductor, and Intel -- yet produce much of their microchips, computers, etc. elsewhere.

The implications of this failure to transform scientific excellence into export dollars have become particularly serious with the influx of highly-trained Soviet immigrants. According to the Ministry of Absorption, of every 100 Soviet adult immigrants possessing an occupation, 41 had academic degrees, and of these, half were scientists and engineers.

In its 67-year history, Israel's leading school of engineering, the Technion, graduated about 35,000 engineers. It is estimated that a greater number have arrived in Israel from the U.S.S.R. in the wave of some 400,000 immigrants during the past two years.

The value of the human capital embodied in this high-level immigrant manpower, that arrived in Israel at a rate of about 200,000 a year for over two years, between mid-1989 and end-1993 -- has been estimated at about $50 billion a year (taking the discounted present value of lifetime value added). [Maital, 1990].

This influx of human capital will further strengthen Israel's comparative advantage in R& D-intensive exports. But in order to fully exploit this advantage, it is vital that conditions be created that enable Israel not only to produce world-class Research and Development, but also to produce at low cost and high quality the goods and services that emerge from this R&D. Only in this fashion will Israel gain jobs, income and exports that it requires, and that its scientific excellence can make possible.

Porter (1990) has argued that global competitive advantage springs from a healthy national environment.

> "...I developed a strong conviction that the national environment does play a central role in the competitiv success of firms. With striking regularity, firms from one or two nations achieve disproportionate worldwide success in particular industries. Some national environments seem more stimulating to advancement and progress than others." (p. xii.)

Apparently, while some aspects of Israel's "national environment" are highly favorable for global competitiveness-- those related to production of science and technology inputs -- other aspects, related to the economy, are far less favorable. Through its scientific and technological achievements, a relatively large amount of value added *originates* in Israel's science base. But far too little of it accrues to *Israel*, rather than to other countries. Israel must act to recapture its own value added and retain more of it at home.

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Apendix 1: DATA

STATE	GERD 81-85	GDP 81-85	GERD/ GDP %	PUB-SCIENG 81-85	PUB-SCIENG/ GDP	CIT-SCIENG 81-85	CIT-SCIENG/ GDP	PAT 84-86	PAT/ GDP 84-86	PATPOT-77-86	PATPOT/ GDP
Germany	16.66	655.91	2.54	54169	82.59	173437	264.42	12461	16.07	38205	58.25
France	12.48	576.7	2.16	43190	74.89	122344	212.14	4370	6.74	13871	24.05
U.K.	12.69	542.17	2.34	58774	108.41	184502	340.30	4472	7.21	14443	26.64
Netherland	2.98	147.97	2.01	12278	82.98	41167	278.21	1527	9.37	4595	31.05
Belgium/Lux.	1.49	97.48	1.53	6151	63.10	15363	157.60	461	4.25	1480	15.18
Denmark	0.65	55.23	1.18	3690	66.81	15418	279.16	288	4.58	838	15.17
Ireland	0.16	21.57	0.74	1060	49.14	2401	111.31	83	3.40	181	8.39
Spain	1.15	257.83	0.45	8215	31.86	12748	49.44	181	0.61	413	1.60
Italy	5.28	555.79	0.95	19845	35.71	48420	87.12	1777	2.85	5235	9.42
Greece	0.15	53.93	0.28	2550	47.28	3345	62.02	11	0.18	33	0.61
Portugal	0.19	49.64	0.38	622	12.53	923	18.59	2	0.04	7	0.14
Israel	0.7	24.21	2.89	7892	325.98	23416	967.20	326	12.89	859	35.48

STATE	EXPHI 1988	IMPHI 1988	TOTEXP 1988	TOTIMP 1988	EXPHI/ GDP	(EXPHI-IMPHI)/ GDP	EXPHI/ TOTEXP	EX-IMhi/ EX-IMtot	RCA 1988
Germany	150.000	76.497	315.731	216.489	22.87	11.21	47.51	74.06	28.76
France	55.344	59.976	149.206	158.323	9.60	-0.80	37.09	50.81	-2.10
U.K.	58.207	69.711	130.837	171.556	10.74	-2.12	44.49	28.25	9.07
Netherland	29.42	30.375	93.825	86.618	19.88	-0.65	31.36	-13.25	-11.22
Belgium/Lux.	27.043	21.928	86.348	77.005	27.74	5.25	31.32	54.75	9.47
Denmark	6.422	7.503	23.341	23.072	11.63	-1.96	27.51	-401.86	-16.55
Ireland	7.889	5.804	17.106	14.172	36.57	9.67	46.12	71.06	11.84
Spain	13.761	25.693	40.039	58.696	5.34	-4.63	34.37	63.95	-25.80
Italy	43.554	49.398	136.613	126.34	7.84	-1.05	31.88	-56.89	-23.46
Greece	0.323	3.106	4.383	10.842	0.60	-5.16	7.37	43.09	-87.57
Portugal	1.694	6.165	10.783	15.488	3.41	-9.01	15.71	95.03	-73.06
Israel	2.808	4.996	8.935	11.576	11.60	-9.04	31.43	82.85	-30.69

Appendix 2: List of R&D Intensive Products

No	SITC III	Product group (non-official terms)	R&D intensity
1	516	Advanced organic chemicals	Leading-edge goods
2	525	Radio-active materials	Leading-edge goods
3	541	Pharmaceutical products	Leading-edge goods
4	575	Advanced plastics	Leading-edge goods
5	591	Agricultural chemicals	Leading-edge goods
6	714	Turbines and reaction engines	Leading-edge goods
7	718	Nuclear,water,wind power generators.	Leading-edge goods
8	752	Automatic data processing machines	Leading-edge goods
9	764	Telecommunications equipment	Leading-edge goods
10	774	Medical electronics	Leading-edge goods
11	776	Semi-conductor devices	Leading-edge goods
12	778	Advanced electrical machinery	Leading-edge goods
13	792	Aircraft and spacecraft	Leading-edge goods
14	871	Advanced optical instruments	Leading-edge goods
15	874	Advanced measuring instruments	Leading-edge goods
16	891	Arms and ammunition	Leading-edge goods
17	266	Synthetic fibres	High-level products
18	277	Advanced industrial abrasives	High-level products
19	515	Heterocyclic chemistry	High-level products
20	522	Rare inorganic chemicals	High-level products
21	524	Other precious chemicals	High-level products
22	531	Synthetic colouring matter	High-level products
23	533	Pigments. paints, varnishes .	High-level products
24	542	Medicaments	High-level products
25	551	Essential oils. perfume, flavour	High-level products
26	574	Polyethers and resins	High-level products
27	598	Advanced chemical products	High-level products
28	663	Mineral manufactures, fine ceramics	High-level products
29	689	Precious non-ferrous base metals	High-level products
30	724	Textile and leather machinery	High-level products
31	725	Paper and pulp machinery	High-level products
32	726	Printing and bookbinding machinery	High-level products
33	727	Industrial food-processing machines	High-level products
34	728	Advanced machine-tools	High-level products
35	731	Machine-tools working by removing	High-level products
36	733	Machine-tools without removing	High-level products
37	735	Parts for machine-tools	High-level products
38	737	Advanced metalworking equipment	High-level products
39	741	Industrial heating and cooling goods	High-level products
40	744	Mechanical. handling equipment	High-level products
41	745	Other non-electrical machinery	High-level products
42	746	Ball and roller bearings	High-level.products
43	751	Office machines,word-processing	High-level products
44	759	Advanced parts:for computers	High-level products
45	761	Television snd video equipment	High-level products
46	762	Radio-broadcast,radiotelephony goods	High-level products
47	763	Sound and video recorders	High-level products
48	772	Traditional electronics	High-level products
49	773	Optical fibre and other cables	High-level products
50	781	Motor vehicles for persons	High-level products
51	782	Motor vehicles for good transport	High-level products
52	791	Railway vehicles	High-level products
53	872	Medical instruments and appliances	High-level products
54	873	Traditional measuring equipment	High-level products
55	881	Photographic apparatus and equipment	High-level products
56	882	Photo- and cinematographic supplies	High-level products
57	883	Optical fibres, contact, other lenses	High-level products

Appendix 3. Definitions

The following is a description of the entire database, from which we extracted selected variables for our analysis.

Definitions of Variables

GERD - Gross R&D Spending, annual average for 1981-85; converted to U.S. dollars using Purchasing Power Parity index of O.E.C.D.; $ billion. Source: O.E.C.D., scientific indicators. For Israel: R&D data are taken from the Central Statistical Bureau's Statistical Yearbook.

GDP 81/85 - Gross Domestic Product, average for 1981-85, $ billion, converted to U.S. $ using Purchasing Power Parity index as for variable 1.

GERD/GDP - ratio of GERD to GDP, as per cent.

PAT- number of patents matched to high-tech products, U.S. Patent and Trademark Office, invented between1984-86.

PAT/GDP - PAT as a ratio to GDP.

PATPOT - cumulative number of patents at USPTO, 1977-86, for high-tech goods.

PATPOT/GDP - PATPOT as a fraction of GDP.

PUBSCIENG - number of publications, in both scientific and engineering publications, as measured by the Science Citation Index, for the period 1981-85. .

PUBSCIENG/GDP - PUBSCIENG as a fraction of GDP.

CITSCIENG - number of citations received, listed in Science Citation Index, in both science and engineering periodicals, for 1981-85.

CITSCIENG/GDP -: CITSCIENG as a fraction of GDP.

EXPHI - Science-based (high technology) exports, total $, 1988; for 2-digit industrial branches included, see Appendix 2

IMPHI - Science-based (high technology) imports, total $, 1988.

TOTEXP - total manufactures exports, $, 1988.

Endnotes

1. This variable measures not only patent activity in the U.S., but also the degree of willingness of firms and inventors to apply for patents at the United States Patent Office. For many reasons, the eagerness to patent inventions in the U.S. is not identical across all countries. Hence, this variable reflects not only some measure of scientific output, but also the extent to which firms and inventors are prepared to create a "footprint" of this output in the form of patents.

2 "..there are two hemispheres in the world of R&D intensity. One (the high-level consumer products with expectations of a relatively good turnover per R&D investment), in which technical performance by patents does play a role and is a decisive factor for international competitiveness alongside with R&D activities by industry. Scientific achievements are not so important here. The other hemisphere (the leading-edge technologies with moderate expectations in turnover per R&D investment) in which factors other than technology guarantee international success, is characterized by stronger government intervention both on the side of R&D and also in terms of procurement and regulation. Here, scientific excellence is indispensable. " Grupp (1991, p. 26).

Grupp adds: "Business-financed R&D governs the high-level commodities and thus all high technologies, whereas international success in leading edge products must be nurtured from somewhere else. ...the financial means of governments poured into the business R&D system largely explains where the position of a country in leading-edge products is. ...Governments in EC countries are the drafthorses in very R&D intensive fields and provide financial means for the pioneering of possibly less effective new leading-edge technologies."

The Relation between Scientific and Technological Excellence and Export Performance:

Theoretical Model and Empirical Test for European Community Countries

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Abstract

A two-stage model of innovation is presented, in which: I. economic inputs (such as R&D spending) generate science and technology outputs (such as publications, citations, and patents), and II. these science and technology outputs in turn serve as inputs, that generate knowledge-based exports. An integrated system of science and technology indicators, built on a "stages" model of the innovation process developed by Grupp (1992), is used as the basis for testing the model for 12 European Community countries, through statistical regression. It is shown that a systematic empirical relationship exists between inputs and outputs, for both Stage I and Stage II.

Introduction

The purpose of this paper is to utilize quantitative indicators of scientific and technology performance to examine empirically the link between scientific and technological excellence and export performance, for 12 European Community countries. Specifically, we propose to analyze (a) whether, among these countries, investment of resources in applied and basic research -- as measured by spending on Research and Development -- is related empirically to technological and scientific "output", and (b) whether scientific "output" is empirically related to generation of exports.

The structure of our paper is as follows. The first section presents a "stages" model of innovation, together with an operational, integrated network of indicators that serve to quantify each stage. In the next section, we construct a two-stage model of comparative advantage, in which two types of types of efficiency are defined: Stage I, *efficiency in translating R&D resources into technological and scientific output*, and Stage II, *efficiency in translating scientific output into export sales of R&D-intensive products.* In section 3, we define and describe our data set. Section 4 presents our regression results, and in Section 5, we conclude and summarize, and list some policy implications of our findings.

1. A "Stages" Model of Innovation

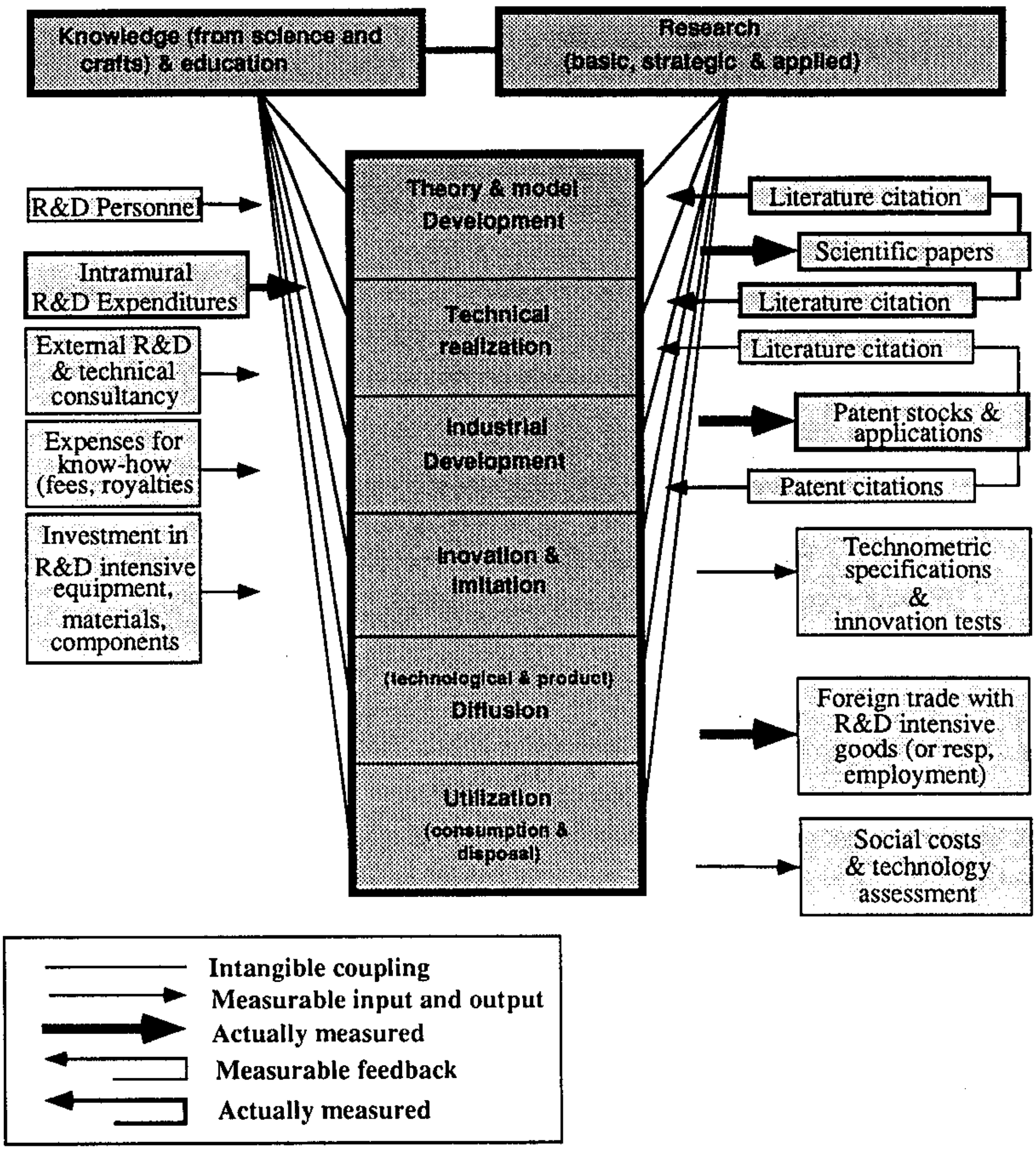
Grupp et al. (1992a) have constructed a "stages" model of the innovation process, in which six different phases or functions are defined: theory and model development, technical realization, industrial development, innovation and imitation, diffusion, and finally utilization. The model is accompanied by a comprehensive, operational set of indicators that quantify each stage and enable researchers to examine its relation with succeeding and preceding stages. (See Table 1). While, as Grupp noted, "...the well-known approach by indicators...grasps only parts of the complex and cyclical (feedback) innovation-oriented processes", nonetheless, such indicators "offer an opportunity to speak a common language in science and innovation research."

The model takes a somewhat "economic" perspective, in the sense that each of the stages is characterized by "inputs" and "outputs". The model is highly recursive, or "feedback", in nature, because the outputs of one stage become the inputs of succeeding stages. As Grupp (1992) notes,

> "..the description of the knowledge transfer between science and technology and within technology seems to be quite complex so that the definition of simple quantitative procedures is not possible.
> Nonetheless, a network of indicators, which are based partly on sample patents, partly on the respective references, can be established, giving an interesting insight into the interface processes. " (p. 39).

The initial stage, theory and model development, uses R&D spending as its inputs or resources, and generates scientific outputs: publications, and citations of publications. The field of scientometrics -- the quantitative measurement of scientific output -- is by now well developed, and comprehensive databases of publications and citations, by subfield, are now widely accessible. The second and third stages of the innovation process build on scientific expertise, as expressed in publications and citations, to generate patent applications and stocks of patents. Here, too, data are widely available for a wide range of products, services and processes. At the innovation and imitation stage, technology -- as expressed in patents -- is used to generate products, processes and services, whose quality or level of sophistication can be measured by the "technometric" approach (Grupp, 1990). In the technological diffusion stage, product and process quality is transformed into export sales and global market share.

Table 1. Stages of Research, Development and Innovation, and corresponding Science and Technology indicators



Detailed data are available on exports, according to standard industrial product classifications, by country of origin and by country of destination. It should be emphasized that this model is not necessarily linear or rigidly sequential; for some products and processes, some stages may be skipped, while for others, the precise sequence may differ from that in Table 1 (for instance, patents may precede publications and citations).

Since each stage of the innovation process is characterized by empirical indicators, the "integrated network model" is an operational one; using it, it is possible to test hypotheses and to conduct cross-country comparisons.

The focus of this paper is on the extent to which inputs are used efficiently to generate outputs. In order to examine this important issue, it is first necessary to model the process through which nations acquire comparative advantage in high-technology products, and then utilize that comparative advantage in achieving high levels of exports and export market share. This is the task of the next section.

2. A Two-Stage Model of Comparative Advantage

A nation's export value-added can be partitioned according to the sources of that value added: Research and Development -- value added accruing from R&D spending, leading to goods and services that perform well in global markets; production of those goods and services, at minimum cost and maximum quality; and marketing and distribution. This is the so-called "value-added chain", used effectively by Porter (1980).

It is possible to model the innovation process as a two-stage one. In the first stage, economic resources -- physical and financial capital, and skilled manpower -- expressed as Research and Development spending are invested, in order to generate scientific and technological outputs (publications, citations, patents, etc.). In the second stage, the scientific and technological outputs become inputs, that generate new products and processes, of which some are exported. Presumably, comparative advantage in high-technology products (where science and technology play important roles) can arise either from excellence in generating scientific outputs (stage one), or from excellence in utilizing scientific outputs, or both.

Stage One:

Let X be a vector of variables x_1, x_2, ..., x_n, measuring the magnitude of resources invested in R&D, and let Y be a vector of variables y_1, y_2, ..., y_n measuring the resulting scientific and technological outputs (citations, publications, patents, etc.). Then there exists a "production function" F( ), that maps from R&D inputs X to scientific output Y:

[1] $Y = F(X)$

This production function can be subjected to the same types of economic analyses as conventional production functions, that map from, say, labor and capital, into value-added. In particular, the efficiency of translating R&D resources into scientific outputs can be measured. Grupp, Maital, Koschatzky, and Frenkel, 1991, for example, adopt a linear-programming approach to measuring efficiency in transforming scientific excellence into exports. Or, alternately, using regression analysis, the empirical relation of Y and X can be examined, and individual countries' performance compared with the trend line -- an approach that we take here.

Equation [1] is a measure of Stage I efficiency -- the degree to which resources invested in research are efficiently utilized to achieve scientific excellence.

Stage Two:

The second stage in the export process involves the translation of scientific excellence into R&D-intensive goods and services that capture export sales. This stage encompasses the production, marketing and distribution components of the value-added chain.

Let Z be a measure of export performance, and Y be, as above, the measure of scientific excellence. Then a production function G( ) exists that maps from scientific excellence to export performance:

[2] $Z = G(Y)$

As with F( ), G( ) can also be analyzed empirically, and used for comparing various countries with one another.

Availability of adequate data for X, Y and Z makes it possible to study Stage I and Stage II efficiency for a sample of countries. Such analysis makes it possible to partition causes of superior or inferior export performance between Stages I and II, and as a result, to construct policies for stimulating exports that attack the root of the problem.

We propose to test this hypothesis, using data for X, Y and Z for 11 EC countries. Before presenting our empirical results, we first describe the extensive data set itself.

3. Scientometric and Economic Indicators

The variables used in this study are listed below, together with a description of their nature and their sources. For our purposes, "high-technology" products are defined as those with R&D spending equal to or greater than 3.5 per cent of sales. A complete list of product groups that meet this criterion, according to the three-digit SITC code, is given in Appendix 2.

A. "X" Variables:

For our measure of R&D inputs, we simply used gross spending on Research and Development, expressed as a fraction of GDP. Data were all converted to U.S. dollars using purchasing power parity indexes, that measure the buying power of currencies rather than existing market exchange rates.

GERD: Gross R&D Spending, annual average for 1981-85; converted to U.S. dollars using Purchasing Power Parity index of O.E.C.D.; $ billion. Source: O.E.C.D., scientific indicators.

GDP 81/85: Gross Domestic Product, average for 1981-85, $ billion, converted to U.S. $ using Purchasing Power Parity index as for variable 1.

GERD/GDP: ratio of GERD to GDP, as per cent.

B. "Y" Variables:

For our measures of scientific excellence, we used indicators in three different areas: patents, citations, and publications.

a) Patent Indicators:

For patents, we measured the number of patents granted, for the 12 EC countries, at the United States Patent and Trademark Office (USPTO), as a measure of a country's aggressiveness in seeking global protection for its intellectual property. We computed the sum total of patents invented in 1977-86, as an expression of cumulative patent activity, at the USPTO, and expressed them as a fraction of GDP for each country.[1]

PAT - number of patents, matched to product groups, USPTO, 1984-86

PAT/GDP - PAT, as a ratio to GDP.

PATPOT: cumulative no. of patents, USPTO, 1977-86.

PATPOT/GDP: PATPOT as a fraction of GDP.

b) Publications and Citations:

These indicators measure, for each country, the number of scientific publications by scholars who cite that country as their primary address in their publications, as listed by the databases of the Institute for Scientific Information (I.S.I.), in Philadelphia, Pa. The publications are for articles in scientific and engineering journals. Citations are similarly drawn from the I.S.I. databases.

For publications, we used the listings of the Science Citation Index, for engineering and science journals separately, and then added the two. We also expressed this indicator as a fraction of GDP.

For citations, we used similar listings from the Science Citation index, also divided between engineering and scientific periodicals and then summed, and also expressed as a fraction of GDP.

PUBSCIENG: number of publications in both scientific and engineering publications. (not including Life Science publications), 1981-85.

PUBSCIENG/GDP: PUBSCIENG as a fraction of GDP.

CITSCIENG: number of citations in both scientific and engineering periodicals, 1981-85.

CITSCIENG/GDP: CITSCIENG as a fraction of GDP.

C. "Z" Variable:

RCA : revealed comparative advantage, for product groups; 1988, defined as:

$$RCA = 100 \{ (ES^2 - 1)/(ES^2 + 1) \},$$

where Export Share $$ES = \frac{EX / IM}{EXTOT / IMTOT}$$

EX is a country's total Exports of high-tech products, IM is that country's Imports of such products, **EXTOT** is the country's total exports of manufactures , and **IMTOT** is the country's total imports of manufactures.[2]

The data based on trade figures were derived from Grupp and Legler (1991). It is important to note that high-tech exports are compared to total exports (and imports) of *manufactured goods* only. The trade variables therefore serve as a measure of the extent to which trade in *manufactured products* is high-tech. (See Grupp, 1990, and Grupp and Legler, 1991.) The data themselves are given in Appendix 1.

4. Empirical Results

Regression equation estimates for the Stage 1 and Stage 2 Models are shown in Table 2. For purposes of this analysis, we chose to combine the "leading-edge" (goods for which R&D spending equals 8 per cent or more of sales) and "high-level" products (between 3.5 per cent and 8 per cent). Disaggregation does not substantively alter our conclusions. In general, the level of government intervention in leading-edge products is much greater, and hence exports of such products are less influenced by pure market forces.[3]

a) Stage I: translating R&D into scientific excellence:

Figures 1, 2, 3 and 4 show the relation between four measures of scientific output -- publications, citations, patents, and cumulated patents -- expressed as a fraction of GDP, and Gross R&D spending, also as a fraction of GDP, for 12 European countries.

The European countries chosen are: Germany, France, UK, Netherlands, Belgium/ Luxemburg, Denmark, Ireland, Spain, Italy, Greece, Portugal.

For each Figure, the regression line for the "Y" (dependent) variable regressed on the "X" (independent) variable is shown.

Table 2:

Regression Equations for "Stage 1" Model: Twelve European Countries

Scientific and Technological Output Indicators as a Function of Gross R&D Spending/ GDP: (Independence Variable: Gross R&D Spending as percentage of GDP)

Dependent Variable	Intercept	Coefficient of Independent Variable (GERD/GDP)	R^2 adj	P	N
PUBSCIENG/GDP	21.15 (5.18)	29.02	0.75	.0003	11
CITSCIENG/GDP	16.42 (21.82)	115.34	0.73	.0005	11
PATH/GDP	-1.68 (0.85)	5.066	0.78	.0002	11
PATPOT/GDP	-7.28 (2.97)	18.59	0.79	.0001	11

* (standard error of slope coefficient in brackets)

Figure 1

Publications in Science & Eng. per GDP As a Function of Gross R&D Spending (as % of GDP 1981-85) in 12 EC Countries

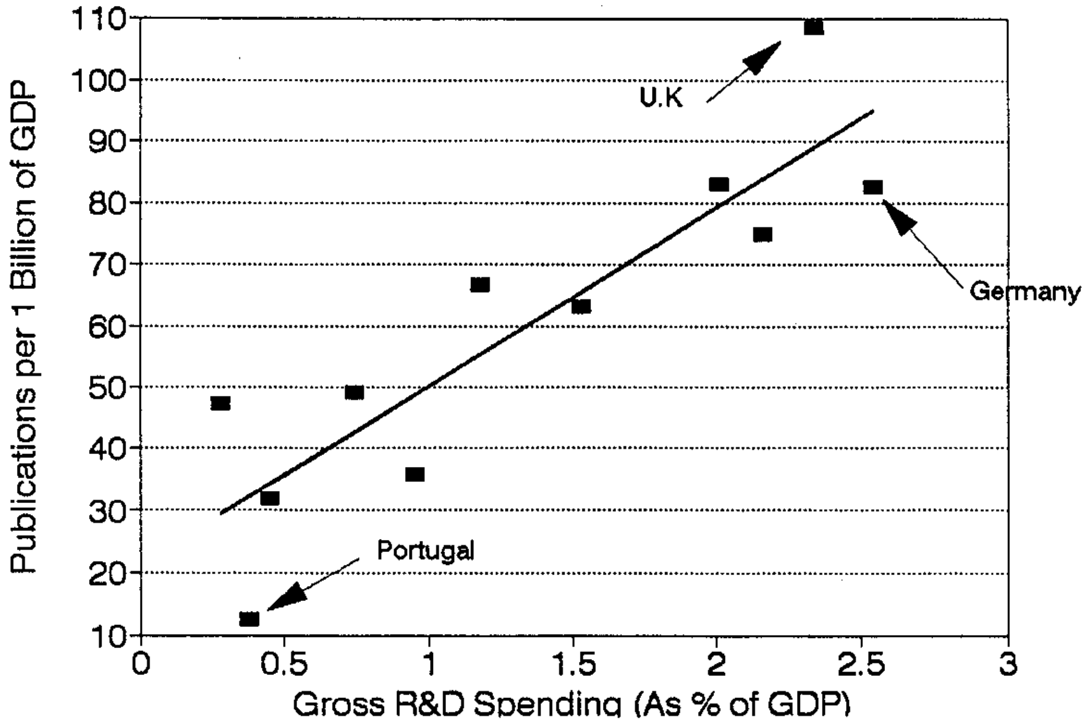


Figure 2

Citations in Science & Eng. per GDP, As Function of Gross R&D Spending (as % of GDP 1981-85) in 12 EC Countries

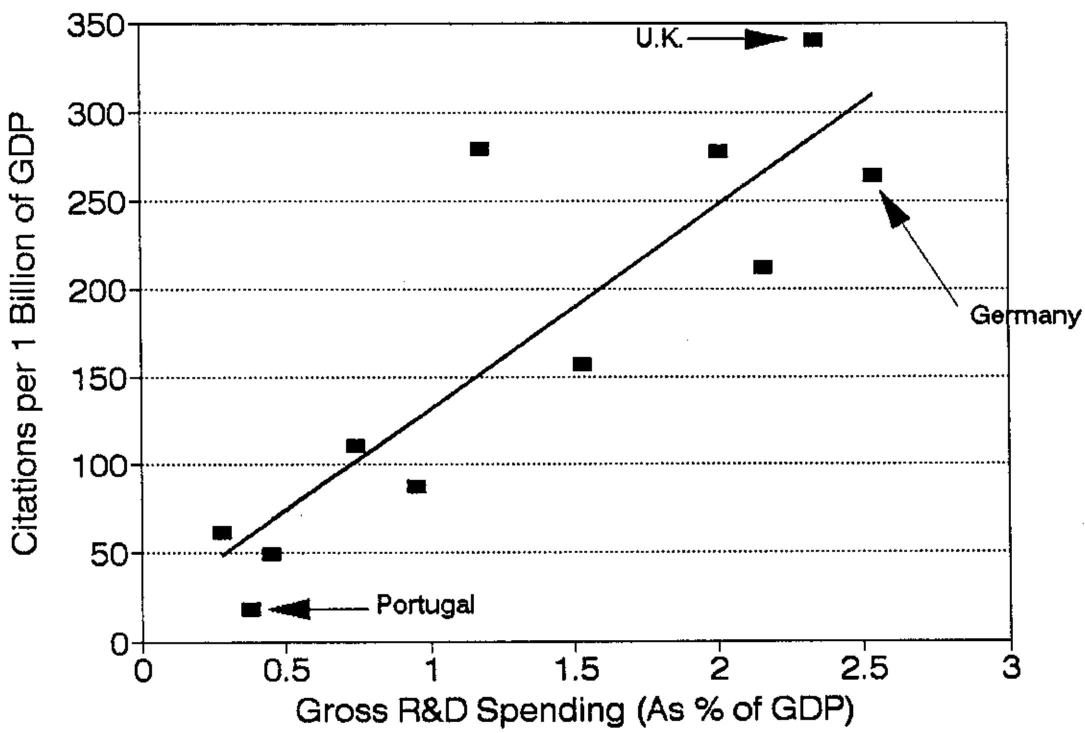


Figure 3

Patents Per GDP (At USPTO 1984-86) as a Function of Gross R&D Spending (as % of GDP 1981-85), in 12 EC Countries

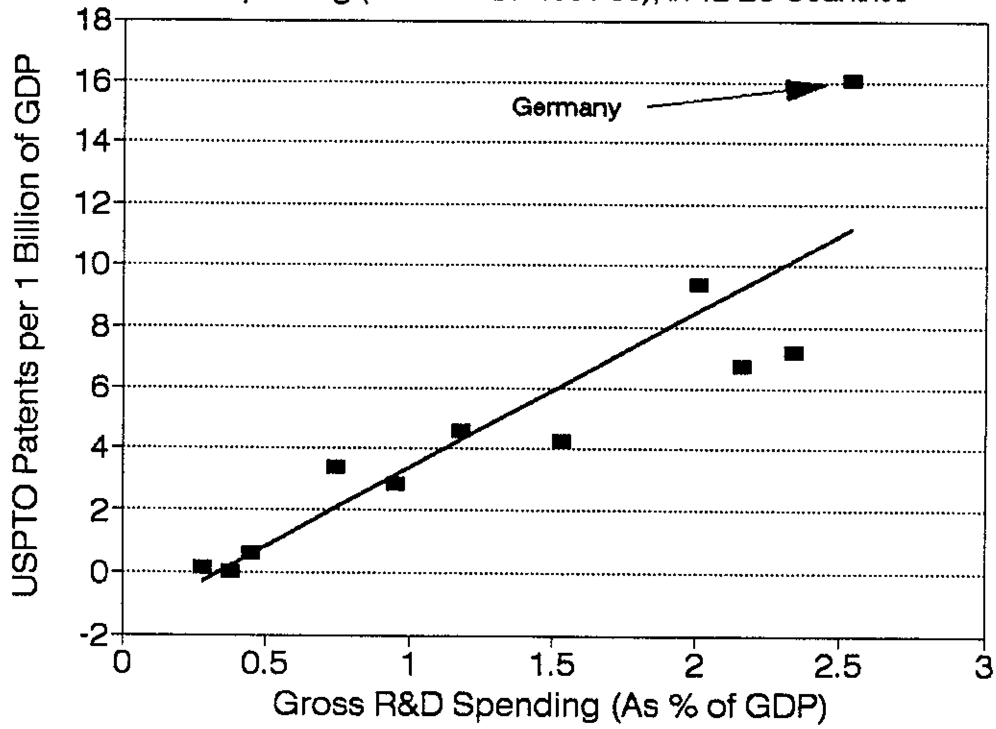
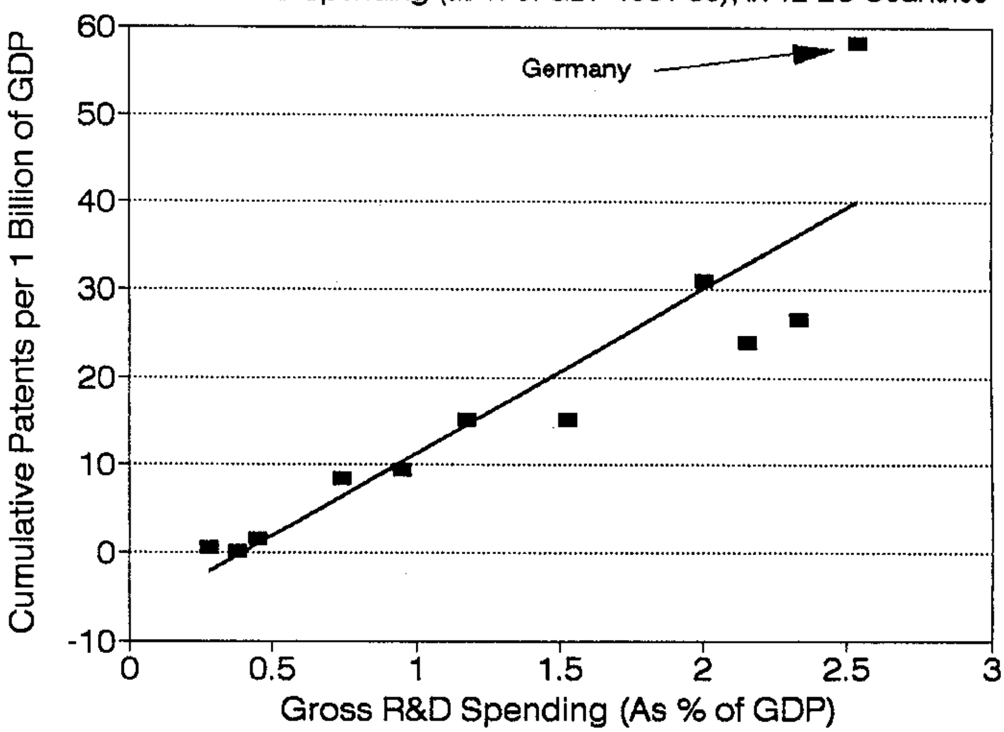


Figure 4

Cumulative Patents Per GDP (At USPTO 1977-86) as a Function of Gross R&D Spending (as % of GDP 1981-85), in 12 EC Countries



The United Kingdom lies above the 12-country trend line both for publications and for citations, suggesting considerable Stage I efficiency in that country in generating scientific outputs from R&D resourcess, while Germany lies somewhat below the trend line. (See Figs. 1 and 2). It is possible that the ISI database used for publications and citations, which comprises mainly English-language periodicals, biases the results in favor of English-speaking nations (like the U.K.). However other studies suggest that irregardless of this bias, the U.K. does achieve a very high level of publications and citations, relative to other countries.

The slope of the two regression lines can be interpreted as:

$$\frac{d(\text{PUBSCIENG} / \text{GDP})}{d(\text{GERD} / \text{GDP})} \text{ and } \frac{d(\text{CITSCIENG} / \text{GDP})}{d(\text{GERD} / \text{GDP})}$$

meaning, the increase in publications and citations, respectively, normalized by GDP, for a one per cent increase in R&D spending (as a percentage of GDP). The respective slopes are, approx., 30 and 115.

A different picture emerges for patents. Here, Germany lies well above the trend line, both for Patents per GDP and for Cumulative Patents per GDP (see Figs. 3 and 4). This suggests that German firms in large part follow an aggressive patenting policy at the United States Patent Office, to a greater extent than that practiced by firms in other European countries.

Apart from the German "outlier", the regression-line fit between R&D spending (as a percent of GDP) and patents/GDP is a relatively close fit for the 12 EC countries. Here again, the slope of the regression line is a measure of the incremental rise in patents /GDP for a one percentage point increase in R&D spending/GDP.

Stage Ib: Translating Publications into Patents: Our empirical analysis suggested to us that Stage I -- transforming R&D resources into scientific and technological "intellectual property" --is really comprised of two substages: Ia) use of R&D resources to generate research results, expressed as publications and citations; and Ib) use of scientific and technological knowledge (which find expression in publications and citations) in order to generate patentable inventions.

To test this hypothesis, we computed two additional statistical regression lines, in which Patents/GDP was the dependent variable, and Citations/GDP and Publications/GDP each served as the independent variables, respectively. The results are shown below in Table 3, and in Figures 5 and 6.

The results clearly indicate a) that there is a strong trend line between patents/GDP and citations and publications; and that the two major outliers in the data are Germany, which lies well above the trend line in terms of its energetic patenting activity, and the U.K., which lies well below the trend line in its patenting activity. The U.K.'s weak patenting performance may explain in part the relative weakness of the U.K.'s performance in knowledge-based exports, relative to its comparatively strong scientific and technological achievements.

Table 3
Regression Equations for Stage "Ib" PAT/GDP as function of CITSCIENG/GDP and PUBSCIENG/GDP in 12 European Countries

Dependent Variable	Intercept	Slope	R^2 adj	P	N
CITSCIENG/GDP	0.76223	0.21577	0.534	0.0064	11
PUBSCIENG/GDP	0.74245	0.22330	0.501	0.0089	11

Figure 5

Patents Per GDP(At USPTO 1984-86) as a Function of Citations in Science & Eng. per GDP 1981-85, in 12 EC countries

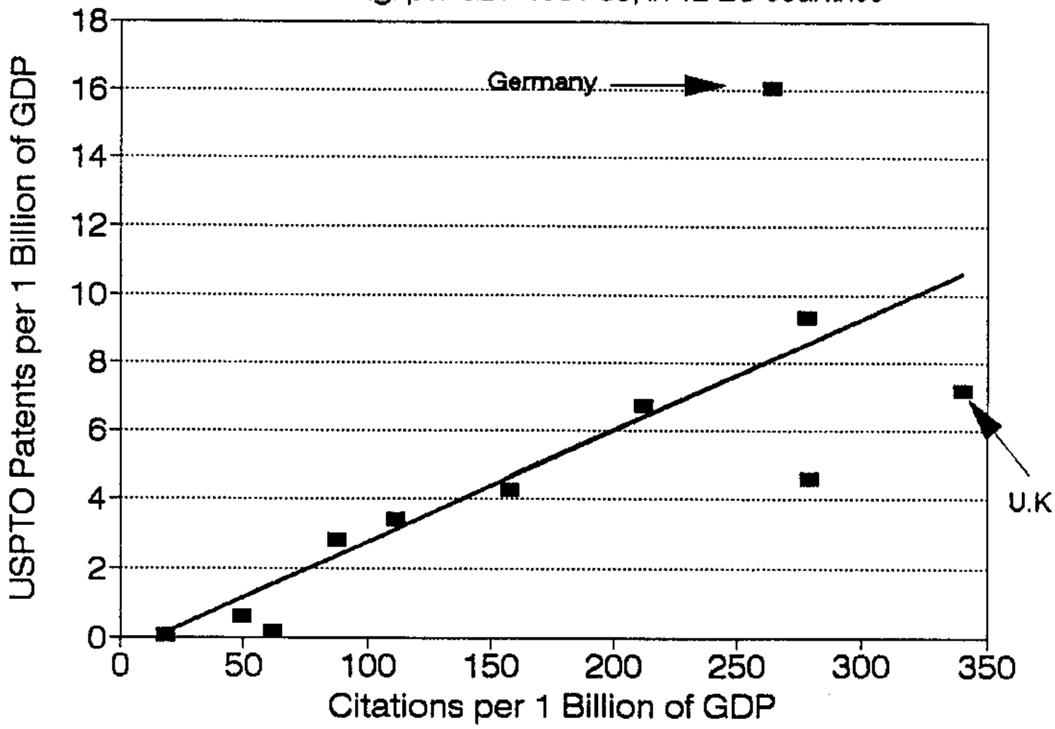
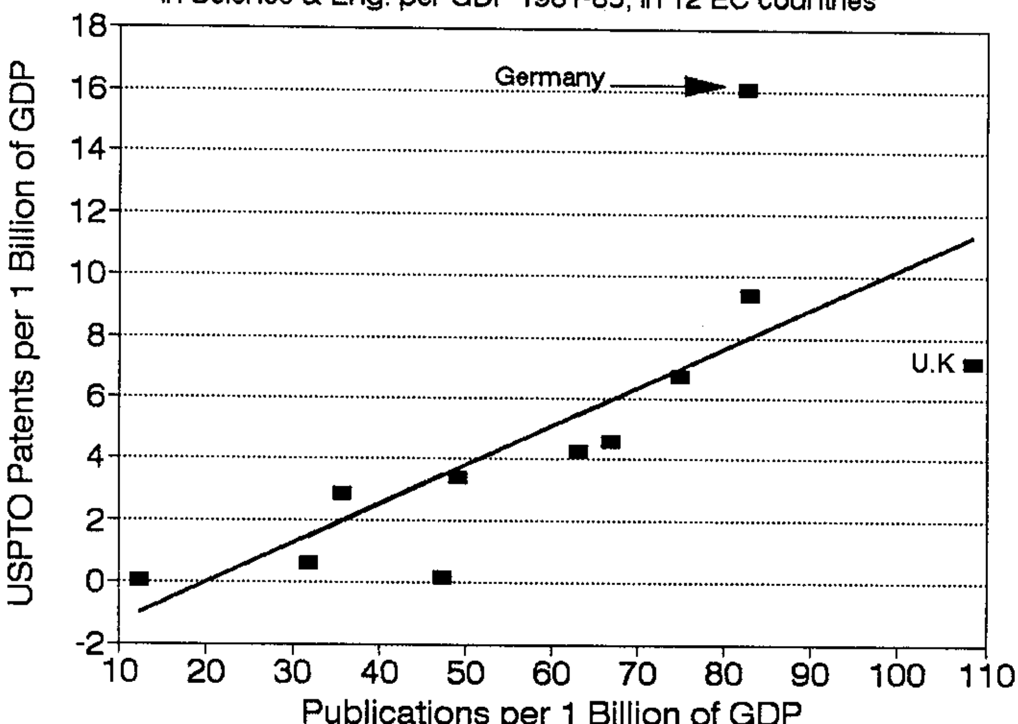


Figure 6

Patents Per GDP(At USPTO 1984-86) as a Function of Publications in Science & Eng. per GDP 1981-85, in 12 EC countries



b) Stage II:

Translating scientific excellence into export sales, Figures 7 and 8 and Table 4 show the statistical regression lines for the Stage II equation, which expresses relative comparative advantage RCA) as a function of patents and cumulative patents. Here too, the statistical fit is relatively good, confirming the close empirical link between knowledge-based export performance, in terms of an index of world market share, and patent performance.

The goodness of the regression fit is diminished because of the inclusion of Portugal and Greece. These two countries have very little patenting activity at the USPTO and are not yet really players in the global knowledge-based export market. Excluding these countries would substantially increase the value of the multiple correlation coefficient.

For Germany, success in translation of patenting activity into exporting success is not impressive. While the distance between the point signifying Germany, and the 12-country trend line, is not significantly different from zero, nonetheless Figures 7 and 8 do indicate that resources invested in Germany in activities related to patenting may not be used with full efficiency.

Table 4

Regression Equation for Stage II: Revealed Comparative Advantage as a Function of Scientific Inputs (Dependent Variable: RCA)

Dependent Variable	Intercept	Slope*	R^2 adj	P	N
PAT/GDP	-43.72 (1.75)	5.43	0.46	.0126	11
PATPOT/GDP	-41.58 (0,49)	1.45	0.43	.0166	11

* (standard error of slope coefficients in brackets)

Figure 7

Revealed Comparative Advantage Index 1988, as a Function of Patents per GDP (at USPTO 1984-86), in 11 EC Countries

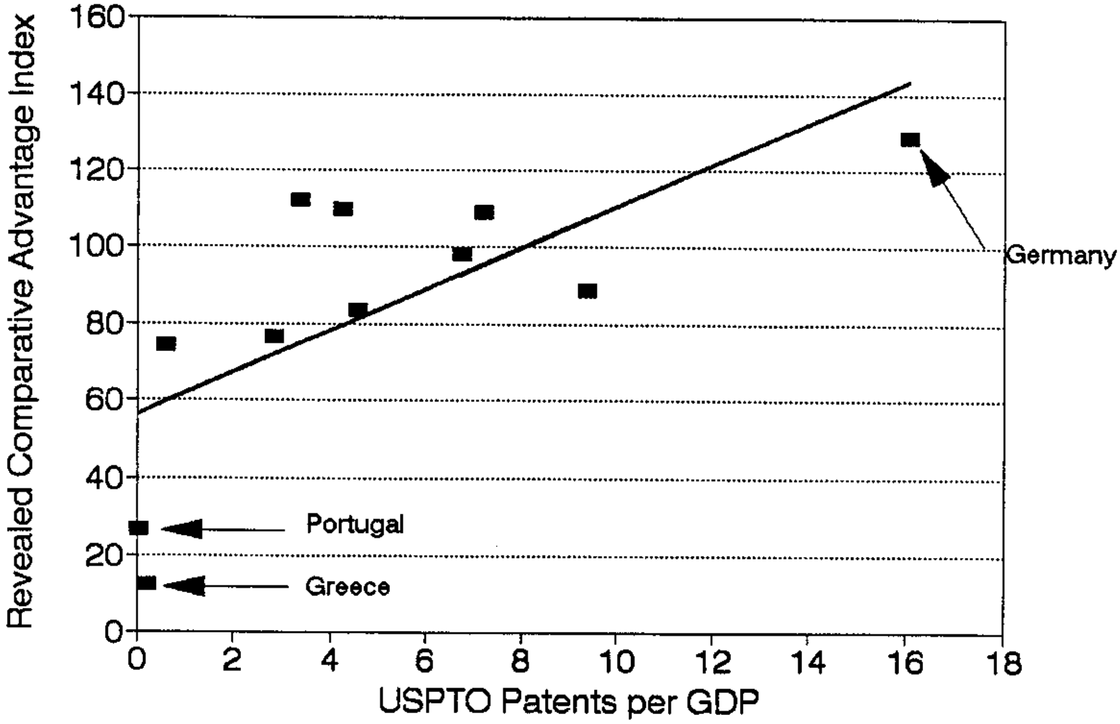
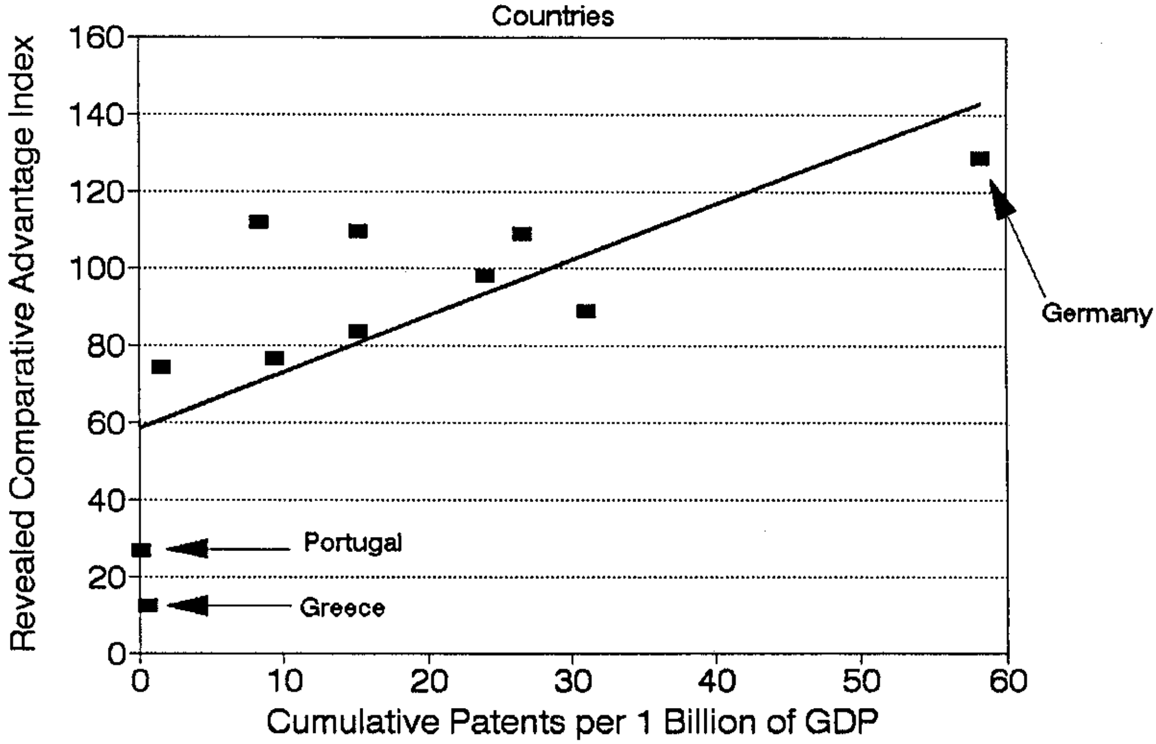


Figure 8

Revealed Comparative Advantage Index 1988, as a Function of Comulative Patents per GDP (at USPTO 1977-86), in 12 EC Countries



5. Conclusion and Implications

Our empirical results have confirmed the posited link between inputs and outputs, in both stages of our two-stage innovation model: a) between R&D resources and scientific outputs, and b) between scientific outputs and export performance, among 12 EC countries. The Stage I link between R&D resources and scientific and technological outputs (publications and citations) is much stronger, in terms of the least-squares fit, than the Stage II link between scientific and technological output and export performance. The model's performance is somewhat improved by introducing an intermediate stage, in which patents are expressed as a function of citations and publications.

In general, the results confirm our basic hypothesis presented at the start of this paper, that international commercial success in high-technology products exports is basically supported by R&D spending as a fraction of GDP, and by the resulting outputs of scientific and technical knowledge and patents.

One straightforward policy implication is this: There is no free lunch. Achieving larger export shares in knowledge-based products requires investment of substantial resources in Research and Development. At the same time, there is still considerable variation among countries in the efficiency with which they exploit scientific and technological excellence. Great Britain is a case in point -- that country's sizeable output of publications and citations is rather inefficiently converted into high-tech exports and market share, compared to other EC countries. While the reasons for this are not clear, they may be related to passive patenting policy abroad and insufficient skill and investment in marketing.

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Apendix 1: DATA

STATE	GERD 81-85	GDP 81-85	GERD/ GDP %	PUB- SCIENG 81-85	PUB- SCIENG/ GDP	CIT- SCIENG 81-85	CIT- SCIENG/ GDP	PAT 84-86	PAT/ GDP 84-86	PATPOT- 77-86	PATPOT/ GDP	RCA 1988
Germany	16.66	655.91	2.54	54169	82.59	173437	264.42	12461	16.07	38205	58.25	28.76
France	12.48	576.7	2.16	43190	74.89	122344	212.14	4370	6.74	13871	24.05	-2.10
U.K.	12.69	542.17	2.34	58774	108.41	184502	340.30	4472	7.21	14443	26.64	9.07
Netherland	2.98	147.97	2.01	12278	82.98	41167	278.21	1527	9.37	4595	31.05	-11.22
Belgium/Lux.	1.49	97.48	1.53	6151	63.10	15363	157.60	461	4.25	1480	15.18	9.47
Denmark	0.65	55.23	1.18	3690	66.81	15418	279.16	288	4.58	838	15.17	-16.55
Ireland	0.16	21.57	0.74	1060	49.14	2401	111.31	83	3.40	181	8.39	11.84
Spain	1.15	257.83	0.45	8215	31.86	12748	49.44	181	0.61	413	1.60	-25.80
Italy	5.28	555.79	0.95	19845	35.71	48420	87.12	1777	2.85	5235	9.42	-23.46
Greece	0.15	53.93	0.28	2550	47.28	3345	62.02	11	0.18	33	0.61	-87.57
Portugal	0.19	49.64	0.38	622	12.53	923	18.59	2	0.04	7	0.14	-73.06

Appendix 2: List of R&D Intensive Products

No	SITC III	Product group (non-official terms)	R&D intensity
1	516	Advanced organic chemicals	Leading-edge goods
2	525	Radio-active materials	Leading-edge goods
3	541	Pharmaceutical products	Leading-edge goods
4	575	Advanced plastics	Leading-edge goods
5	591	Agricultural chemicals	Leading-edge goods
6	714	Turbines and reaction engines	Leading-edge goods
7	718	Nuclear,water,wind power generators.	Leading-edge goods
8	752	Automatic data processing machines	Leading-edge goods
9	764	Telecommunications equipment	Leading-edge goods
10	774	Medical electronics	Leading-edge goods
11	776	Semi-conductor devices	Leading-edge goods
12	778	Advanced electrical machinery	Leading-edge goods
13	792	Aircraft and spacecraft	Leading-edge goods
14	871	Advanced optical instruments	Leading-edge goods
15	874	Advanced measuring instruments	Leading-edge goods
16	891	Arms and ammunition	Leading-edge goods
17	266	Synthetic fibres	High-level products
18	277	Advanced industrial abrasives	High-level products
19	515	Heterocyclic chemistry	High-level products
20	522	Rare inorganic chemicals	High-level products
21	524	Other precious chemicals	High-level products
22	531	Synthetic colouring matter	High-level products
23	533	Pigments. paints, varnishes .	High-level products
24	542	Medicaments	High-level products
25	551	Essential oils. perfume, flavour	High-level products
26	574	Polyethers and resins	High-level products
27	598	Advanced chemical products	High-level products
28	663	Mineral manufactures, fine ceramics	High-level products
29	689	Precious non-ferrous base metals	High-level products
30	724	Textile and leather machinery	High-level products
31	725	Paper and pulp machinery	High-level products
32	726	Printing and bookbinding machinery	High-level products
33	727	Industrial food-processing machines	High-level products
34	728	Advanced machine-tools	High-level products
35	731	Machine-tools working by removing	High-level products
36	733	Machine-tools without removing	High-level products
37	735	Parts for machine-tools	High-level products
38	737	Advanced metalworking equipment	High-level products
39	741	Industrial heating and cooling goods	High-level products
40	744	Mechanical. handling equipment	High-level products
41	745	Other non-electrical machinery	High-level products
42	746	Ball and roller bearings	High-level.products
43	751	Office machines,word-processing	High-level products
44	759	Advanced parts:for computers	High-level products
45	761	Television snd video equipment	High-level products
46	762	Radio-broadcast,radiotelephony goods	High-level products
47	763	Sound and video recorders	High-level products
48	772	Traditional electronics	High-level products
49	773	Optical fibre and other cables	High-level products
50	781	Motor vehicles for persons	High-level products
51	782	Motor vehicles for good transport	High-level products
52	791	Railway vehicles	High-level products
53	872	Medical instruments and appliances	High-level products
54	873	Traditional measuring equipment	High-level products
55	881	Photographic apparatus and equipment	High-level products
56	882	Photo- and cinematographic supplies	High-level products
57	883	Optical fibres, contact, other lenses	High-level products

Appendix 3. Definitions

The following is a description of the entire database, from which we extracted selected variables for our analysis.

Definitions of Variables

GERD - Gross R&D Spending, annual average for 1981-85; converted to U.S. dollars using Purchasing Power Parity index of O.E.C.D.; $ billion. Source: O.E.C.D., scientific indicators. For Israel: R&D data are taken from the Central Statistical Bureau's Statistical Yearbook.

GDP 81/85 - Gross Domestic Product, average for 1981-85, $ billion, converted to U.S. $ using Purchasing Power Parity index as for variable 1.

GERD/GDP - ratio of GERD to GDP, as per cent.

PAT - number of patents matched to high-tech products, U.S. Patent and Trademark Office, invented between1984-86.

PAT/GDP - PAT as a ratio to GDP.

PATPOT - cumulative number of patents at USPTO, 1977-86, for high-tech goods.

PATPOT/GDP - PATPOT as a fraction of GDP.

PUBSCIENG - number of publications, in both scientific and engineering publications, as measured by the Science Citation Index, for the period 1981-85.

PUBSCIENG/GDP - PUBSCIENG as a fraction of GDP.

CITSCIENG - number of citations received, listed in Science Citation Index, in both science and engineering periodicals, for 1981-85.

CITSCIENG/GDP - CITSCIENG as a fraction of GDP.

RCA - revealed comparative advantage, for high-tech goods, for 1988, defined as:

$$RCA = 100 \{ (ES^2 - 1)/(ES^2 + 1) \},$$

where Export Share $$ES = \frac{EX / IM}{EXTOT / IMTOT}$$

and EX is a country's total Exports of high-tech products, IM is that country's Imports of high-tech products, EXTOT is the country's total exports of manufactures , and IMTOT is the country's total imports of manufactures.

Endnotes

1 This variable measures not only patent activity in the U.S., but also the degree of willingness of firms and inventors to apply for patents at the United States Patent Office. For many reasons, the eagerness to patent inventions in the U.S. is not identical across all countries. Hence, this variable reflects not only some measure of scientific output, but also the extent to which firms and inventors are prepared to create a "footprint" of this output in the form of patents.

2 Grupp (1992, p. 11) explains that RCA (Revealed Comparative Advantage) answers two questions simultaneously, a) Do the domestic suppliers of high technology products have a solid footing in the international market compared with foreign competitors and suppliers of other domestic sectors? And b) Do they succeed in substituting domestic production for high technology imports, compared with suppliers in other sectors?

3 "..there are two hemispheres in the world of R&D intensity. One (the high-level consumer products with expectations of a relatively good turnover per R&D investment), in which technical performance by patents does play a role and is a decisive factor for international competitiveness alongside with R&D activities by industry. Scientific achievements are not so important here. The other hemisphere (the leading-edge technologies with moderate expectations in turnover per R&D investment) in which factors other than technology guarantee international success, is characterized by stronger government intervention both on the side of R&D and also in terms of procurement and regulation. Here, scientific excellence is indispensable. " Grupp (1991, p. 26).

Grupp adds: "Business-financed R&D governs the high-level commodities and thus all high technologies, whereas international success in leading edge products must be nurtured from somewhere else. ...the financial means of governments poured into the business R&D system largely explains where the position of a country in leading-edge products is. ...Governments in EC countries are the drafthorses in very R&D intensive fields and provide financial means for the pioneering of possibly less effective new leading-edge technologies."

Identifying the Sources of Market Value for Science-Based Products:

The Case of Industrial Sensors

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Abstract

This paper presents an integrated model for evaluating consumer perceptions of science-based products or services. The model combines a new approach to benchmarking, known as technometrics, that provides a quantitative profile of a product's key attributes, with direct and indirect methods for measuring buyers' perceptions regarding the relative importance of product attributes as a source of value. A new measure, called the "index of appropriateness", is proposed, which shows the extent to which a product's "supply" of characteristics or attributes matches the "demand" for them in the marketplace. The model is illustrated using several types of industrial sensors.

"You can't say it often enough: Don't lose touch with the customer".

"The New Computer Revolution", *Fortune*, June 14, 1993, p. 20

This paper outlines a comprehensive, integrated method for identifying and quantifying the sources of market value for science-based high-technology products. The objective is to determine and quantify the extent and nature of differences between a product's "supply" of customer value, and the demand for such value. The theoretical basis of the model is the notion that consumers do not buy goods or services but rather the attributes of those goods or services; hence, marketplace success rests on creating products whose attributes match what the market wants and needs. An operational system for evaluating the "appropriateness" of a product's (or service's) attributes -- its ability to satisfy consumer needs -- is constructed and illustrated, with reference to several types of industrial sensors.

1. An Integrated Model for Quantifying Sources of Value

Marketing expert Theodore Levitt (1993) stressed the importance of a market-oriented competitive strategy by advising managers to ask continually: "What business am I in?" He offers many examples of businesses (such as American railroad companies, or Hollywood movie studios) that went bankrupt because they failed to heed the voice of their markets by asking that question often enough.

Another way to phrase Levitt's question is: *How do I create value for my customers?* That question, in turn, leads to several others:

* *Who are my customers?*
* *What particular aspects or characteristics of my products are especially important in creating value ?*
* *How can I best enhance those value-creating properties?*

Knowledge of the market value that attaches to each of the most important attributes of a technology-based product is important information for managers. Many businesses are built on products that have a single outstanding characteristic that none of the competing products can match, while satisfying minimal standards in other characteristics.

For instance, Wellfleet Communications tops the list of America's 100 fastest growing companies, with annual growth in sales of 243 per cent during the past 3-5 years. Wellfleet produces local and wide area computer networks (LAN's and WAN's). In a highly-competitive industry, "Wellfleet's Backbone Node routers were designed to limit downtime to only one sector of the network during a failure" and "would be easy to upgrade". [Fortune, Aug. 9, 1993, p. 42]. Those two key characteristics -- limited downtime and ease in upgrading -- gave Wellfleet the edge. "They were just what consumers wanted," Fortune reported.

Quantitative detailed information on perceived product quality can provide important "voice of the market" data to managers, who seek to improve their products, revise their pricing policies, or shape a competitive strategy. Rapidly-changing market conditions make it vital for managers to track the quality of their products and services on an ongoing basis. This paper suggests a new approach to quantifying the relative importance of product characteristics, in satisfying customer needs. It proposes a way to "triangulate" product quality by comparing two different perspectives: the market (through price regressions) and direct surveys of customer preferences, and the objective quality of products through benchmarking. The result is a finely-detailed picture of a product's strengths and weaknesses, one that reacts quickly to changing market conditions, and enables managers to make early decisions long before declining market share signals a crisis situation.

Our model has three main components. The first is Lancaster's new approach to consumer theory; the second is the "technometric" approach to measurement of product quality; and the third is the "hedonic price index" technique. We now proceed to describe each of these components in turn.

Lancaster"s new consumer theory: The basis of the model is a new approach to consumer demand developed by Kelvin Lancaster (1991). According to this theory, "consumers are not interested in goods as such, but in their properties or characteristics." (p. 5). The theory addresses such issues as the optimal "basket" of characteristics, for a given set of consumer preferences and the relative value that consumers attach to each characteristic.

In conventional consumer theory, consumer utility is posited to be a function of the quantities of a product purchased. This has very limited application, as it fails to address the underlying reasons people purchase products -- to satisfy wants and needs or to solve specific problems.

In Lancaster's New Consumer Theory, utility is posited to be a function of the characteristics of a product. Utility functions, therefore, instead of mapping from "quantities" into "utility", map from "product characteristics" into utility. This theory is more appropriate as a conceptual basis for responding to Levitt's "sources of value" question than conventional consumer theory. According to the theory, products will array themselves according to the characteristics or attributes from which consumers derive utility or satisfaction. Those goods that offer such attributes in the combinations that match buyer's utility functions will find buyers, at a price that reflects those goods' want-satisfying power.

In markets that are competitive and efficient -- that is, producers compete with other producers for sales, and consumers are well-informed about the nature of the competing products and their attributes -- we should therefore expect to find an empirical relation between the quantitatively-measured attributes of a product and the product's price. By methods of linear regression, it should be possible to estimate equations where the dependent variable is market price and the independent variables are product attributes. The absolute value of the attributes' coefficients will indicate how valuable the market perceives that attribute . The relative value of the coefficient, in comparison to other attributes' coefficients, will show the relative market importance of the attribute compared to the product's other characteristics. This is sometimes known as a hedonic price index.

To make Lancaster's new consumer demand theory more operational, we need to find a way to a) quantify product characteristics, in a way that permits ready comparisons across products and aggregation across characteristics within given products, and b) measure the statistical relation between the level of product characteristics and the prices of those products. Quantifying product characteristics, and benchmarking them against their competitors, can best be done through the so-called technometric approach to benchmarking, which satisfies (a), and the hedonic price index approach, which satisfies (b).

Technometrics: The "technometrics" (Grupp, 1992; 1993; Grupp & Hohmeyer, 1986, 1988) method profiles a product's comparative strength in relation to its leading competitors, by selecting the product's key attributes and quantifying them on a zero-one scale, where zero represents the lowest level of that attribute in the product class, and one represents the state-of-the-art in the highest-quality competing product. The zero-one metric enables ready aggregation and comparison of these attributes.

Technometrics begins by observing that every product or process has a set of key attributes that define its performance, value or ability to satisfy customer wants. Most of these attributes can be quantified -- for instance, in the case of industrial sensors that measure pressure, such attributes as range, accuracy, maximum and minimum operating temperatures, weight, linearity, hysteresis, overpressure, diameter, and thermal properties are important.

Each of these attributes has a different unit of measurement. Problems then arise in aggregating attributes to build a single quality index. The technometric indicator surmounts this difficulty by converting each measured attribute into a [0,1] metric, enabling construction of weighted averages, etc., and permitting comparisons across products, firms, industries and countries.

Formally, let subscripts i, j and k represent product brands, product attributes or characteristics, and subgroup (industry or country), respectively. Let K(i,j,k) represent the measurement of an attribute for given i, j and k.

The technometric indicator, K*, is defined, on the [0,1] metric, as the relative performance of attribute j, product brand i :

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

where:

$K_{(i,j,k)}$ = the value of product characteristic "j" for product brand "i", for industry k,

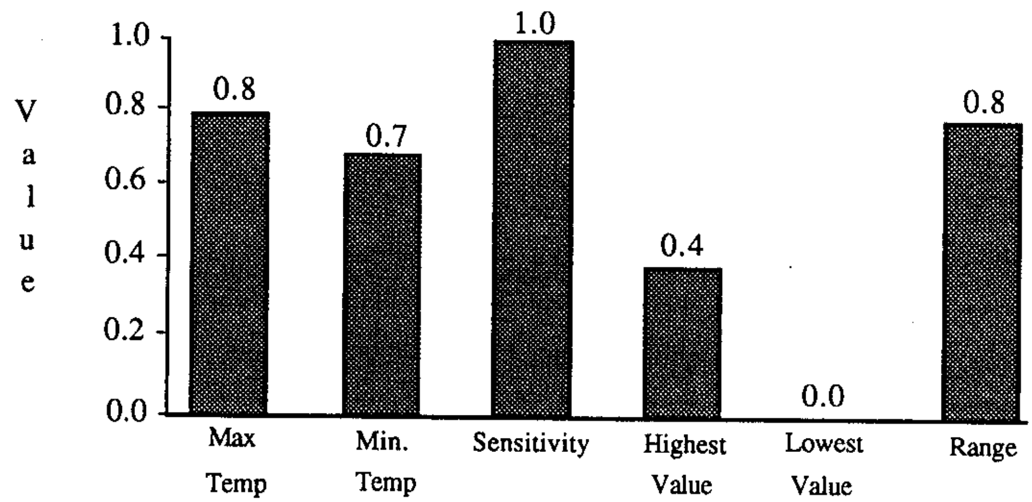
$K_{min}(i,j,k_{min})$ = the **lowest** value of product characteristic "j", for industry k, produced by some firm in that industry

$K_{max}(i,j,k_{max})$ = the **highest** value of product characteristic "j", among **all** firms in industry k, produced by some firm in that industry

It is possible to aggregate K* across all key attributes of a particular product or process, in order to achieve an aggregate K* measure. This aggregate technometric measure can then be correlated with other variables to determine the link between technological excellence and, for instance, market success. K* can also be readily portrayed graphically, as a product "profile", in comparison with its main competitors.

An example of a technometric product profile is shown in Figure 1. The particular product is industrial sensors used to measure pressure, made by Israeli firms, and based on piezo-resistance. The zero value on the scale represents the lowest value of the attribute for firms producing this product, in eight countries: Germany, Israel, Switzerland, U.S., Japan, Great Britain, Netherlands and Luxembourg, and the one value, the highest value of that attribute for sensors in those same countries. The actual value shows the "score" of each attribute for Israeli pressure sensors, on the zero-one metric. Note that unlike the particular use of the technometric profile suggested here, for a particular "brand-name" sensor, this profile is for a type of sensor produced by all firms in a nation. In principle, however, such profiles can be constructed on a "brand-name", rather than national, basis.

Figure 1: **Technometric Profile for Pressure Sensors: Israel vs. Other Countries**



Hedonic Price Indexes: The computation of technometric indexes of product quality provides only one part -- perhaps, the least important part -- of the overall picture. We must next ask: How much value to consumers attach to various attributes of the product, and to what degree does a particular product match those values? One approach to answering this question is the so-called hedonic price index approach.

The notion that much valuable information could be obtained by statistically relating a product's price to its characteristics is the basis of a large and useful literature [Griliches, 1961, 1971; Saviotti, 1985; Chow, 1968]. The main purpose of the hedonic price index literature, however, was not as a marketing or technology-policy tool. Generally, the objective was to find a way to standardize rapidly-changing technology-based products for quality changes, in order to measure the product price for a "standard" unit of the product. Once such a price index is constructed, one can derive standard units of output. This, in turn, can permit construction of equations to forecast demand for the product.

Chow [1968] constructs such a hedonic price index for computers, expressing the price (or "rental value") of computers as a function of their memory, access time and speed. He then fits a logistic demand function to the "quality-constant" units of output of computing power, and finds that it provides a reasonable fit to actual demand. (One of the most interesting findings in Chow's paper was not the well-fitting demand function, but the fact that the main attribute that seemed to drive demand for computers at that time (1950's and 1960's) was **memory**. The coefficient of memory in the hedonic price equation was by far the largest, indicating that it was memory that constrained computing operations at that time, and hence was the attribute buyers were most willing to pay for in proportion to its magnitude).

Saviotti (1985) notes that product quality can be portrayed as a weighted average Q_j, such that:

$$Q_j = \Sigma_i \ a_i X_{ij} \qquad j = \text{j-th good}, \ i = \text{i-th characteristic}$$

He proceeds to note that if there is a relationship between product quality and price, then it can be hypothesized that market price Pj depends on product characteristics, along with other factors "a_0":

$$P_j = a_0 + \Sigma_i \ a_i X_{ij} + u_j$$

where u_j represents the random statistical error term. By means of statistical regression, the values of the "a_i" coefficients can be estimated, and interpreted as the relative importance of property X_i in influencing the price of the product. "Price equation coefficients," Saviotti notes, "can therefore be considered an approximation for users' judgment of the relative value of the various characteristics." (p. 312).

What emerges, therefore, is this: a) the use of technometric profiles enables managers to benchmark their products, with reference to highest-quality competitors, and identify key characteristics that offer competitive advantage or are sources of disadvantage in the market; this provides an objective profile of a product's want-satisfying ability, across a range of key characteristics; and b) hedonic price equations provide information about which of the product characteristics are most important in the determination of market price, with price serving as a measure of customer value.

Questionnaire Surveys: Another approach exists to determining consumer value apart from the hedonic price indexes -- direct market surveys. In this approach, consumers are shown lists of product characteristics or specifications, and are asked to give each characteristic a weight between "1" and "10", that reflects its importance to the customer. This information can provide a useful, additional perspective to statistical regressions. Moreover, the same survey can be given to sellers -- producers, sales managers, etc. -- to examine their perceptions of their product and the aspects of that product that are most important in creating value.

An example of this approach is shown in Table 1 - a questionnaire used to survey opinions about the importance of a set of characteristics describing civilian airliners. By checking the appropriate box, respondents indicated whether an attribute had zero importance, or weights ranging from "1" through "10". We canvassed buyers of sensors in a similar manner, for example, to determine their subjective perception of the importance of sensor attributes.

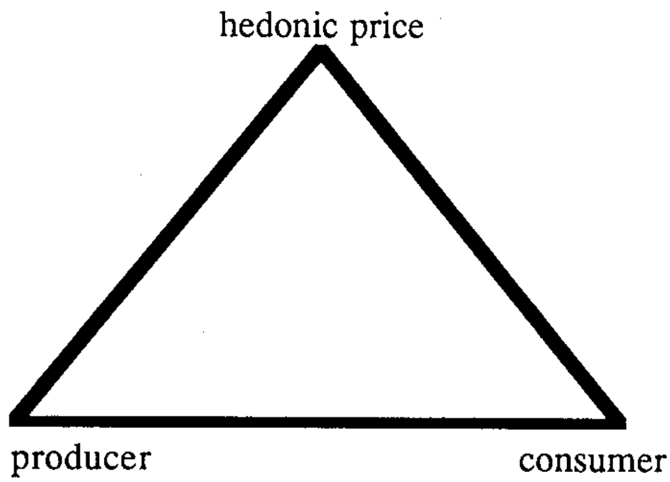
A three-way comparison is thus possible, among price regressions, consumer perceptions, and producer perceptions. This method in a sense "triangulates" the sources of market value by collating different sorts of information. (See Figure 2).

Table 1: **Questionnaire**

Please indicate the relative importance that you place on the following factors when evaluating aircraft for purchase.

Low ... High	
☐☐☐☐☐☐☐☐☐☒☐☐	**Crew Costs:** *(e.g. two member crew, common type ratings for multiple products)*
☐☐☐☐☐☐☐☐☐☒☐☐	**Fuel Efficiency:** *(e.g., weight)*
☐☐☐☐☐☐☐☐☐☒☐☐	**Dispatch Reliability:** *(e.g., system complexity, robustness of design, failure tolerance, structural design)*
☐☐☐☐☐☐☐☐☐☒☐☐	**Maintainability:** *(e.g., mean time between maintenance, engine maintenance, centralized maintenance recording system)*
☐☐☐☐☐☐☐☐☐☐☒☐	**Payload/Range Capability**
☐☐☐☐☐☐☐☐☐☒☐☐	**Block-Time Performance, Function of Dispatch Reliability**
☐☐☐☐☐☐☐☒☐☐☐☐	**Airport Factors** *(e.g., runway capability, ramp space, field length, flexible interface with ground support, airport noise, emissions)*
☐☐☐☐☐☐☒☐☐☐☐☐	**Customer Support** *(e.g., AOG, technical support, spare parts availability)*
☐☐☐☐☐☐☐☐☐☐☐☒	**Safety** *(e.g., emergency exits, windshear annunciation, flight envelope limits)*
☐☐☐☐☐☒☐☐☐☐☐☐	**Technology leadership** *(e.g., avionics, fly by wire, heads up display, glass flight deck, advanced wing design, advanced materials)*
☐☐☐☐☐☐☐☐☐☐☒☐	**Passenger capacity, goes with payload-range**
☐☐☐☐☐☐☐☐☒☐☐☐	**Cargo** *(e.g., cargo weight/volume, standard cargo containers, interline container flexibility, mechanized cargo loading, bulk, forward pallets)*
☐☐☐☐☐☐☒☐☐☐☐☐	**Cabin Interior Flexibility** *(e.g., class potential, seating flexibility, vacuum lavatories)*
☐☐☐☐☐☐☐☐☐☐☒☐	**Comfort Level of Interior** *(e.g., number of middle seats, legroom, seat width/pitch, stowage compartment size, cabin noise, air quality)*
☐☐☐☐☐☐☒☐☐☐☐☐	**Service Life**
☐☐☐☐☐☐☒☐☐☐☐☐	**Features Availability**
☐☐☐☐☐☐☐☐☒☐☐☐	**Market Flexibility** *(e.g., family concept, engine choice flexibility)*
☐☐☐☐☐☒☐☐☐☐☐☐	**Non-Airplane Issues** *(e.g., existing customer base, delivery time, manufacturer financing, political alignment)*

Figure 2: **Triangulating the sources of value: a) Market price regressions, with specifications as independent variables; b) surveys of producers' perceptions; c) surveys of consumers' perceptions**



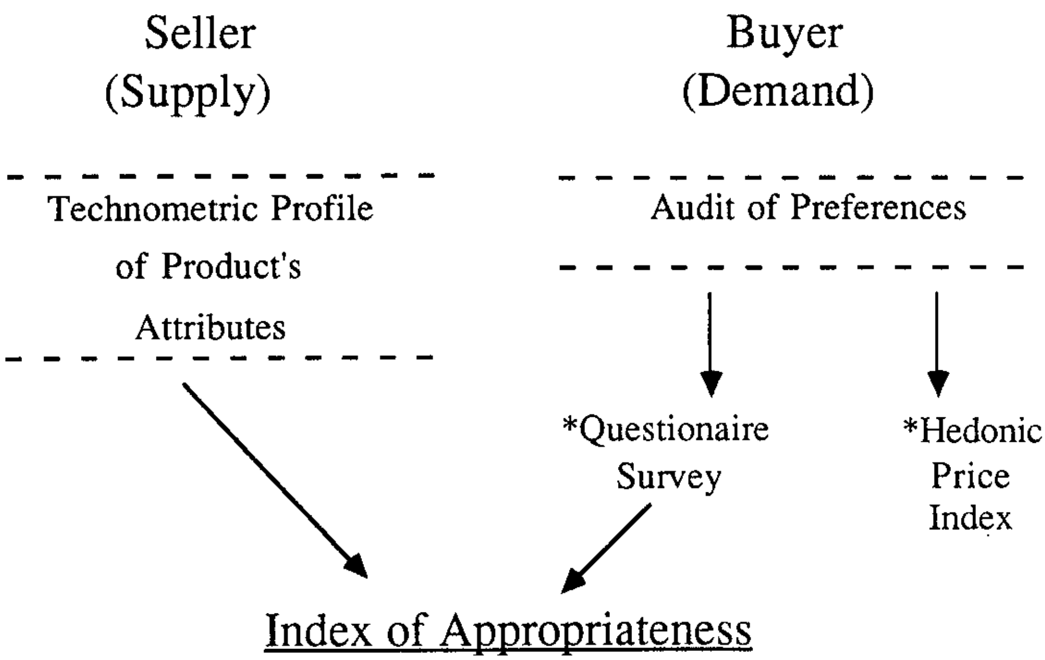
The final step in applying the method is to test the match, or appropriateness, of the attributes that a product supplies to its buyers, with the demands of those buyers. Since both the audit of preferences , through the questionnaire, and the technometric profile are quantitative indexes, they can be correlated, in what we term an "index of appropriateness".

This is a measure of the "goodness of fit" between what the product offers and what the market demands. A high value for this index indicates the product suits its market; a low value indicates the opposite.

Figure 3 shows a schematic view of the overall model.

We now proceed to a case-study application of the method, for industrial sensors. Our objective is to analyze several kinds of industrial sensors made by firms in Israel, Germany, Austria and the United States.

Fig 3.**An integrated Model for Quantifying Sources of Market Value**



2. Quantifying the Sources of Value: The Case of Industrial Sensors

We conducted a comprehensive survey of various types of industrial sensors produced by companies from several different countries. Initial data collection took place at the major international sensor-industry trade fair in Nuremberg, Germany, in May 1991. At this trade fair, some 450 companies displayed their wares. Preliminary data were collected there and contacts were made with producers of sensors in the five specific areas of interest to us: pressure, force, temperature, acceleration, and relative humidity.

We then contacted producing companies and requested their catalogs, which provided technical specifications in fairly precise detail. Some 107 catalogs were acquired. We then wrote to some of those 107 producers and asked for their price lists.

We ended up with 19 such detailed price lists for some 150 different industrial sensors, and some 27 different physical characteristics. Represented in this sample are companies from seven different countries: Germany, U.S., Japan, Switzerland, U.K., Italy and France.

We begin with results for pressure sensors. The data comprise 80 observation points, where each is a different sensor, and 19 different physical characteristics. Companies from five countries are included: Germany, U.K., U.S., Japan and Switzerland.

For some of the 80 sensors, data were not available for some of the characteristics. We eliminated from the data those sensors with extensive missing data. We also did "box plots" of each of the attributes, and redefined as "missing data" those values that were in the upper or lower 5 per cent of the attribute's distribution.

This procedure left us with 68 data points, or sensors, where each point consisted of a price, the physical principle on which the sensor measurement is based, and data on a dozen physical characteristics. (See Table 2). The characteristics that were measured for each pressure sensor were:

1. RANGE - Measuring range, the range of values over which the sensor is able to measure optimally, subject to the accuracy level specified by the producer.

2. ACCURACY - the degree of accuracy with which the sensor performs its measurements, measured as maximum % of deviation from measured, accurate values, within the permitted range. There is generally a tradeoff between RANGE and ACCURACY - the larger the RANGE of the sensor, the smaller the degree of ACCURACY.

3. MAX-TEMP - the maximum temperature at which the sensor can operate. The higher this value, the wider the range of environments under which the sensor can operate, and hence the wider its range of uses.

4. MIN-TEMP - the lowest temperature at which the sensor can operate.

5. WEIGHT - the weight of the sensor, measured in grams.

6. LINEARITY - the maximum deviation of the sensor from a straight-line reaction curve (% FSO).

7. HYSTERESIS - the maximum error, induced by the tendency of the sensor to remain at its existing value; measured by starting at the sensor's lowest measurement-value, raising it to its highest value, then lowering it back to the initial value; measured as % deviation from the initial starting value.

8. OVER-PRESSURE - maximum pressure that can be exerted on the sensor without causing damage, measured as a multiple of the sensor's maximal range.

9. SENS-DIAM - the diameter of the sensor's operating element, measured in mm.

10. THERM-ZERO - Thermal effect on zero, the error induced when measurements are conducted at the lowest end of the sensor's operating range, as % FSO/ degrees C. This is the percentage deviation from zero, for each degree C.. The lower this value, the more accurate the sensor is.

11. THERM-SPAN - Thermal effect on span, the thermal effect on the final measurement range of the sensor, measured as per cent deviation from the maximal operating range.

The lower this value, the better the sensor.

12. MAX-VOLT - maximum input voltage, the highest permissible input voltage for the sensor.

Initially, we conducted a factor analysis of the largest data set (that included 80 different sensors) to try to identify whether the data set could be reduced, by grouping together some of the 12 different physical attributes.

We found that much of the common variance among the variables could be explained by two predominant factors, that could be characterized as "range" (with high loadings on max-temp and min-temp) and "accuracy" (including such variables as hysteresis, accuracy, therm-zero and therm-span). These two factors alone accounted for close to half of the total common variance, and provided an early clue that many of the attributes would likely not figure in the analysis as contributors to market price.

At this stage, we chose to drop the factor-analysis approach and proceed with standard least-squares regression, with price as the dependent variable. Factor analysis is useful when there is a degree-of-freedom problem (large number of explanatory variables relative to observations), but this problem did not face us. Moreover, our objective was to identify the contribution of each attribute to price, and combining attributes in weighted averages or factors would obscure this individual contribution.

Table 2: Pressure Sensors: Basic Data

			Specifications												
Country	Company Name	Phys. Prin -ciple	Measurin Range (bar)	Accu-racy (%)	Operating Temperature (C)		Weight (gr)	Linea -rity (%FSO)	Hyste -rez (%FSO)	Over Pressure (%FSO)	Sensor Diam. (mm)	Termal Effe Zero (%/C)	Span (%/C)	Max Input Voltage	Price(*) for one specimen ($)
USA	KISTLER	PZE.	1034		260	-195	7	1.0	1.0	1.2	5.5	0.03	0.03		340
USA	KISTLER	PZE.	689		120	-55	7	1.0		1.5	5.5	0.06	0.06	30	450
USA	KISTLER	PZE.	34		120	-55	7	1.0		5.0	5.5	0.06	0.06	30	450
USA	KISTLER	PZE.	248		350	-195	1.8	0.8		1.4	5.6	0.01	0.01		1500
USA	KISTLER	PZE.	14		120	-55	7	1		5	5.5	0.06	0.06	30	450
USA	KISTLER	PZE.	1034		260	-195	12	1		2	6.4	0.03	0.03		325
USA	KISTLER	PZE.	200		350	-195	30	0.8		1.2	12.0	0.01	0.01		1820
USA	KISTLER	PZE.	5171		260	-195	20	1.5		1.1	9.5	0.03	0.03		495
USA	KISTLER	PZE.	1999		240	-50	9	1.0		1.5	6.0	0.01	0.01		1280
USA	KISTLER	PZE.	600		240	-195	10	0.5	0.5	1.7	9.5	0.03	0.03		1080
USA	KISTLER	PZE.	200		350	-195	10	1.0	0.8	1.5	6.2	0.01	0.01		1650
USA	KISTLER	PZE.	9997		200	-50	18	1.0	1.0	1.1	10.5	0.03	0.03		2375
USA	KISTLER	PZE.	6895		260	-195	12	1.0		1.1	10.5	0.03	0.03		660
USA	KISTLER	PZE.	4826		260	-195	12	2.0		1.4	6.4	0.03	0.03		315
USA	KISTLER	PZE.	4826		120	-55	12	2.0		1.4	6.4	0.06	0.06		310
GER	JUMO	PZR.	1.6	1	120	-30	255	0.6	0.1	2.0		0.02	0.02	30	373
GER	JUMO	PZR.	400	1	120	-30	255	0.6	0.1	1.5		0.02	0.02	30	373
GER	JUMO	PZR.	6	1	80	0	100	0.5	0.1	2.0	54	0.03	0.04	20	221
GER	JUMO	PZR.	16	1	80	0	100	0.5	0.1	1.3	54	0.03	0.04	20	221
GER	JUMO	PZR.	1.6	1	120	-30	200	0.3		2.0	52	0.02	0.02	10.3	256
GER	JUMO	PZR.	400	1	120	-30	200	0.3		1.5	52	0.02	0.02	10.3	256
GER	JUMO	PZR.	6	0.6	60	-30	310	0.5	0.1	2.0	26	0.03	0.03	10.3	633
GER	JUMO	PZR.	250	0.6	60	-30	310	0.5	0.1	1.5	26	0.03	0.03	10.3	633
GER	JUMO	PZR.	1	0.6	50	-30			0.1	2.0	25	0.03	0.03	10.3	424
GER	JUMO	PZR.	16	0.6	50	-30			0.1	2.0	25	0.03	0.03	10.3	424
GER	JUMO	PZR.	400	0.6	120	-30	14	0.3	0.1	1.5	19	0.03	0.03	10.3	209
GER	UNIMESS	PZR.	800		100	-20		0.5	0.1	1.3	40			30	326
USA	KULITE	PZR.	1379	1	120	-20	13		0.1	1.8		0.05	0.05	15	460
USA	KULITE	PZR.	1379	1	260	-55	13		0.1	1.8		0.05	0.03	15	648
USA	KULITE	PZR.	1379	1	120	-55	35		0.3	3.0		0.03	0.03	32	812
USA	KULITE	PZR.	345	0.5	120	-40	110		0.3	4.0		0.05	0.05	12	375
USA	KULITE	PZR.	345	0.35	120	-40	110		0.1	4.0		0.03	0.03	12	397
USA	KULITE	PZR.	345	0.35	120	-40	150		0.1	4.0		0.03	0.03	12	900
USA	KULITE	PZR.	345	1	120	-40	150		0.1	4.0		0.05	0.05	32	1000
USA	KULITE	PZR.	69	0.5	120	-55	100		0.1	3.0		0.01	0.01	12	158
SWS	PEWATRON	PZR.	13		100	-20	1	0.3		1.5	7.4	0.06	0.05		18
SWS	PEWATRON	PZR.	1		100	-30			6.0	2.0		0.06	0.01		20
SWS	PEWATRON	PZR.	100		80	-30	170				58	0.03	0.03		112
SWS	PEWATRON	PZR.	25		80	-30		0.5	0.2	1.5		0.04	0.04		58
GER	JUMO	S.G.	50	0.5	120	-55	120		0.1	2.0		0.02	0.03	10	522
GER	JUMO	S.G.	1000	0.5	120	-55	120		0.1	2.0		0.03	0.03	10	522
GER	JUMO	S.G.	50	1	400	120		0.3	0.1	1.5	245	0.02	0.02	8	2025
GER	JUMO	S.G.	2000	1	400	120		0.3	0.1	1.2	245	0.02	0.02	8	2227
GER	RMP	S.G.	16	0.5	50	0	500	0.3	0.1	3.0		0.03	0.03	26.5	513
GER	RMP	S.G.	250	0.5	50	0	500	0.2	0.1	3.0		0.03	0.03	26.5	513
GER	RMP	S.G.	1400	0.5	50	0	500	0.2	0.1	1.5		0.03	0.03	26.5	513
GER	RMP	S.G.	16	0.2	50	0	500	0.2	0.1	3.0		0.01	0.01	26.5	752
GER	RMP	S.G.	250	0.2	50	0	500	0.1	0.1	3.0		0.1	0.1	26.5	752
GER	RMP	S.G.	1400	0.2	50	0	500	0.1	0.1	1.5		0.01	0.01	26.5	752

Table 2: Continued

			Specifications												
Country	Company Name	Phys. Prin -ciple	Measurin Range (bar)	Accu-racy (%)	Operating Temperature (C)		Weight (gr)	Linea -rity (%FSO)	Hyste -rez (%FSO)	Over Pressure (%FSO)	Sensor Diam. (mm)	Termal Effe Zero (%/C)	Span (%/C)	Max Input Voltage	Price(*) for one specimen ($)
ITL	AST	S.G.	400		140	-55	5	0.3	0.3	1.5	18	0.03	0.01	30	53
ITL	AST	S.G.	400	0.5	80	-25		0.5	0.5		18	1.00	0.01	32	154
ITL	AST	S.G.	400		125	-55		0.5	0.5	1.3	30	0.04	0.01	30	61
ITL	AST	S.G.	350		150	-55		0.1	0.1		30	0.01	0.01	30	67
JAP	KYOWA	S.G.	2000	0.5	80	-20	200	0.2	0.2	1.5	27	0.02	0.01	15	444
JAP	KYOWA	S.G.	1		70	-20	40	0.5	0.3	1.5	19	0.02	0.03	5	569
JAP	KYOWA	S.G.	1		60	0	80	1.0	1.0	1.2	4.5	0.10	0.5	3	132
JAP	KYOWA	S.G.	500		180	-196	530	0.4	0.4	1.2	46	0.03	0.03	15	93
JAP	KYOWA	S.G.	200		300	80	180	1.0	1.0	1.3	26				701
ENG	IMO	S.G.	400	0.25	80	-20	87	0.3	0.3	1.5	25	0.02	0.02	15	118
ENG	IMO	S.G.	400	0.25	80	-20	100	0.3	0.3	1.5	27	0.02	0.02	36	145
ENG	IMO	S.G.	400	0.25	80	-20	100	0.3	0.3	1.5	27	0.02	0.02	36	172
ENG	IMO	S.G.	400	0.2	80	-20		0.2	0.2	1.5		0.02	0.02	36	243
ENG	IMO	S.G.	400	0.15	80	-20		0.2	0.2	1.5		0.01	0.01	36	462
GER	JUMO	MECH	1.6			50					63				10
GER	JUMO	MECH	40	1.6		50					63				10
GER	JUMO	MECH	1	1.6		50					160				34
GER	JUMO	MECH	40	1.6		50					160				34
GER	JUMO	MECH	0.1	1.6		100				1.3	100				209
GER	JUMO	MECH	25	1.6		100				1.3	160				133
GER	JUMO	MECH	0.1	1.6		100				1.3	100				190
GER	JUMO	MECH	25	1.6		100				1.3	160				114
GER	JUMO	MECH	0.01	2.5	80	-20	440	2.5	2.5	3.3		0.10	0.10	24	188
GER	BECK	MECH	1	2	60	0	80	0.5	0.1	1.5		0.01	0.01	24	104
GER	JUMO	IND.	0.4	0.25	50	10		1.0	0.1	2.0		0.02	0.03	31	484
GER	JUMO	IND.	1.6	1	80	-30	330		0.1	1.3		0.02	0.03	31	367
GER	JUMO	IND.	16	1	80	-30	330		0.1	1.3		0.02	0.03	31	367
GER	JUMO	IND.	25	1	80	-30	330		0.1	1.3	50	0.02	0.03	31	367
GER	WALDSEE	IND.	0.03	2.5	60	10		1		1.5	53.2		0.12	13	50
SWS	PEWATRON	CAP.	1		85	0	250	0.5	0.1	2.0	44	0.01	0.01	24	219
SWS	PEWATRON	CAP.	1		60	0	80	0.5	0.1	1.5	13	0.01	0.01	24	119

S.G. = STRAIN-GAUGE MECH. = MECHANICAL PZE. =PIEZOEL PZR. =PIEZO-RESISTIVE IND. = INDUCTIVE
* = PRICE IS IN AMERICAN DOLLARS AT THE EXCHANGE RATE ON 13.12.1991

Table 3 presents results of our linear regressions. All coefficients are expressed as "Beta" coefficients, which are normalized by the units of measurement and hence permit comparison across different coefficients.

TABLE 3. **Regression Results, for Price as Dependent Variable and Physical Attributes as Independent Variables: 68 Sensors ***

Reg.	Intercept	Range	Accuracy	Max Temp	Min Temp	Weight	Linearity	Hysteres	Overpress.	Sensitiv.	Thermal-s	Thermal-z	Maxim.inp	R squarred
1	-81	.0013	-	823**	0.026	.279**	-0.182	0.078	0.201	-0.1	-0.516	.465**	-0.05	0.50
2	-244		-	904**		.300**	-0.179		.20**		-0.5**	.478**		0.53
3	-185		-	812**		.360**					-0.334	.386**		0.47
4	-144		-	782**		.359**					0.008			0.45
5	-138		-	781**		.357**								0.46

* coefficients are "Beta" values

** Significant at $p < 0.05$

We note first that accuracy was not used as a dependent variable, because too many of the 68 sensors did not have data for this characteristic.

Our initial regression (#1) used all 11 attributes as explanatory variables (excluding accuracy, as noted above). Overall, the fraction of the variance in Price explained by the independent variables was relatively high, exactly half. Depending on one's perspective, this can be interpreted as either: fully half of the variation in price is explained solely by physically-measurable attributes of the product; or fully half of the variation in price is not explained by its attributes, and must be found elsewhere, in the reputation of the firm, its marketing efforts, servicing, etc.

In regression #1, only four explanatory variables were statistically significant at $p < .05$ level: MAXTEMP, WEIGHT, THERMZERO and THERMSPAN.

We next chose to apply stepwise regression, in which explanatory variables are entered in order of their ability to increase the proportion of explained variance (according to the F-test). The results are shown as regression #2. Five significant independent variables emerged, the same four as in regression #1, with OVERPRESSURE joining as the fifth. The 6th variable that entered the regression, LINEARITY, was not statistically significant. In terms of their magnitude, the coefficient of MAXTEMP was nearly twice as large as the next-largest coefficient, THERMZERO and THERMSPAN. The fraction of the variation in price explained by the independent variables remained approximately one-half.

We then eliminated the Linearity and Overpressure from the explanatory variables, slimming the list down to only four. Of the four, THERMZERO became only marginally statistically-significant. (Regression #3). A statistical difficulty emerged, owing to the high correlation between THERMZERO and THERMSPAN, creating multicollinearity and resulting biased estimates of the variables' standard deviations. Moreover, the direction of the THERMSPAN coefficient was perverse -- positive (indicating a direct relation), rather than negative (indicating an inverse relation).

We therefore chose to drop THERMSPAN from our independent variables and retain THERMZERO, in Regression #4. THERMZERO was no longer statistically significant, even marginally, leaving WEIGHT AND MAXTEMP.

In the final regression equation, #5, only MAXTEMP and WEIGHT remained as statistically-significant dependent variables, with MAXTEMP more than twice as large in magnitude as WEIGHT. The proportion of explained variance remained very close to one-half (R^2adj = 0.46).

We conclude, therefore, that only two attributes of pressure sensors are capable of explaining almost half of the total variance in those sensors' prices -- the maximum temperature under which the sensor can operate, and its weight. The positive relation between price and weight is probably a reflection of the higher cost incurred in producing larger (and presumably, stronger and more durable) instruments. It suggests that for this particular group of sensors, buyers are not very interested in weight-saving or miniaturization (as might be the case for space applications, for instance).

These results echo findings in a considerable number of other studies of this type -- often, it is a very small number of product attributes that have a disproportionately large impact on market price. The reason for this is clear. As products mature, a dominant design emerges. Such a design consists of a standard set of attributes, whose values must attain at least minimum values in order for a product to be marketable. Above this standard, dominant design, products achieve premium prices and high sales by attaining excellence in a small number of characteristics that consumers perceive as important. For instance, Wellfleet attained outstanding success by designing network hardware, equivalent to its competitors in most respects but far ahead of them in its robustness, or resistance to crashes. Heeding the "voice of the market" often requires producers to alter their own perceptions about their product and to listen carefully to what consumers are saying, regarding the true sources of product value. We now turn to this topic.

Consumer and Producer Perceptions: We conducted a survey of buyers of pressure and temperature sensors, to determine how important they regarded each of the sensor's specifications, on a scale of one to ten. Some 50 buyers of pressure sensors responded, and 50 buyers of temperature sensors. The results are shown in Table 4.

At the same time we asked the same question of producers, with the objective of determining whether sellers' perceptions matched those of their buyers. Seven pressure-sensor producers responded, and nine temperature sensors. We correlated the average weights of consumers and producers, for both temperature and pressure sensors.

For pressure sensors, with a total of 22 specifications, the correlation coefficient between weights assigned by consumers and producers is statistically insignificant. Consumers tended to weight highly such properties as linearity, repeatability and hysteresis. Producers placed greater emphasis on overpressure and accuracy. The degree of correlation for temperature sensors was higher, though still relatively low. (See Figure 4). Only for measurement range did all three producers agree, scoring it a "10". (See Figure 5, on page 167).

Table 4 . **Consumer Preferences: Average Preference Weights for Pressure and Temperature Sensors And Standard Deviations ***

A. Temperature Sensors (N=50)

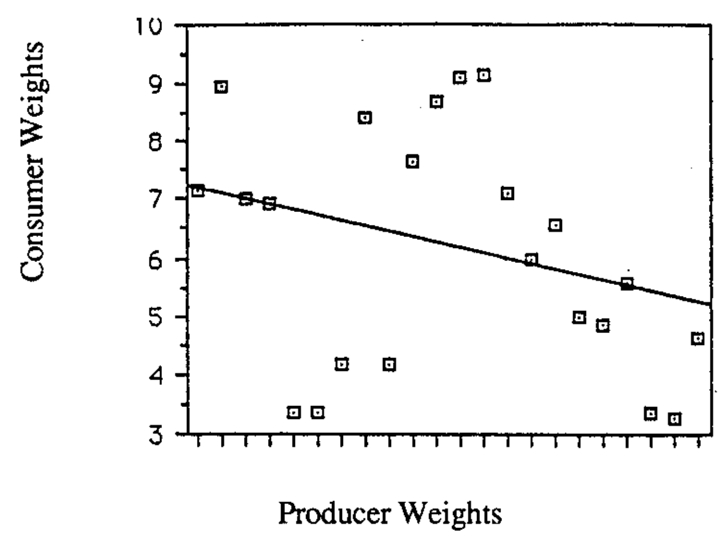
Specification	Average Wt.	Std. Dev.
1	6.2	4.12
2	9	1.51
3	7.28	1.92
4	6.74	2.47
5	3.53	2.08
6	3.53	2.08
7	8.43	1.82
8	5.92	2.89
9	2.79	2.78
10	8.87	1.42
11	9.09	1.04
12	7.15	3.28
13	4.56	3.17
14	2.89	2.69

Pressure Sensors (N = 50)

Specification	Av. Wt.	Std. Dev.
1	7.15	3.70
2	8.94	1.51
3	7.02	2.26
4	6.92	2.33
5	3.34	2.08
6	3.34	2.08
7	4.17	2.76
8	8.43	1.79
9	4.17	3.39
10	7.64	2.56
11	8.68	1.57
12	9.09	1.02
13	9.15	1.14
14	7.11	3.12
15	6	2.72
16	6.56	3.45
17	5	2.83
18	4.83	2.88
19	5.56	3.44
20	3.38	2.83
21	3.29	3.07
22	4.64	3.06

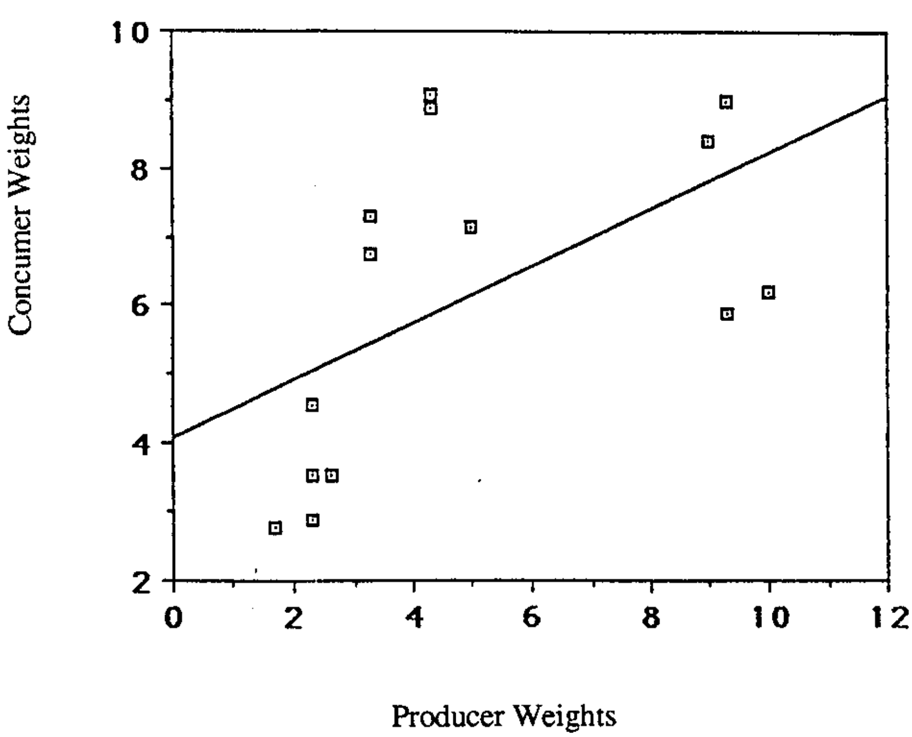
Figure 4. **Pressure Sensors: Spec. Weights for Consumers vs. Producers**

$Y = 7.2821 - 0.10196\,x \quad R^2 = 0.105$



Specification Weights: Producer vs. Consumer: Temperature Sensors

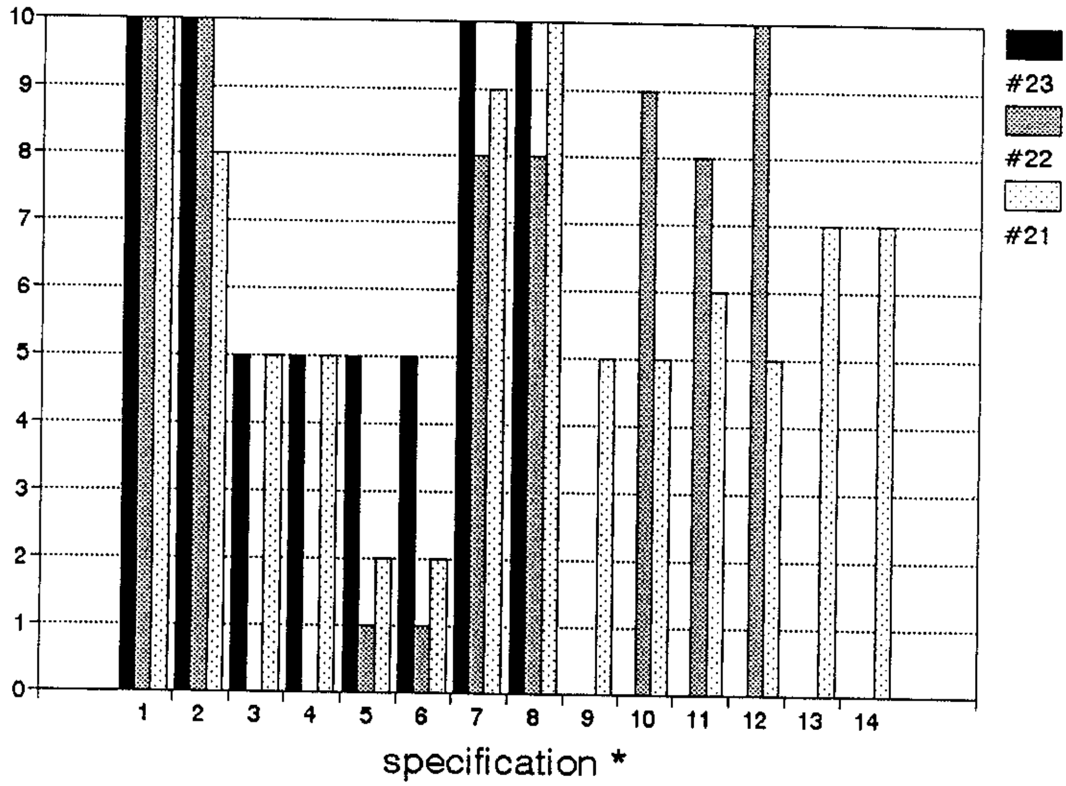
$Y = 4.08950{+}00.4132\,x \quad R^2 = 0.304$



We were also interested in learning to what extent producers agreed amongst themselves on which attributes were relatively more important. For both pressure and temperature sensors, we compared the relative weights given by two producers from Germany and one from Austria (see Figure 5). The results show considerable variation across the producers. For temperature sensors, for the 14 specifications selected for study, only for the first attribute -- measuring range -- did all the producers agree, in assigning it the maximum weight of "10". While the general direction for the other specifications was similar, there was substantial variation among the three respondents. This was the case for pressure sensors as well (Figure 5 B).

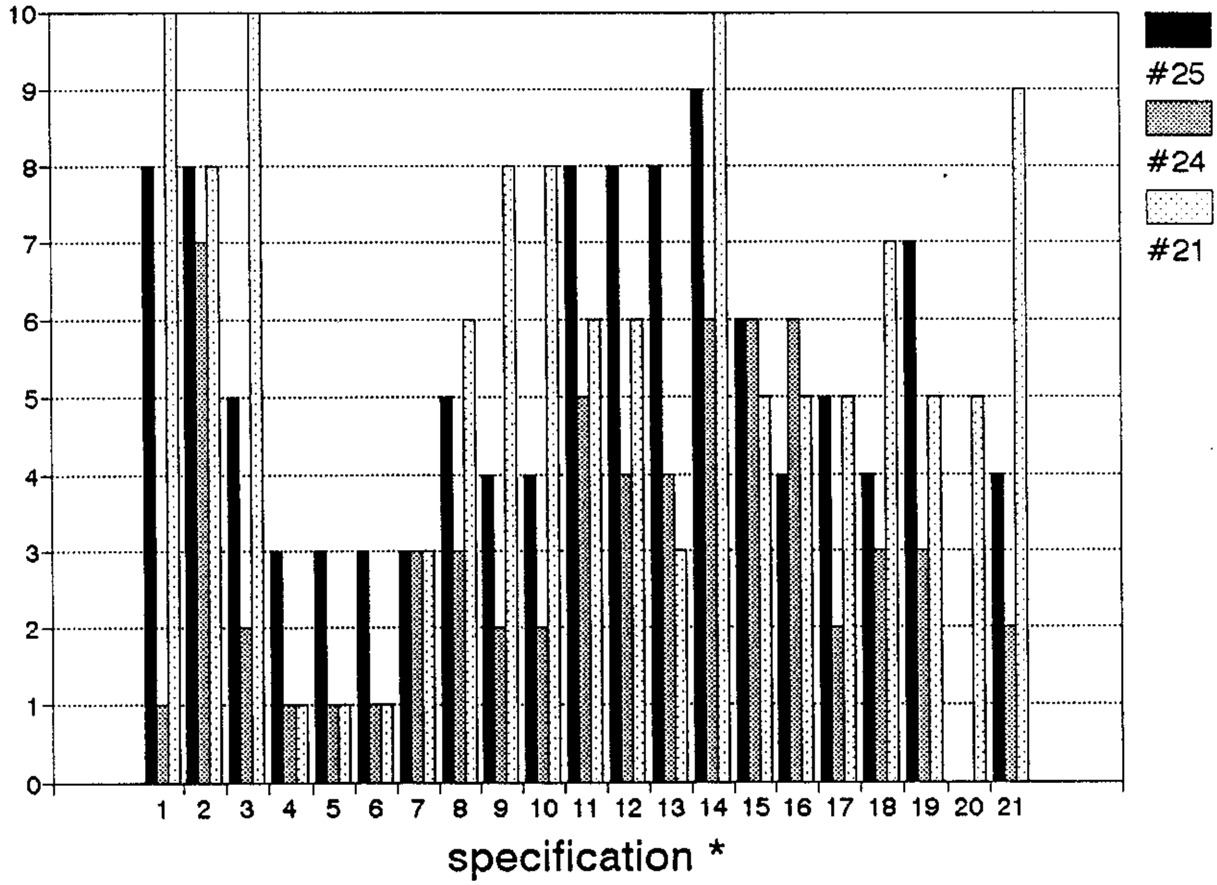
We also found that the higher the degree of importance given to the particular specification, by buyers, the **greater** was the degree of agreement, as measured by the coefficient of variation (standard deviation of the weight across respondents, divided by the mean weight). Figure 6 shows the correlation between the average weight assigned to a specification, and its coefficient of variation, for both temperature and pressure sensors. The negative relation is strong and statistically significant. This implies that for these two products at least, consumers seem to agree more on the important specifications than on the unimportant ones.

Figure 5. : **A. Specification Weights: Three producers - # 21, #23 (Germany), #22 (Austria) Temperature Sensors**



* 1 Measuring range, 2 Accuracy, 3 Max. ambient temperature, 4 Minimum ambient temperature, 5 Maximum Storage temperature, 6 Minimum storage temperature, 7 Response time, 8 Sensor size, 9 Output impedance, 10 Linearity, 11 Repeatability, 12 Temperature dri, 13 Input voltage, 14 Input impedance

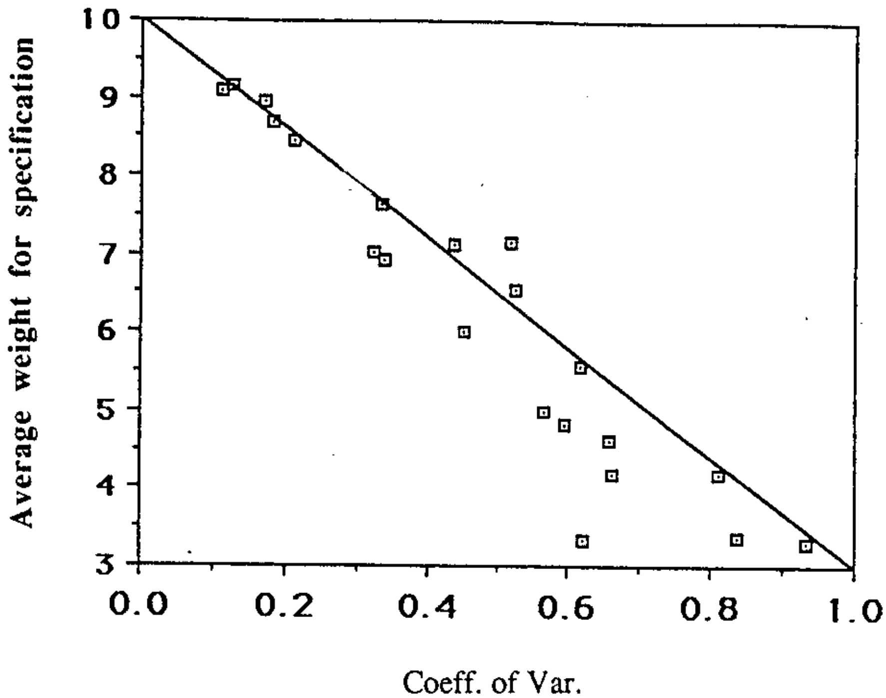
B. Specification Weights: Three producers - # 21, #23 (Germany), #25 (USA)



* 1 Measuring range, 2 Accuracy, 3 Max. ambient temperature, 4 Minimum ambient temperature, 5 Maximum Storage temperature, 6 Minimum storage temperature, 7 Weight, 8 Response time, 9 Resonant frequency, 10 Sensitivity, 11 Linearity, 12 Repeatability, 13 Hysteresis, 14 Overpressure, 15 Sensor size, 16 Thermal effect, 17 Minimum supply voltage, 18 Max. supply voltage, 19 Output Signal, 20 Bridge resistance, 21 Output impedance, 22 Insulation resist.

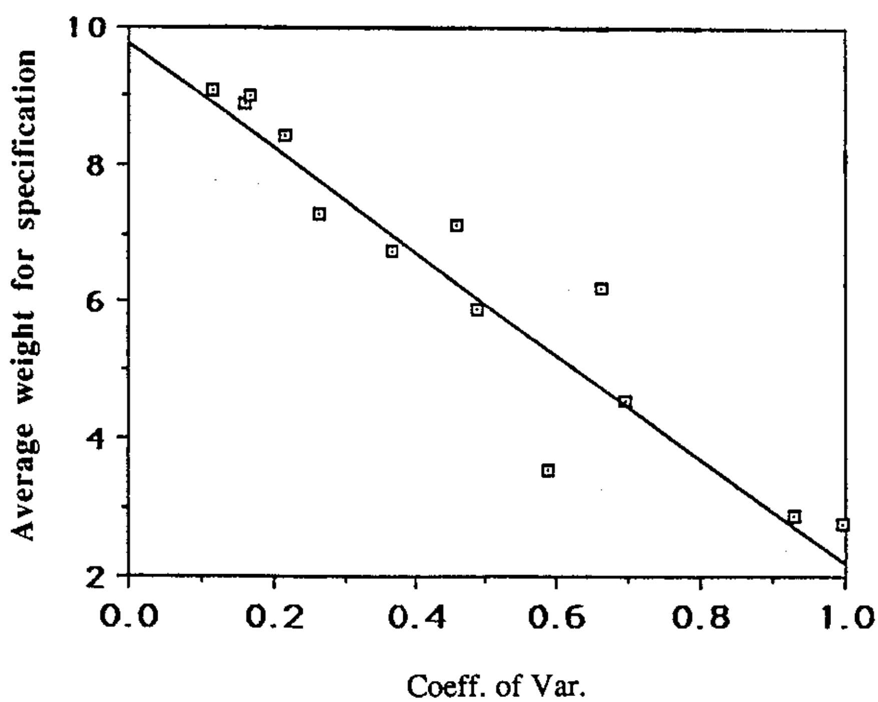
Figure 6: **Pressure sensors: Av. Wt. for Specification vs. Coefficient of Variation - Consumers**

$y = 10.019 - 8.0693x \qquad R^2 = 0.876$



Temperature sensors: Average Weight for Specification vs. Coefficient of Variation - Consumers

$y = 9.7774 - 7.5968x \qquad R^2 = 0.853$



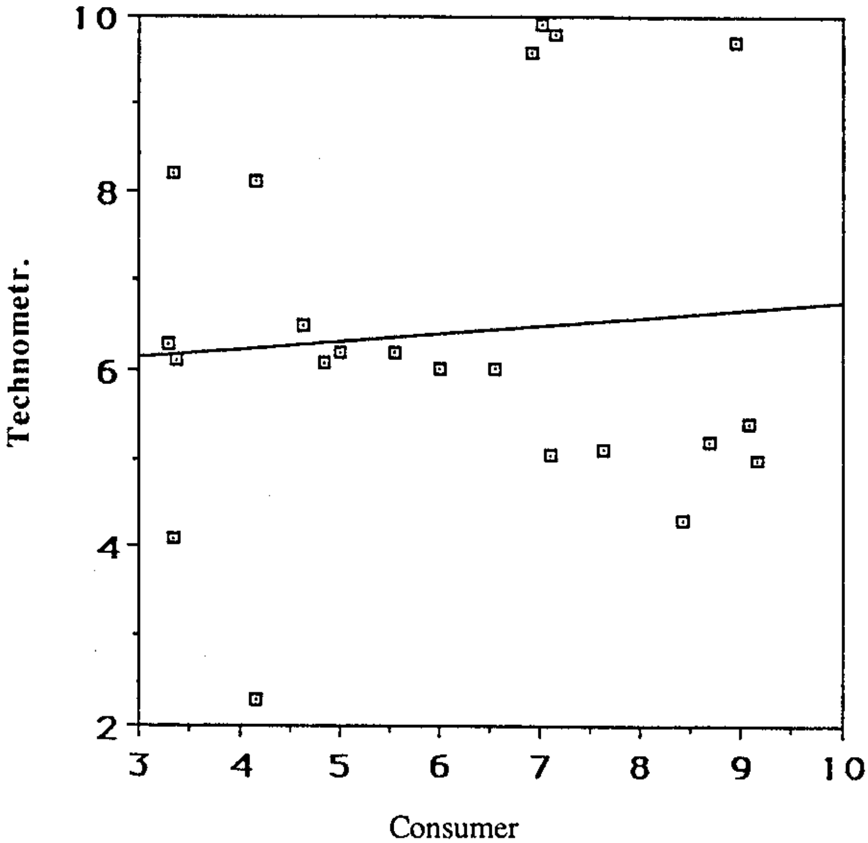
Finally, given both objective information on the product's attributes, and subjective information on the importance buyers attach to each attribute, it is possible to measure objectively the index of appropriateness: the extent to which the product's profile conforms to the "voice of the market". This is done by simply correlating the technometric scores for each attribute with the weights assigned by consumers, in the questionnaire survey.

An example of such an index is shown in Figure 7. This example is illustrative - we have contrived technometric scores for an imaginary sensor for a particular firm, though it would be straightforward to compute such scores for any given product. The consumer preference data are real, and are drawn from the preceding table.

This example shows, for instance, that there is no correlation between excellence in attributes and the importance consumers attach to those attributes. High technometric scores in attributes 1, 2, 3 and 4 correspond to only moderate weights for consumers, while, for instance, a middling technometric score for attributes 11, 12 and 13 corresponds to relatively high consumer weights. This is an example of a relatively high-quality product (one which would gain a high aggregate technometric score) that is somewhat out of step with its market. Managers who possessed this information would be better equipped to make important decisions, regarding marketing efforts or, for example, second-generation R&D investments to improve the product and adapt it to its customers' needs.

Figure 7: **Illustrative Example: Pressure Sensors - Product "Profile" vs. Consumer Preferences**

$y = 5.8871 - 8.7143e\text{-}2x \qquad R^2 = 0.008$



Spec.	Technometr.	Consumer
1	9.80	7.15
2	9.70	8.94
3	9.90	7.02
4	9.60	6.92
5	4.10	3.34
6	8.20	3.34
7	8.10	4.17
8	4.30	8.43
9	2.30	4.17
10	5.10	7.64
11	5.20	8.68
12	5.40	9.09
13	5.00	9.15
14	5.05	7.11
15	6.02	6.00
16	6.03	6.56
17	6.20	5.00
18	6.10	4.83
19	6.22	5.56
20	6.11	3.38
21	6.31	3.29
22	6.49	4.64

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A Technometric Assessment of Sensor Technology in Israel vs. Europe, the United States & Japan

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Abstract

"Technometrics" is a multidimensional index useful for assessing technological performance levels, sophistication and complexity of products, processes and services. Technometric profiles permit quantitative comparisons of the quality of products between companies, industries and nations, and have proved helpful in constructing corporate innovation strategy and technology policy.

The method of constructing technometric profiles is outlined, and accompanied by a technometric benchmarking case study of Israel's sensor industry in comparison with parallel products in the United States, Europe and Japan. It is found that even such small players as Israel -- whose GDP is only one per cent that of the U.S. -- are able to establish a competitive sensor industry with quality comparable to that of their much larger competitors.

Technometric assessment of product performance is a useful tool for identifying market niches -- customers whose needs are not met by existing products -- and hence can help avoid fruitless, costly rivalry with firms who enjoy superior human and capital resources.

Introduction

Quantitative measures of technology are vital ingredients for decision-making on R&D and innovation at all levels, from the individual firm through an entire industry or even nation. Several different approaches for assessing technology have been suggested in the literature (see, for instance, [13], [14]).

In this paper, a relatively new approach to technology assessment -- known as technometrics [6] -- is outlined, and applied to a study of Israel's sensor industry, in comparison with that of Europe, United States and Japan.

The structure of the paper is as follows. The first section provides a brief overview of the global sensor industry. Next, a description of the technometric methodology is outlined and applied to evaluating several types of industrial sensors, including sensors that measure pressure, temperature, acceleration, force and relative humidity. The final section draws conclusions.

1. Sensors: An Overview of Technology and Markets

Sensor technology is a key technology for nearly all products in the industries of metrology, analytics, automation, and transportation. It is estimated that the civil sensor market will grow by annually 7.8% up to a volume of US$ 43 billion in the year 2001 [1].

The sensor market is highly heterogeneous -- many different measuring principles and types of sensors can be found. Sensors can measure temperature, pressure, acceleration, force and other physical conditions. Measurement principles range from extensometers through optical, infrared or biochemical principles.

Due to the wide variety of sensors there is no clear-cut sensor industry. Manufacturers can be found in different branches, that produce different kinds of sensors. Biosensor production is more closely related to the chemical or biotechnological industry, optical sensors is closer to optics and electronics and other principles are more related to machinery and mechanics. Also the size of companies varies greatly. There are many small companies, each of which produces a very specific type of sensor (e.g. glucose sensor). On the other hand big international companies like Honeywell, Bosch, Siemens, ABB, Ginsbury, Fasco or Endeveco are major world-wide producers and suppliers of a wide and diversified range of sensors.

Occasionally, in the "sensor industry", companies do not produce the sensing element (which is the measuring unit), but combine an element supplied by another company with an electronic device and put it in a box which matches the requirements for the specific measuring conditions (e.g. measuring water, air, or acid environment). This raises the question: what is a sensor?

Generally, distinctions are made between a sensing element, a sensor and a sensor system. A sensing element (or transducer) is the first member in the measuring chain and converts the measured value into an electric signal. The sensor often incorporates processing of the signal. The sensor system permits full information processing, i.e. a computer and software for analysing the measuring values. Whether sensor systems are still sensors, or rather belong to measuring instruments, is a controversial issue.

In this study sensors are defined as *sensing elements and sensor components including electronic devices for signal processing, microprocessors and A/D transformers.*

According to a study made by Intechno market research institute in 1991 nearly 35% of world wide sensor demand results from process technology and mechanical engineering ([1]. Some 14% of the world's sensor production is being used in car manufacturing. Some years ago it was estimated that this sector would grow much faster. In 1991 the market volume for car sensors only reached US$ 2.7 billion. Demand grew slower than expected, especially in products related to car safety and car comfort. But market estimates now show an increase in demand (e.g. for automatic tire pressure control, automatic shock absorption or airbags) which will be further stimulated by new environmental laws in the USA during the 1990's.

Although car manufacturing is already the second most important application field of sensors (after process automation and machinery construction), the difference in market volume between both fields will decrease until 2001. With an average growth rate of 12.4% the market volume in sensors used in car manufacturing will reach around US$ 9 billion in

2001 whereas process automation sensors' demand is estimated to rise to nearly US$ 14 billion.

The third most important application field is machinery (US$ 2.2 billion in 1991, US$ 4.5 billion in 2001). Most important are machine tools, packaging machinery, handling and robots. The most dynamic market segment is conveyor equipment with an annual growth rate of 9.8%. Other important application fields are information and communication technology, building and security technology, medical engineering and environmental technology.

The world market share for the United States ranges around 34%. Japan ranks second (23.6%) and Germany third (13.5%). Between these three countries only minor changes will occur till 2001. The market share of the US will decrease slightly to 34.1%, and Japan's and Germany's shares will increase to 24.3% and 14.1% respectively. France holds a share of 7.1% (2001: 7.0%), Great Britain of 5.9% (2001: 5.5%) and Italy of 5.7% (2001: 5.5%).

Pressure sensors are the most common type of sensor. Their market volume will reach US$ 7.2 billion in 2001 after US$ 3.2 billion in 1991. Flow and temperature sensors rank second and third. They are followed by: binary position sensors (proximity switches), filling level sensors, chemical sensors, position sensors, speed and revolution sensors, ultrasonic image sensors, and flue gas sensors. The highest annual growth rates of 10% and above characterize sensors for measuring distance, acceleration, vibration, speed and revolution, as well as optical and biosensors.

Sensor Survey: Out of the above mentioned sensor types, five were chosen for an international comparison. Selection criteria were market importance, along with data accessibility and comparability. According to these criteria, sensors measuring pressure, temperature, acceleration, force and relative humidity were selected. A detailed technical description of these sensor types and also of the underlying measurement principles can be found in the technical literature (see for example [11] [15]).

A previous technometric study on sensors carried out by FhG-ISI in 1986/87 was based on data supplied by the SENSOR database hosted by STN [8]. However, another method of data collection had to be chosen for this study, because regrettably, the SENSOR database was not updated after 1986. (Market reports could be an alternative source, although they are mostly biased towards national manufacturers and suppliers, are quite expensive and have the same updating problem as electronic databases.)

For that reason "primary" data collection was selected. During the SENSOR exhibition of May 1991 in Nuremberg, Germany, the world's largest exhibition of its kind, all exhibiting firms producing or supplying types of sensors under investigation were asked for catalogues containing descriptions and technical specifications.

Not all companies could be approached during the exhibition. Those not approached were asked afterwards to submit relevant catalogues and data sheets. Out of 286 companies from whom information was requested, 151 answered and were included in the sample. Together with 10 Israeli companies interviewed directly, data from 161 sensor firms were analysed. The technical information represents the state of the art in sensor technology, as of spring/summer 1991, with some supplemental updates as of autumn 1991.

The country distribution of companies reflects participation of countries in the SENSOR exhibition, since the official catalogue was used as address database. Some 86 (or 53%) of the companies or suppliers are of German origin. 34 (or 21%) are from the US and 10 (or 6%) are from Israel (which mostly not attended the exhibition). Other countries included are Switzerland (8 companies), Great Britain (5), the Netherlands (5), Japan (3), France (2), Italy (2), and Austria, Denmark, Finland, Ireland, Luxemburg, and Norway (one company each). It should be noted that this survey is biased towards Germany and Europe. Nevertheless, 21% of the companies are U.S. in origin.

It should be emphasized that the country distribution in the survey is more dependent on the variety of the sensor principles found in the different catalogues, than on the number of companies. If, for example, a German company distributes sensors from a Swiss company, these sensors were regarded as Swiss in origin. For that reason, the bias is mitigated by the different size structure of the companies and by selling sensors of parent or other companies.

2. Technometric analysis

Methodology

Technometrics is the quantitative measurement of the technological quality or sophistication of a product or process, group of products or processes, or industry. This approach produces a quantitative profile of a product or process, showing graphically its performance characteristics for selected key attributes, in comparison to those of other firms or countries. Such indices can be aggregated across groups of products, to permit comparisons of the comparative technological level of subsectors or even entire industries [3] [5] [6] [7] [8] [10] .

Every product or process has a set of key specifications or attributes that define its performance, value or ability to satisfy customer wants. Almost by definition, every specification or attribute can be quantified. Each of these attributes has its own unit of measurement: mm. per second, years of lifetime, etc. Problems arise in aggregating attributes to build a single quality index. The technometric indicator surmounts this difficulty by converting each measured attribute into a [0,1] metric, enabling construction of weighted averages, etc., and permitting comparisons across products, firms, industries and countries. The "0" point of the metric is set as the technologically-standard attribute; the "1" point is set as the most technologically-sophisticated attribute in existence.

According to the sensor study performed by FhG-ISI in 1986 (see Grupp, Hohmeyer 1988) six key technical specifications were selected for describing the performance of a sensor. These are:

* measuring range
* lowest measurable value
* highest measurable value
* sensitivity
* minimal operating temperature
* maximal operating temperature.

This selection also reflects the accessability of data. Although there is a group of specifications given in each catalogue or data sheet, only a few are comparable and can be found for most types of sensors.

It is obvious that the decision to buy a sensor for very specific purposes is made according to criteria other than the ones used in this study. Often it is a question of size, of linearity, of hysteresis, or of stable measuring results, under critical conditions, or just a matter of the price. In an initial stage of this study, more specifications were included in the analysis, but it soon emerged that international comparison was only possible by using the above-mentioned six specifications. Nevertheless, the selected specifications represent well-established characteristics of different types of sensors.

To sense a signal, different physical principles may be used. It is only possible to measure pressure not only by using a strain gauge, but also piezoresistive, piezoelectric, inductive, capacitive or mechanical principles can be found. The same is true for the other groups of sensors. Those physical or measurement principles have been included in the study where data from at least two countries were available. This makes it possible not only to compare the technological level of pressure, temperature, acceleration, force and relative humidity sensors, internationally, but also the ability to use different physical principles to measure and convert the measured value into an electric signal.

For that reason the technometric analysis not only indicates the single [0,1] metric values (K*, in technometric terminology) for six specifications, but also for different measurement principles under one measurement parameter (e.g. pressure). Single K* figures are shown in tables 1 through 6. A graphical example of technometric profiles is given for pressure sensors. Here single technometric figures are linked by lines which generate a technometric plane. This plane should not suggest homogenity but should enable the reader to have a better look on the ups and downs in the technometric profile. It was not possible to calculate values for all countries over all measurement principles because of data heterogenity. For that reason only countries with complete or nearly complete sets of data will be reviewed.

Pressure sensors

The most common principles among pressure sensors are mechanical extensometers (strain gauge), piezoresistive (strain gauge on an electrical/electronical basis) and inductive principles. Pressure sensors are for example used in motor-management control, in airbags, airconditioning equipment and in all industrial production processes where pressure in tanks, vessels and pipes needs to be controlled. K* values for these principles are shown in figure 1.

For Germany, Israel and Switzerland data were available for all three principles, whereas profiles for the USA, Japan and the United Kingdom could only be drawn on the basis of two principles. The Netherlands and Luxemburg were included with piezoresistive pressure sensors only. Respective data can be found in table 1 (page 185), which contains figures for piezoelectric and mechanic pressure sensors as well.

The profiles reveal a strong position for Germany (DEU), especially in the case of strain gauge sensors. US pressure sensor technology is also well advanced although there are some weaknesses in strain gauge sensors (highest measurable value and maximal operating temperature). Israel (ISR) does well in inductive pressure sensors and to a lesser extent also in piezoresistive pressure sensors. Switzerland's (CHE) performance over all specifications is diverse with some strong positions in piezoresistive and strain gauge sensors.

When all pressure sensor principles are combined into a single aggregate index -- made possible by the [0,1] technometric index -- Germany attains an overall technometric indicator of 0.84, which emphasises her leading international position in pressure sensors (figure 2, page 186). The United States (USA) ranks second at 0.78, followed by Great Britain (GBR) with 0.63. Israel is in fourth position (0.62), ahead of Switzerland (0.59). Since only a few Japanese (JPN) companies were included in the survey the technometric indicator for Japan (0.38) should be regarded as a only a rough indicator.

Figure 1: Technometric profiles for pressure sensors

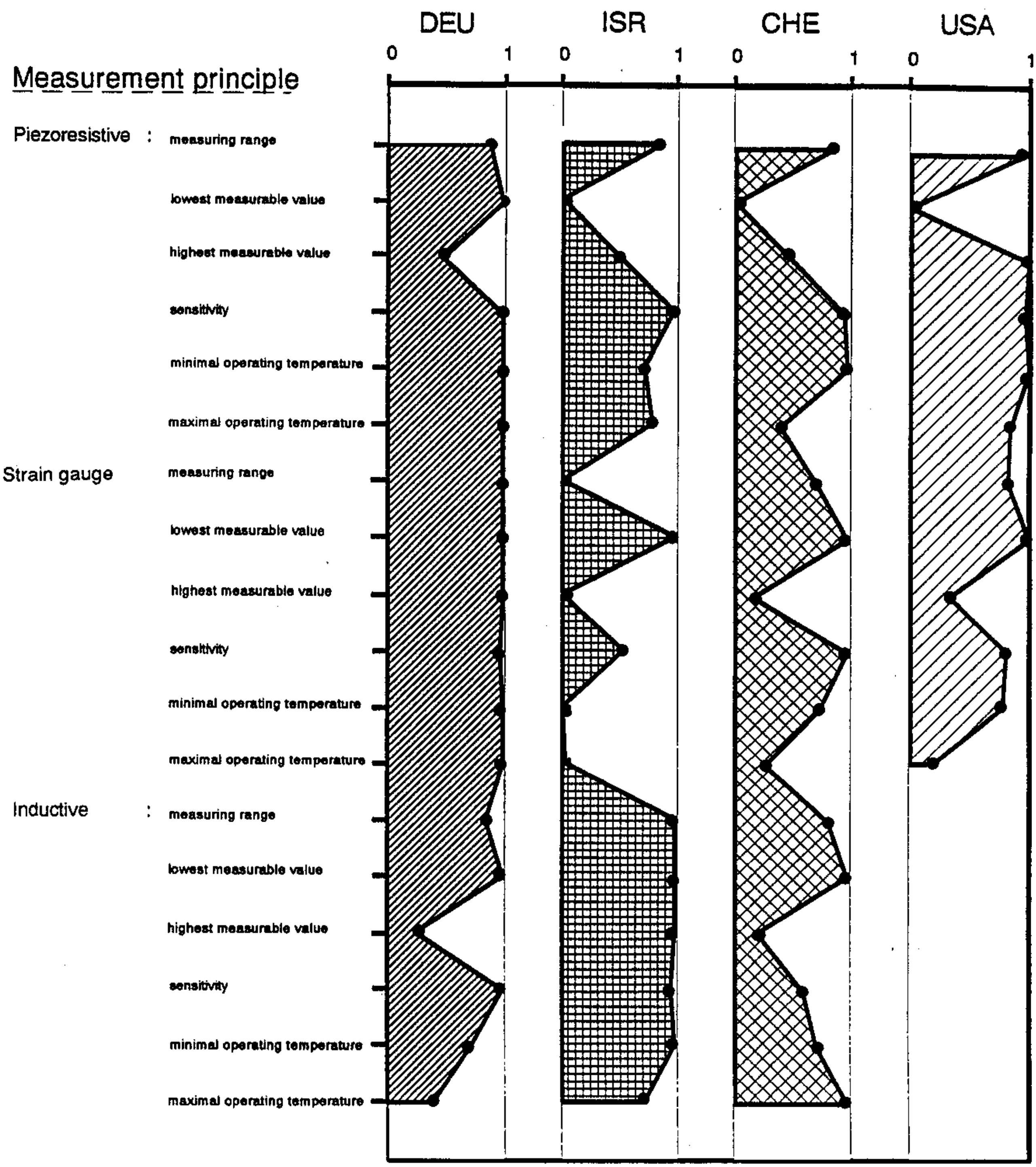


Figure 1 continued

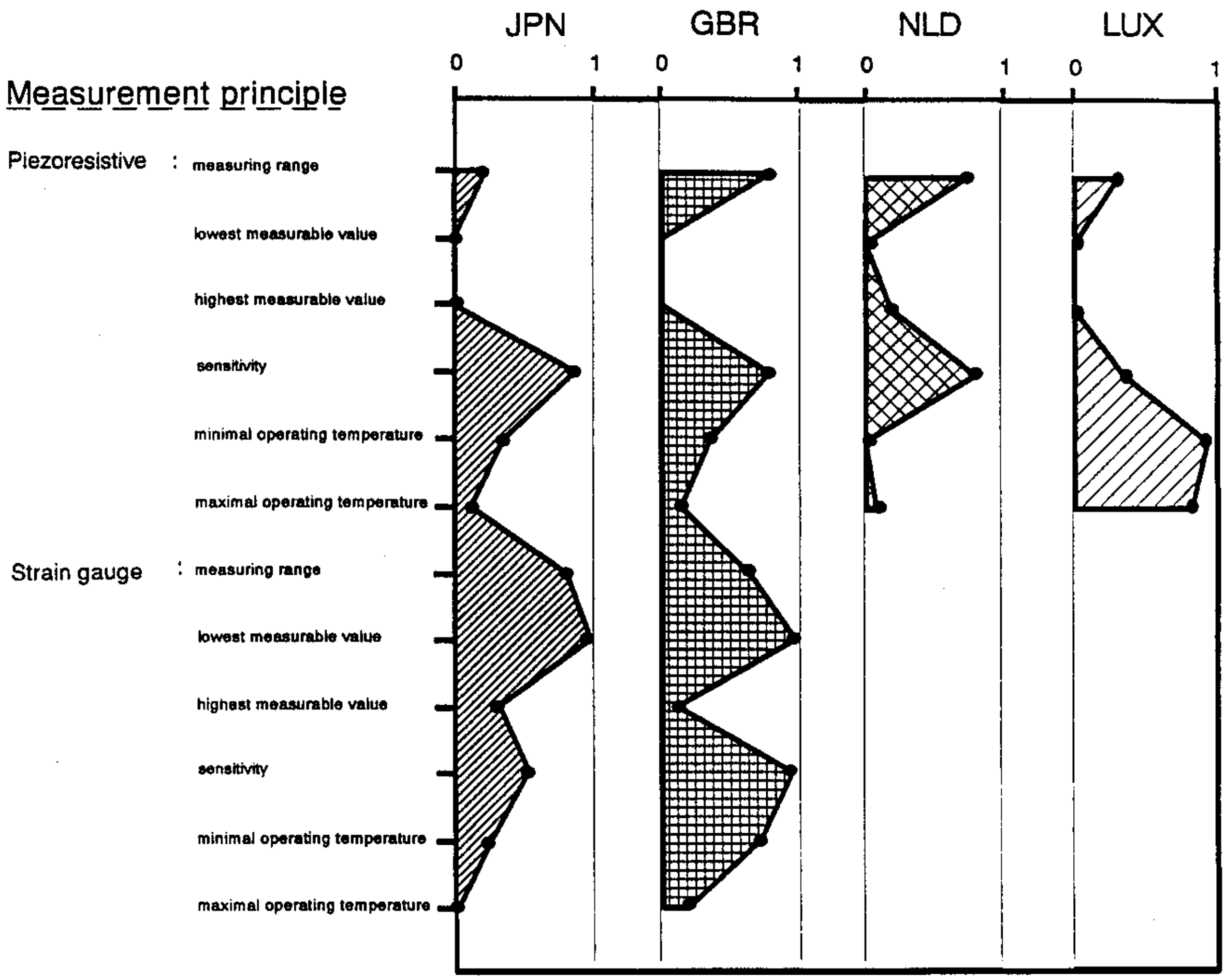


Figure 1 continued

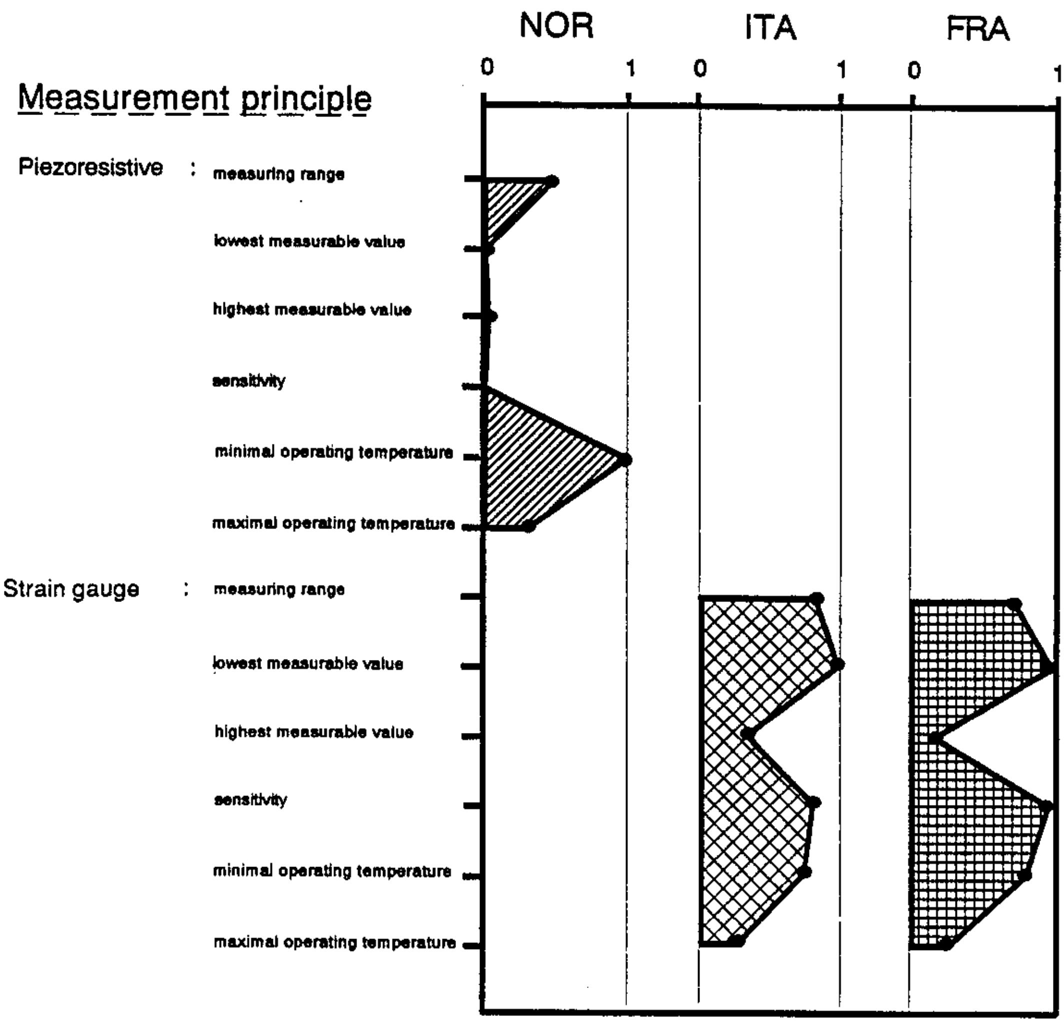
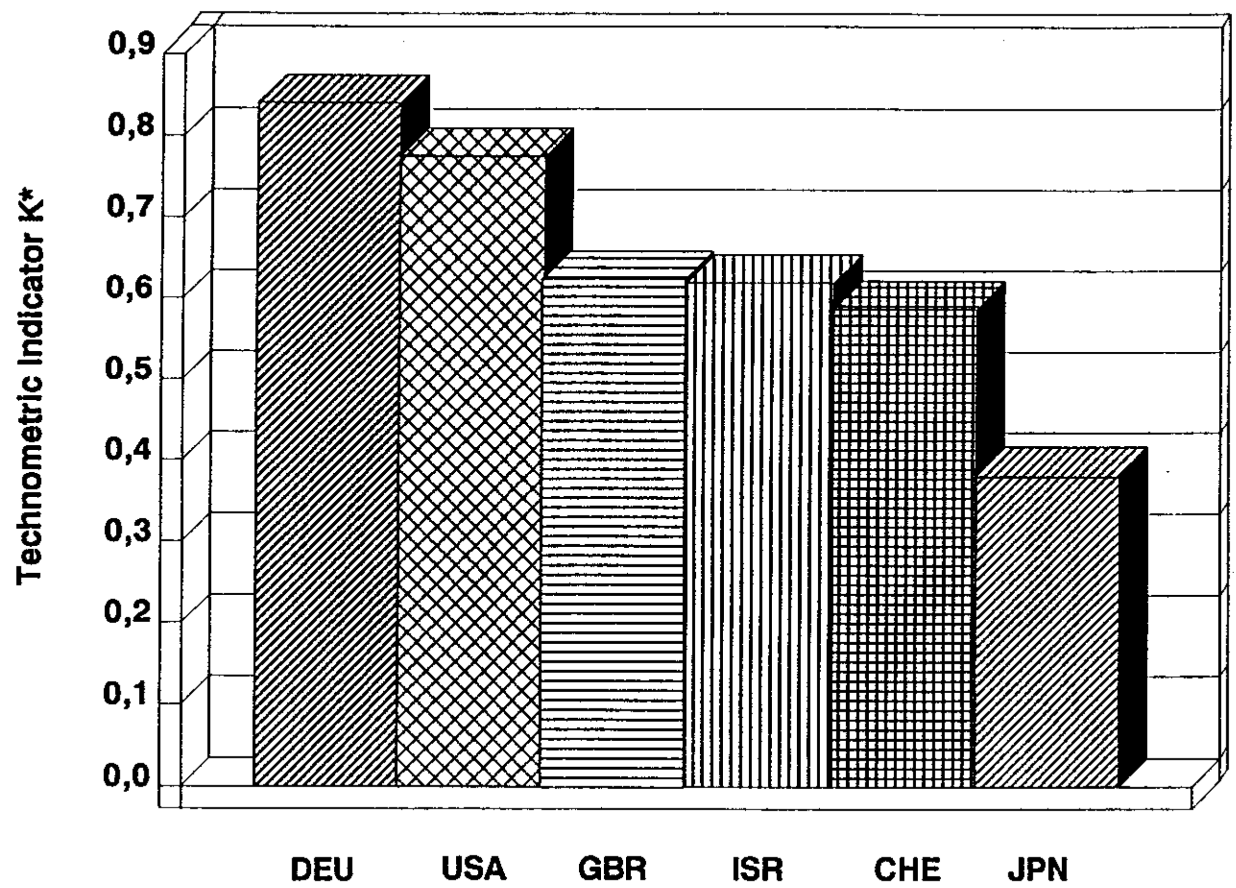


TABLE 1: TECHNOMETRIC INDICATOR VALUES FOR PRESSURE SENSORS

Principle	Country	Average K*	Measuring range K*	Lowest measuring value K*	Highest measuring value K*	Sensitivity K*	Minimal operating temperat. K*	Maximal operating temperat. K*
Piezoresistive	DEU	0.90	0.90	1.00	0.48	1.00	1.00	1.00
	ISR	0.65	0.90	0.00	0.48	0.99	0.73	0.80
	JPN	0.27	0.23	0.00	0.00	0.89	0.36	0.12
	NLD	0.31	0.76	0.00	0.19	0.81	0.00	0.08
	LUX	0.24	0.18	0.00	0.00	0.20	0.55	0.48
	NOR	0.36	0.49	0.00	0.03	n/a	1.00	0.30
	CHE	0.62	0.90	0.00	0.48	0.97	1.00	0.40
	USA	0.80	1.00	0.00	1.00	0.97	1.00	0.84
	GBR	0.54	0.84	n/a	n/a	0.81	0.36	0.14
Strain gauge	DEU	1.00	1.00	1.00	1.00	0.98	1.00	1.00
	GBR	0.62	0.66	1.00	0.12	0.98	0.74	0.19
	ISR	0.26	0.00	1.00	0.00	0.54	0.00	0.03
	ITA	0.67	0.83	1.00	0.33	0.82	0.75	0.26
	FRA	0.66	0.72	1.00	0.17	0.98	0.82	0.26
	JPN	0.50	0.83	1.00	0.33	0.54	0.27	0.03
	CHE	0.65	0.72	1.00	0.17	1.00	0.75	0.26
	USA	0.66	0.83	1.00	0.33	0.82	0.78	0.19
Inductive	DEU	0.70	0.85	1.00	0.25	1.00	0.73	0.40
	ISR	0.95	1.00	1.00	1.00	0.97	1.00	0.73
	CHE	0.73	0.83	1.00	0.20	0.60	0.73	1.00
Piezoelectric	DEU	0.61	0.78	0.00	0.14	1.00	0.81	0.91
	USA	0.87	1.00	1.00	1.00	0.22	1.00	1.00
Mechanical	DEU	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	CHE	0.35	0.76	0.00	0.16	0.95	0.22	0.00

Figure 2: Technometric Indicator Values for Pressure Sensors



Temperature sensors

Temperature sensors are mainly based on thermoelectric, resistive and infrared principles. Thermoelectric and resistive sensors measure temperature through an electric or resistive change induced by temperature variation. Thermoelectric sensors can be found in temperature measurement in gases or liquids and can also be utilized for calibrating measurement equipment. Resistive sensors are used for several industrial applications where temperature needs to be measured under different conditions concerning pressure or flow. Infrared sensors belong to the group of contactless measuring equipment. Their application field is high temperature measurement for example in metallurgical engineering. Beside these major principles fibre-optic, electro-optic and mechanical temperature sensors can also be found.

Table 2 presents technometric data for five major principles. Again, Germany reaches the highest scores in nearly all specifications. Compared to Israel and the USA there are only a few weak points in thermoelectric sensors (i.e. highest measurable value and maximal operating temperature). Israel's temperature sensor technology is also quite strong, with some slight weaknesses in lowest and highest measurable value (both for thermoelectric and resisitve sensors). Data for the USA and Switzerland reveal a standard performance only in some specifications of infrared and thermoelectric sensors, but show high K* figures otherwise.

Combining individual K* figures for all analysed temperature sensors, Germany reaches again the highest technometric indicator (0.96). Israel takes the second position (0.76) slightly ahead of the USA (0.72). Switzerland ranks fourth (0.61) whereas Japan's rather low figure is due to technological weaknesses in fibreoptic temperature sensors (and in addition, the low number of companies included in this study).

TABLE 2: TECHNOMETRIC INDICATOR VALUES FOR TEMPERATURE SENSORS

Principle	Country	Average K*	Measuring range K*	Lowest measuring value K*	Highest measuring value K*	Sensitivity K*	Minimal operating temperat. K*	Maximal operating temperat. K*
Thermoelectric	DEU	0.94	0.95	1.00	0.86	1.00	1.00	0.85
	ISR	0.96	0.96	0.89	0.90	1.00	1.00	1.00
	CHE	0.58	0.89	0.89	0.77	0.95	0.00	0.00
	USA	0.81	1.00	0.80	0.99	0.99	0.25	0.84
	FRA	0.75	0.65	0.89	0.44	0.97	1.00	0.51
	ITL	0.63	0.98	0.53	1.00	0.00	n/a	n/a
Resistive	DEU	0.99	1.00	1.00	1.00	1.00	1.00	0.94
	GBR	0.58	0.72	0.28	0.57	0.90	0.32	0.69
	ISR	0.91	0.90	0.80	0.84	1.00	0.91	1.00
	JPN	0.52	0.71	0.20	0.57	0.60	n/a	n/a
	CHE	0.75	0.92	0.80	0.84	0.80	0.91	0.20
	USA	0.91	0.92	0.80	0.84	1.00	0.91	1.00
Infrared	DEU	1.00	1.00	1.00	1.00	0.99	1.00	1.00
	CHE	0.49	0.92	0.09	0.84	1.00	0.00	0.08
	USA	0.64	0.98	0.00	1.00	0.92	0.72	0.23
Mechanical	DEU	0.92	1.00	1.00	1.00	1.00	0.50	1.00
	ISR	0.42	0.23	0.36	0.00	0.95	1.00	0.00
Fibreoptic	JPN	0.08	0.00	0.25	0.00	n/a	n/a	n/a
	USA	0.50	1.00	1.00	1.00	0.00	0.00	0.00

Acceleration sensors

Acceleration sensors are needed for motorcar development (crash analysis) and are used in aircraft and space technology. Two major physical principles can be found: piezoelectric and inductive sensors. Other types of acceleration sensors are based on piezoresistive, capacitive, fibre-optic and strain gauge principles.

As the measurement of acceleration is closely linked with aircraft and space technology the United States reaches the highest scores in the technometric analysis, although the K* figures for sensitivity and the lowest measurable value in piezoelectric sensors represent only standard technology (table 3).

Switzerland as well as Israel are strong in some specifications of piezoelectric sensors. Here sensors from Israel are internationally ahead in sensitivity. Acceleration sensors from Germany only represent standard technology. Only one high score is reached for the minimal operating temperature at inductive sensors. No figures could be found for lowest and highest measurable value for these sensors in the catalogues. For that reason no technometric figures have been calculated. (Norway also shows some strong positions in the field of inductive acceleration sensors).

The combined technometric indicator values underscore the advanced position of the United States, which could already be seen from the previous figures. The U.S. reaches a K* figure of 0.89, far ahead of Switzerland (0.40) and Israel (0.38). Compared to these three countries German acceleration sensor technology is not very well advanced. Combining all available single K* figures Germany reaches an overall indicator of only 0.35.

Force sensors

Force sensors can measure traction and pressure forces and are used in control equipment as well as in tool machinery, feed presses or robots. Sensors included in this study are based on inductive and strain gauge principles. Piezoelectric and mechanic force sensors can also be found but due to missing figures for certain specifications, they were not included in the technometric analysis.

Table 3: **Technometric indicator values for acceleration sensors**

Principle	Country	Average K*	Measuring range K*	Lowest measuring value K*	Highest measuring value K*	Sensitivity K*	Minimal operating temperat. K*	Maximal operating temperat. K*
Piezoelectric	DEU	0.27	0.65	0.00	0.05	0.00	0.60	0.30
	USA	0.80	1.00	0.00	1.00	n/a	1.00	1.00
	ISR	0.26	0.00	0.00	0.00	1.00	0.54	0.00
	CHE	0.61	0.97	1.00	0.50	0.00	0.59	n/a
Inductive	CHE	0.09	0.53	0.00	0.00	0.00	0.00	0.00
	USA	0.89	1.00	0.34	1.00	1.00	1.00	1.00
	NOR	0.69	0.90	1.00	0.26	n/a	1.00	0.27
	DEU	0.42	0.00	n/a	n/a	n/a	1.00	0.27
Piezoresistive	USA	0.98	1.00	n/a	n/a	n/a	1.00	0.93
	GBR	0.75	0.00	n/a	n/a	1.00	1.00	1.00
Capacitive	ISR	0.50	0.00	n/a	n/a	0.00	1.00	1.00
	CHE	0.50	1.00	n/a	n/a	1.00	0.00	0.00

Inductive sensors are supplied by German, American and Israeli companies, whereas force sensors based on strain gauge principle are also produced by French (FRA) and Japanese companies (table 4). German force sensors never reach a low K* figure but show some weaknesses in sensitivity and operating temperatures (inductive principle). Inductive force sensors are a competitive Israeli product, although the highest measurable value is higher among German sensors. In strain gauge technology, where German products always shows good performance, Japanese sensors rank second despite their comparatively low figures for operating temperatures. France, the USA and Israel follow in the third to fifth positions.

Germany's advantages in strain gauge technology are responsible for an overall technometric indicator of 0.81. Israel's strong position in inductive force sensors put her on a second rank at 0.68 whereas the USA reaches 0.53. Japan is not included in this ranking because data were available for inductive sensors only. For these only, Japan reaches an indicator value of 0.73.

Relative humidity sensors

Relative humidity can be measured by capacitive, resistive and also optic principles. Only in German catalogues, both capacitive and resistive relative humidity sensors were offered. From other countries mentioned in table 5, either capacitive or resistive sensors were found. For this reason no overall indicator values were calculated for relative humidity sensors.

As with many other measurement parameters, German technology is also well advanced in relative humidity sensors. For all but one specification (maximal operating temperature) Germany reaches K* figures of 1 for both sensor types. Nearly the same state of technology can be observed for Finnish (FIN) capacitive sensors. The only weak point is the low sensitivity. France, Switzerland and Austria (AUT) also reach quite high K* figures with 0.75 for Austria as the lowest for capacitive sensors. In the case of resistive sensors Great Britain ranks second behind Germany, followed by Israel. Here no specification was recorded for maximum K* figures. Japan does not reach the forefront of technology in this technical area, as can clearly be seen from the low scores in the table.

Table 4: **Technometric indicator values for force sensors**

Principle	Country	Average K*	Measuring range K*	Lowest measuring value K*	Highest measuring value K*	Sensitivity K*	Minimal operating temperat. K*	Maximal operating temperat. K*
Inductive	DEU	0.70	1.00	1.00	1.00	0.53	0.29	0.40
	ISR	0.83	0.85	1.00	0.40	1.00	0.74	1.00
	USA	0.60	0.13	1.00	0.00	0.95	1.00	0.52
Strain gauge	DEU	0.93	0.94	1.00	0.61	0.99	1.00	1.00
	FRA	0.47	0.73	1.00	0.10	1.00	0.00	0.00
	ISR	0.53	0.81	1.00	0.20	0.99	0.00	0.16
	JPN	0.73	1.00	1.00	1.00	0.98	0.18	0.21
	USA	0.47	0.30	1.00	0.00	0.93	0.31	0.28

Table 5: **Technometric indicator values for relative humidity sensors**

Principle	Country	Average K*	Measuring range K*	Lowest measuring value K*	Highest measuring value K*	Sensitivity K*	Minimal operating temperat. K*	Maximal operating temperat. K*
Capacitive	DEU	0.97	1.00	1.00	1.00	1.00	1.00	0.81
	AUT	0.75	1.00	1.00	1.00	0.00	1.00	0.52
	FIN	0.92	1.00	1.00	1.00	0.51	1.00	1.00
	FRA	0.86	1.00	1.00	1.00	0.61	0.75	0.81
	CHE	0.79	1.00	1.00	1.00	0.91	0.50	0.33
Resistive	DEU	0.93	1.00	1.00	1.00	1.00	1.00	0.60
	GBR	0.93	0.92	0.93	0.80	0.92	1.00	1.00
	ISR	0.61	0.56	0.50	0.50	0.71	1.00	0.40
	JPN	0.20	0.00	0.00	0.00	0.00	1.00	0.20

Technometric indicators according to measurement principles

It was mentioned above that it is possible to compare the technological level of countries in sensor technology, not solely by measurement *parameters*, but also by measurement *principles*. According to table 6, Germany takes the lead in six out of nine analysed physical principles employed in sensors -- strain gauge, resistive, piezoresistive, capacitive, mechanical and infrared. For the last three principles data for only three countries are available, which makes the results less significant than for the first three principles, for which five countries can be compared. Israel performs surprisingly well in thermoelectric and inductive sensors, reaching the top position for each. The United States ranks first in piezoelectric principles, mainly because her good performance in acceleration sensors.

As was noted earlier, the method of data collection produced a bias towards those countries represented by sensor producers at the Nuremberg SENSOR exhibition. For that reason it is not possible to compare directly the results of the FhG-ISI 1986 technometric study with the results derived in this one. Not only is the database is different, but also the variety of measurement principles. Three of the six principles analysed in 1986, piezoelectric, resistive and strain gauge (extensometers) sensors, can only be compared roughly. For piezoelectric sensors Germany lost considerable ground compared to the USA. Both countries reached an indicator value of around 0.8 in 1986. In this study, the United States retained this value. Germany reached only 0.44, mainly because only a few companies still offer this type of sensor.

In resistive sensor technology Germany improved its position significantly from 0.55 in 1986 to 0.96 in 1991. The United States is stable at around 0.9 for both years. Japan's K* figure decreased from 0.55 to 0.36 in 1991; this might be a statistical artifact because of lack of data, hence we offer no analysis or interpretation of these data.

In strain gauge sensors Germany already ranked first in 1986 at 0.85 and still holds this position in 1991 (0.96). The USA reached 0.65 in 1986 and 0.56 in 1991. Israel was not included in the 1986 study so no comparison with recent results can be made.

Table 6

Technometric indicators for sensors according to measurement principles

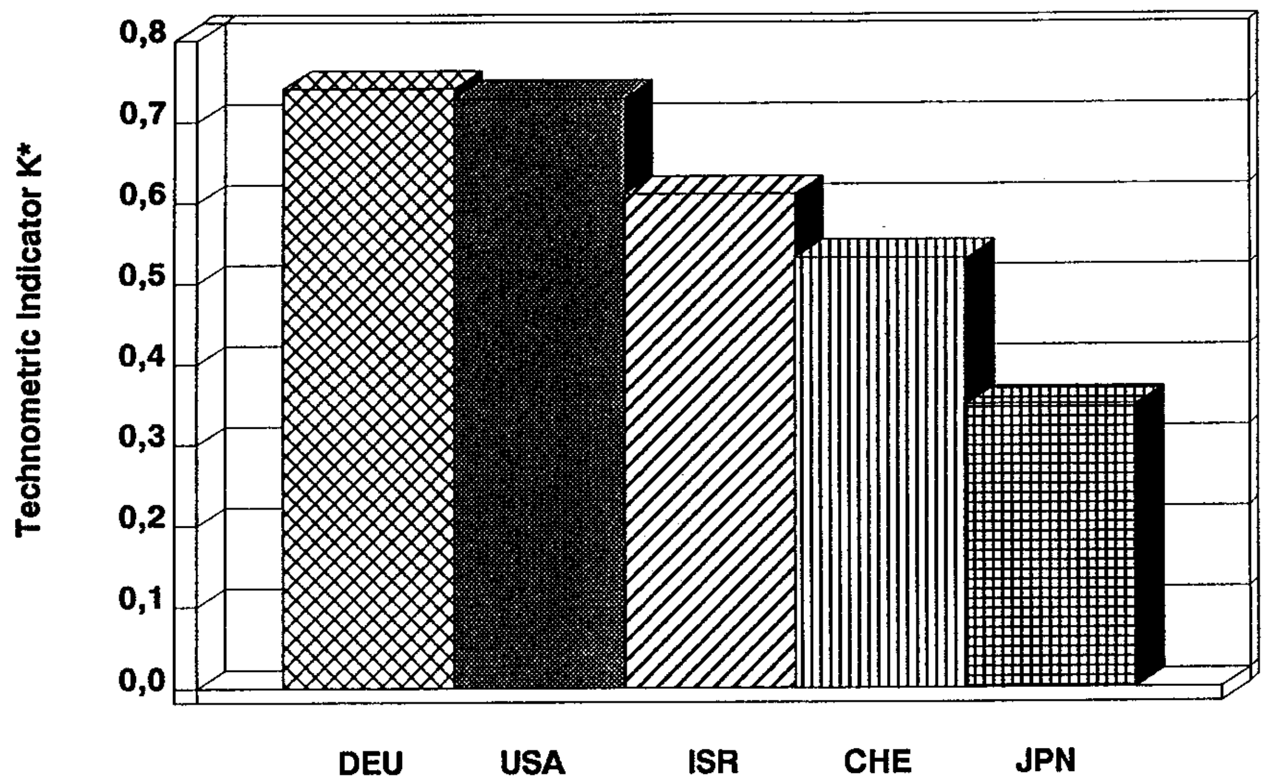
Principle	DEU	USA	ISR	CHE	JPN	GBR	FRA
Strain gauge	0.96	0.56	0.39	0.65	0.61	0.61	0.56
Resistive	0.96	0.91	0.76	0.74	0.37	0.75	
Piezoresistive	0.90	0.89	0.65	0.62	0.27	0.64	
Thermoelectric	0.94	0.81	0.96	0.58			0.74
Inductive	0.61	0.74	0.89	0.41			
Piezoelectric	0.44	0.83	0.26	0.61			
Capacitive		0.97		0.50	0.65		0.86
Mechanical	0.96		0.42	0.35			
Infrared	1.00	0.64		0.49			

This short comparison reveals a quite advanced but also quite stable position for US sensor technology and a technological push in resistive sensors for Germany. During the five years after 1986 Germany was able to extend her solid position in strain gauge sensors, not only because Germany's competitors lagged but also due to improvements in German technology.

Technometric position of countries

The aggregation of all average K* figures per country according to sensor types makes it possible to calculate an overall K* figure for each country (figure 3). What can be observed is a very small advantage of Germany over the USA (0.74 and 0.73 respectively). Nearly close figures were obtained in 1986 when Germany reached 0.75 and the USA 0.74. Although Germany improved her sensor technology in selected areas (e.g. resistive sensors), the small distance between the two countries nearly diminished. As these overall figures are based on different sets of data they can only indicate that both Germany and the USA were and still are the international pacemakers in sensor technology. This technometric based result is also supported by the Intechno market study. According to that survey the United States produce leding-edge sensor technology for application in car and aircraft manufacturing, building and security technology, medical engineering and environmental technology. Germany is especially strong in applying sensors to machinery.

Figure 3 : Technometric Indicators for Sensor Technology According to Countries



Taking all European countries together, they hold the technological lead in machinery ahead of Japan and the United States. The same is true for process technology and mechanical engineering [1].

Although Japan reached relatively low technometric scores in this analysis, it seems justifiable to put Japan in the third position behind Germany and the United States, because of its strong international market position. According to Intechno, Japan holds the world's strongest position in sensors for household appliances and electronic products, as well as in information and communication technology. This is a mass market for cheap sensors where Japan and the US have strong advantages over Europe.

Compared to Switzerland (K* 0.53) where some well-established sensor producers are located, Israel's overall indicator of 0.61 is unexpectedly high. It can be concluded that Israel possesses an advanced sensor industry, although not much of its activities are known abroad. In contrast to Switzerland, Israel's sensor variety is smaller which makes it possible to concentrate technological knowhow in specific fields.

3. Conclusion

We have applied the technometric technology assessment approach, in order to evaluate relative performance levels of sensors, across different types, physical principles, and countries. Overall, technometric indicators provide an in-depth portrait of the relative levels of the major players' sensor technologies.

An important result of this study is that nipping at the heels of the "Big Three" (U.S., Germany, Japan) are not only such well-known players like Great Britain, France, Switzerland and Italy, but also smaller countries like Israel, who proved itself able to establish a competitive sensor industry, at least in certain parts of the market. Israel -- and some other smaller countries as well -- not only produce high-performing competitive sensors, but in some cases sensors that represent the most advanced technology which can be purchased internationally at the present time. The market performance of these countries -- including Israel -- often falls short of what the performance of their products could justify, because of shortcomings in their marketing skills.

By collecting readily-accessible data on product specifications, often obtainable in large part from material distributed at major trade fairs, and by organizing that data in a coherent and systematic fashion, using technometric methods, it is possible to generate an up-to-date audit of the state of technology in a given industry. The results of that audit can provide highly valuable data for plotting both corporate-level innovation strategy (such as R&D plans for second- or third-generation products) and country-level science, innovation and industrial policy.

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Toward A Dynamic Technometric Benchmarking Model for Strategic Innovation and Second-Generation R&D Investment

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Working Paper

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Introduction

Perhaps one of the most critical and difficult decisions faced by senior managers, venture capitalists, and others engaged in R&D funding, is this:

* When should an improved "second-generation" product, service or process be introduced, to replace an existing product, service or process?

* How large an investment in Research and Development should be made in this second-generation project?

* Which characteristics or attributes of the product merit R&D investment, in order to improve them?

* What fraction of total R&D funds should be invested in improving each "attribute"?

The model proposed here aims at producing a concrete, applied decision-support tool able to supply answers to the above questions, based on appropriate data and information.

The model integrates several different strands of thought in the large literatures on R&D, project evaluation, benchmarking and consumer behavior. Emphasis is placed on integrating technological and engineering data with the "voice of the market" [data drawn from surveys of buyers, expressing their subjective evaluation of product attributes].

Background:

Three different bodies of knowledge will be pulled together in this model. They are: the "new consumer theory" developed by Lancaster, together with the new approach for measuring product quality, known as "technometrics"; the technique for evaluating product quality, relative to competing products, known as "benchmarking"; and a mathematical programming technique for optimization, known as linear programming.

a) Technometrics and the "new consumer theory":

"Consumers are not interested in goods as such, but in their properties or characteristics". (Lancaster, 1991, p. 4). In his so-called "new consumer theory", Kelvin Lancaster abandons the relatively vacuous and sterile conventional economics approach to consumer theory, and replaces it with a theory based on the "properties" of goods and services. Consumer preferences are assumed to be defined over "preferences" rather than over goods.

While this new approach to consumer theory yields richer and more rigorous theoretical propositions regarding consumer behavior, it has so far not generated much empirical research. One reason is that the data required for such research -- detailed information on product characteristics -- is not widely available.

This deficiency is remedied by the new approach to measuring product quality developed by H. Grupp et al. (1986, 1988, 1990, 1992), known as "*technometrics*".

Technometrics is the quantitative measurement of the technological quality or sophistication of a product or process, group of products or processes, or industry. This approach produces a quantitative profile of a product or process, showing graphically its performance characteristics for selected key attributes, in comparison to those of other firms or countries. Such indices can be aggregated across groups of products, to permit comparisons of the comparative technological level of subsectors or even entire industries.

Definition: Every product or process has a set of key specifications or attributes that define its performance, value or ability to satisfy customer wants. Almost by definition, every specification or attribute can be quantified. For instance, in the case of diagnostic kits, a key specification is "reliability" (the proportion of tests in which accurate results are obtained). For assembly robots, 14 key specifications are axes, maximum reach, minimum reach, vertical velocity, horizontal velocity, repetitive accuracy, position acuracy, nominal load, maximum load, drive, vertical reach, hand rotation, angular velocity and lifetime. [Grupp, 1990]. All are expressible in quantitative units.

It is always a subjective decision whether an item should be included or not [Grupp and Hohmeyer, 1988]. However, as Clark [1985] and Stankiewicz [1990] have pointed out, as development proceeds, technological diversity gives way to standardization. Particular design approaches achieve dominance and performance criteria are clearly specified. Social processes and patterns of communication between customers will influence the speed and pattern of product (or process) design and broad categorizations are broken down into related subcategories of the characteristics which are refined through experience. Therefore, it is not surprising that (industrial) experts interviewed agree on proposed characteristics and priorities [Grupp, 1990].

Each of these attributes has its own unit of measurement: mm. per second, years of lifetime, etc. Problems then arise in aggregating attributes to build a single quality index. The technometric indicator surmounts this difficulty by converting each measured attribute into a [0,1] metric, enabling construction of weighted averages, etc., and permitting comparisons across products, firms, industries and countries. The "0" point of the metric is set as the technologically-standard attribute; the "1" point is set as the most technologically-sophisticated attribute in existence.

Let subscripts i, j and k represent products, product attributes or characteristics, and subgroup (company, industry or country), respectively.

Let K represent the measurement of an attribute for given i, j and k. The technometric indicator, K* , is defined as:

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

where:

$K_{max}(i,j,k)$ = the highest value of product characteristic "j" for product "i", for subgroup k

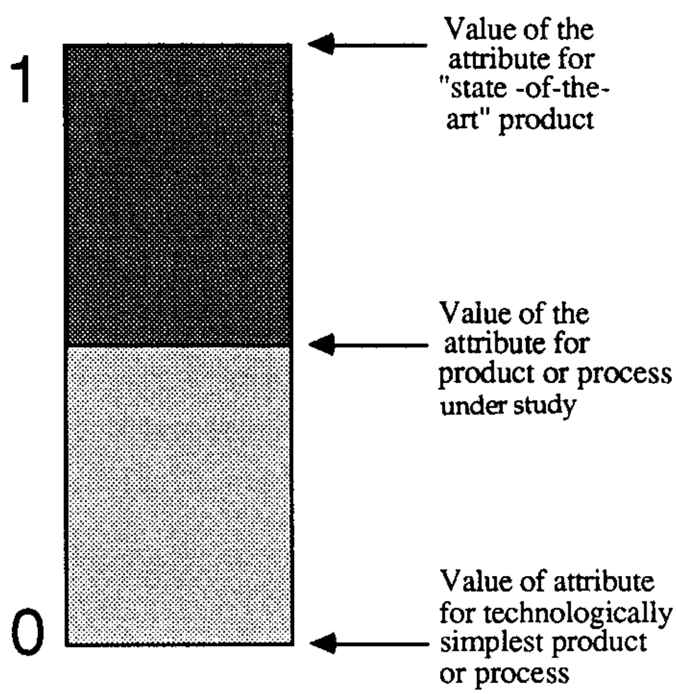
$K_{min}(i,j,k_{min})$ = the lowest value of product characteristic "j", among all members of subgroup k

$K_{min}(i,j,k_{min})$ the highest value of product characteristic "j", among all members of subgroup k

Take, for instance, the product "diagnostic kits". One attribute would be "test duration" -- the length of time needed to carry out the diagnostic test. The numerator of [1] would give the difference between the "best" (i.e. shortest) test duration for an Israeli product, compared to the "worst" (i.e. longest) test duration for any of the products under comparison, for several countries. The denominator would give the difference between the best, shortest test duration for the top state-of-the-art product, and the longest test duration for a technologically standard (and probably, relatively inexpensive) product.

What results is a metric, K*, that ranges from zero to one, showing how a product stacks up for that attribute, relative to the state-of-the-art level. Note that in some cases -- as in this one -- *lower* attribute values represent *higher* levels of technology, requiring the values in the technometric expression to be inverted (by replacing all "max" with "min", and vice-versa, in Equation [1]). {See Figure 1. }

Figure 1: **Diagrammatic Representation of Technometric Index K***



During 1990-92, technometric evaluation of the following products (for Israel, Japan, U.S., and Germany) was conducted in a joint research project between Fraunhofer-ISI, in Karlsruhe, Germany, and the S. Neaman Institute, Techion, Israel:

i) biodiagnostic kits. (See Frenkel, Reiss, Maital, Koschatzky and Grupp, 1992). ii) sensors that measure temperature, pressure, etc.

b) **Benchmarking**:

"Benchmarking" is the systematic comparison by one company or products and processes of another company, considered to be "best in class" or "state of the art". In the past seven years, the application of benchmarking has become extremely widespread across the U.S. and Europe.

In response to the increasingly competitive global economy, companies have made use of benchmarking to examine their products and services with critical eyes. Many firms have found this approach to be a powerful way to raise their standards of quality and excellence. A key reference is the book by Robert C. Camp, manager of benchmarking competency at Xerox Corp.: *Benchmarking: The Search for Industry Best Practices that Lead to Superior Performances.*

The basic assumption that people buy "attributes" of products (that is, properties that enable goods and services to create value for buyers), the essence of the new consumer theory, is the foundation of technometrics; and technometrics, in turn, is a valuable quantitative approach to benchmarking, enabling construction of graphic profiles of a company's products, which permit managers to determine at a glance the product's strength and weaknesses.

c) **Linear Programming:**

The quantative nature of technometric benchmarking indicators points to a natural extension of this method -- the development of quantitative analytical models for optimal investment in R&D, with the aim of improving existing products through optimal investment of labor, capital and time. The mathematical programming technique known as linear programming provides an initial starting point, in view of the linear nature of the technometric indicators.

A Preliminary Programming Model:

As a first approximation, consider the following formulation of one of the difficult questions posed at the outset of this proposal: Which of the many attributes of a product should managers seek to improve, in an R&D program, when faced with dificult constraints on skilled manpower, financial capital and time?

Such a model could be formulated as follows:

Objective:
Choose the most valuable feasible combination of improvements in product (or process) specifications, that meets a) cost; b) skill; and c) time constraints.

Terminology:

i - product or process characteristic, $i = 1, N$

x_i - technometric specification for characteristic "i", based on {0,1} metric {0 is least sophisticated, 1 is most sophisticated}

Δx_i - change in x_i through R&D investment

c_i - cost of making incremental change in x_i

t_i - time to make incremental change in x_i

l_i - skilled labor-hour needed to make an incremental change in x_i

w_i - market value of an incremental change in technometric specification x_i

C - total R&D budget ($ million)

L - total number of skilled labor-hours

T - time available for completing R&D

Model:

$\underset{\Delta x_i}{\text{Max}}\{\Sigma w_i \Delta x_i\}$

subject to:

a) $\Sigma\, c_i\, \Delta x_i \leq C$

b) $\Sigma\, l_i\, \Delta x_i \leq L$

c) $\Sigma\, t_i\, \Delta x_i \leq T$

Note: There may also be feasibility constraints on Δx_i, e.g. $\Delta x_i \leq v_i$, where v_i is the largest feasible change in specification x_i under the existing circumstances.

The cost, skill and time constraints may well be non-linear.

An example of such a model, applied to optimization of the attributes of second-generation civilian jet aircraft, is shown in Table 1 (page 209). This example, constructed by Anderson, Lundstrom and Smith, was based on estimates of cost-performance curves and "voice of the market" surveys. (see below). The last column shows the optimal budgeting of funds, and the second column from the left shows the optimal improvement in each technometric specification.

Table 1
Attributes of second-generation civilian jet aircraft

Quality Factor	Δx_i	c_i	Budgeted Funds
Crew Costs	0.40	18,870.773	7,548.309
Fuel Efficiency	0.10	12,580.515	1,258.052
Dispatch Reliability	0.30	6,290.258	1,887.077
Maintainability	0.23	37,741.546	8,680.556
Payload/Range Capability	0.25	12,580.515	3,145.129
Block Time Performance	0.20	12,580.515	2,516.103
Airport Factors	0.00	44,031.804	0.0
Customer Support	0.30	25,161.031	5,032.206
Technology Leadership	0.30	18,870.773	5,661.232
Passenger Capacity	0.30	6,290.258	1,887.077
Cargo	0.00	50,322.061	0.0
Cabin Interior Flexibility	0.25	6,290.258	1,572.564
Comfort Level of Interior	0.40	6,290.258	2,516.103
Service Life	0.00	56,612.319	0.0
Market Flexibility	0.25	12,580.515	3,145.129
Non-Airplane Issues	0.50	12,580.515	6,290.258

The last column of the above table represents the allocation decision in dollars among each of the various quality factors (manpower allocation is omitted). The column was computed by taking the product of the desirable technometric improvement, Δx_i , and the marginal cost of making such an improvement, c_i , as estimated from the cost-performance curve.

Voice of the Market:

In the above model, the objective function is the weighted average of improvements in each product attribute, with weights determined in some fashion to represent the "importance" of each improvement.

One approach to determining the weights -- which can play a crucial role in deciding which attributes of the product should be improved -- is through conducing "voice of the market" surveys among customers, who indicate on a questionnaire the relative importance of each of the product attributes.

An example of such a survey is shown in Table 2, in which chief flight engineers for airlines were asked to indicate their evaluation of the importance of various aircraft characteristics.

There are several competing approaches to evaluating "voice of the market", apart from the "voice of the market" questionnaire, including the technique known as "hedonic price indexes" (in which product price is the dependent variable of a statistical least-squares regression, with product attributes as the independent, explanatory variables; Beta coefficients then become the relative "weights" for the programming model's objective function).

Table 2
Customer Weightings of Quality Factors

Quality Factor	Customer Weighting
Crew Costs	7.0
Fuel Efficiency	7.9
Dispatch Reliability	5.6
Maintainability	6.7
Payload/Range Capability	9.5
Block Time Performance	6.3
Airport Factors	5.7
Customer Support	5.2
Technology Leadership	5.1
Passenger Capacity	9.8
Cargo	8.0
Cabin Interior Flexibility	4.2
Comfort Level of Interior	7.9
Service Life	5.0
Market Flexibility	4.7
Non-Airplane Issues	5.0

(See questionnaire in Appendix A)

Decision-Support System:

The advantages of the decision-support model outlined above are: a) it is objective, based on physical measurements of product or process attributes; b) the process of data-gathering which it requires encourages quantitative benchmarking, in itself an important aspect of R& D decision-making, and c) it is an optimizing model, and thus seeks to make the most effective use of scarce resources. While based in part of technological data, the model also makes explicit use of "voice of the market" data, in the form of weights attached to each Dxi (product-attribute improvement), and thus also encourages explicit attention to customer preferences.

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Appendix A: Please indicate the relative importance that you place on the following factors when evaluating aircraft for purchase.

Low — High	Factor
☐☐☐☐☐☐☐☐☐☒☐☐	**Crew Costs:** *(e.g. two member crew, common type ratings for multiple products)*
☐☐☐☐☐☐☐☐☐☒☐☐	**Fuel Efficiency:** *(e.g., weight)*
☐☐☐☐☐☐☐☐☐☒☐☐	**Dispatch Reliability:** *(e.g., system complexity, robustness of design, failure tolerance, structural design)*
☐☐☐☐☐☐☐☐☐☒☐☐	**Maintainability:** *(e.g., mean time between maintenance, engine maintenance, centralized maintenance recording system)*
☐☐☐☐☐☐☐☐☐☐☒☐	**Payload/Range Capability**
☐☐☐☐☐☐☐☐☐☒☐☐	**Block-Time Performance, Function of Dispatch Reliability**
☐☐☐☐☐☐☐☒☐☐☐☐	**Airport Factors** *(e.g., runway capability, ramp space, field length, flexible interface with ground support, airport noise, emissions)*
☐☐☐☐☐☐☒☐☐☐☐☐	**Customer Support** *(e.g., AOG, technical support, spare parts availability)*
☐☐☐☐☐☐☐☐☐☐☐☒	**Safety** *(e.g., emergency exits, windshear annunciation, flight envelope limits)*
☐☐☐☐☐☒☐☐☐☐☐☐	**Technology leadership** *(e.g., avionics, fly by wire, heads up display, glass flight deck, advanced wing design, advanced materials)*
☐☐☐☐☐☐☐☐☐☐☒☐	**Passenger capacity, goes with payload-range**
☐☐☐☐☐☐☐☐☒☐☐☐	**Cargo** *(e.g., cargo weight/volume, standard cargo containers, interline container flexibility, mechanized cargo loading, bulk, forward pallets)*
☐☐☐☐☐☐☒☐☐☐☐☐	**Cabin Interior Flexibility** *(e.g., class potential, seating flexibility, vacuum lavatories)*
☐☐☐☐☐☐☐☐☐☐☒☐	**Comfort Level of Interior** *(e.g., number of middle seats, legroom, seat width/pitch, stowage compartment size, cabin noise, air quality)*
☐☐☐☐☐☐☒☐☐☐☐☐	**Service Life**
☐☐☐☐☐☐☒☐☐☐☐☐	**Features Availability**
☐☐☐☐☐☐☐☐☒☐☐☐	**Market Flexibility** *(e.g., family concept, engine choice flexibility)*
☐☐☐☐☐☒☐☐☐☐☐☐	**Non-Airplane Issues** *(e.g., existing customer base, delivery time, manufacturer financing, political alignment)*

How Good Are Our Products

Technometric Evaluation of Product Quality

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Working Paper

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Summary

Objective, quantitative measures of product and process quality are essential both for optimal management decision-making and for optimal public policy. At Fraunhofer-I.S.I., Dr. H. Grupp and associates have developed a series of metrics for evaluating technological sophistication and quality, stretching through all stages of product development from "knowledge" through R&D, innovation, marketing and distribution. (Grupp, 1991; Grupp & Hohmeyer, 1986; Grupp & Hohmeyer, 1988).

One of those metrics, "Technometrics", is a multidimensional index of technological excellence. Technometric product profiles permit objective comparisons of products between companies, industries and nations. Such profiles can reveal weaknesses long before such shortcomings result in declining sales or market share. They are applicable to services as well as goods, to low-tech as well as high-tech products, and provide graphic answers to the question basic to both management and industrial policy:

"How good are our goods?"

The method of constructing technometric profiles is outlined, and global empirical profiles of several types of products are described, including industrial robots, photovoltaic cells, lasers, sensors and biogenetically-engineered drugs. A technometric case study of Israel's fledgling biodiagnostic industry is presented, together with the policy conclusions that emerge.

I. Introduction

"Management begins with Measurement"

Focused decision-making is the attempt to bridge the gap between what is and what ought to be. It follows from that definition that framing or implementing decisions without a clear evaluation of the existing situation is unlikely to succeed. Lord Kelvin once said that "theory begins with measurement". While many theoretical physicists might debate that point, few managers or policymakers would deny that management -- whether at the corporate or government level -- does start with measurement.

In discussing industrial and technology policy for a whole nation, or technology strategy for firms or industries, it is essential to have clear answers to the question:

* *How good are our products and processes, compared to those of competing firms or countries?*

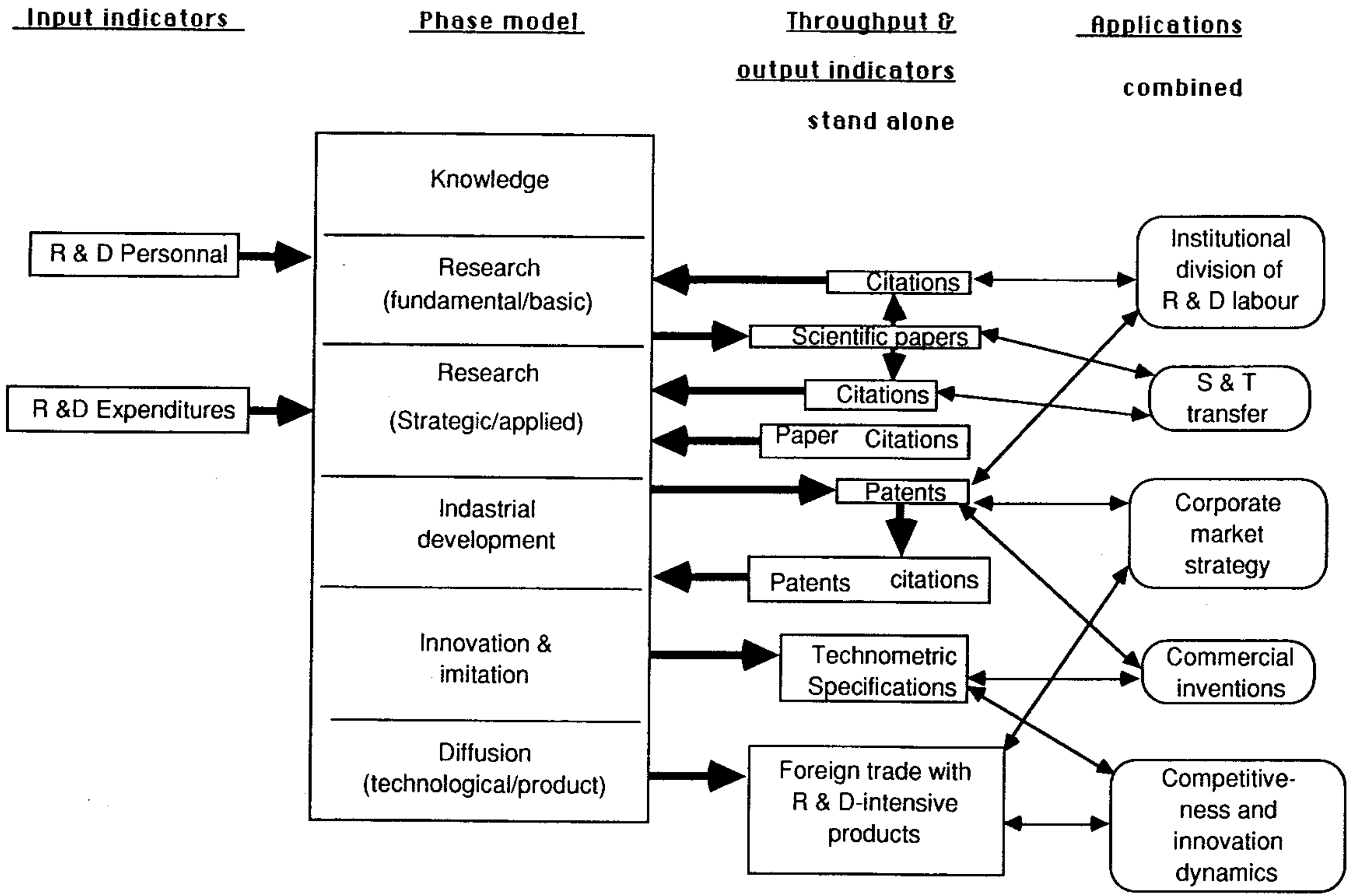
The answers to this question, "what is our competitive situation?", must be objective, accurate and quantitative.

A series of metrics for evaluating and comparing technological sophistication have been developed by Dr. Hariolf Grupp and his team, at the Fraunhofer Institute for Systems and Innovation Research (FhG - ISI). These quantitative indicators have proved useful in measuring the technological level of products and processes and can serve as a "yardstick" for comparison with other firms or countries. This work originated with concern at the German Ministry for Research and Technology in the early 1980's that Germany trailed Japan and the United States in important high-tech areas.

The FhG-ISI approach views technical performance as a multistage input-output process. Each stage has its own characteristics, and hence can be portrayed by quantitative indicators that reflect its achievements. (See Figure 1).

From the earliest stage of basic research -- where citations serve as a measure of output -- through applied R&D -- measured by patents -- and finally new products themselves, FhG-ISI has pioneered a comprehensive set of metric indicators that together make it possible to determine precisely where firms, industries and whole countries stand in the global technology race. At the end of the technology chain is exports and world market share, one of the ultimate goals of technological excellence.

Figure 1. Science and Technology Indicators



Among the FhG-ISI technology indicators are:

a) Relative world market share (RWS), showing, for a given product or group of products, the world market share held by a country, relative to that country's share of the world market for all industrial exports.

b) Relative comparative advantage (RCA), which measures the country's export *surplus* for a product or group of products, relative to its overall export surplus.

c) Patent indicators: several metrics were developed to measure intensity of patenting activity, again relative to other countries. Among them: Preferential patent factor (PPF), which measures the relative intensity of patenting activity in one foreign patent office compared to another; International technological performance (ITP), a measure of worldwide patent output, and Revealed technological performance (RTP), which integrates PPF and ITP to provide a "bandwidth" of technological positions in patenting, worldwide. In addition, Relative patent advantage (RPA) expresses patenting intensity for a given product or process, compared to overall patents for all products and processes, for a given country. (For fuller descriptions of these indicators, see Grupp [forthcoming, 1991], Koschatzky [1990], and Grupp and Hohmeyer [1988].)

d) The technometric indicator, in many ways the centrepiece of all the quantitative metrics, which measures product quality at the stage of innovation.

II. Technometrics

Definition:
One of the most important links in the product-development chain is the innovation stage, where the quality of new products brought to market is evaluated. Grupp and associates developed a method they call "*technometrics*" to quantify product quality at this stage.

Technometrics is the quantitative measurement of the technological quality or sophistication of a product or process, group of products or processes, or industry. [Grupp and Hohmeyer, 1986, 1988; Grupp, 1991]. This approach produces a quantitative profile of a product or process, showing graphically its performance characteristics for selected key attributes, in comparison to those of other firms or countries. Such indices can be aggregated across groups of products, to permit comparisons of the comparative technological level of subsectors or even entire industries.

The technometric indicator has important advantages over other quantitative indicators in existence, being multidimensional, quantitative and susceptible to comparison across countries and products. (For other approaches, see Saviotti, Stobbs, Coombs and Gibbons [1982] and Saviotti [1985]). Every product or process has a set of key attributes that define its performance, value or ability to satisfy customer wants. Many of these attributes can be quantified -- for instance, in the case of diagnostic kits, "reliability" (the proportion of tests in which accurate results are obtained).

Each of these attributes has a different unit of measurement. Problems then arise in aggregating attributes to build a single quality index.

The technometric indicator surmounts this difficulty by converting each measured attribute into a [0,1] metric, enabling construction of weighted averages, etc., and permitting comparisons across products, firms, industries and countries.

Let subscripts i, j and k represent products, product attributes or characteristics, and subgroup (company, industry or country), respectively. Let K represent the measurement of an attribute for given i, j and k.

The technometric indicator, K^*, is defined as:

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

where:

$K_{max}(i,j,k)$ = the highest value of product characteristic "j" for product "i", for subgroup k

$K_{min}(i,j,k_{min})$ = the lowest value of product characteristic "j", among all members of subgroup k

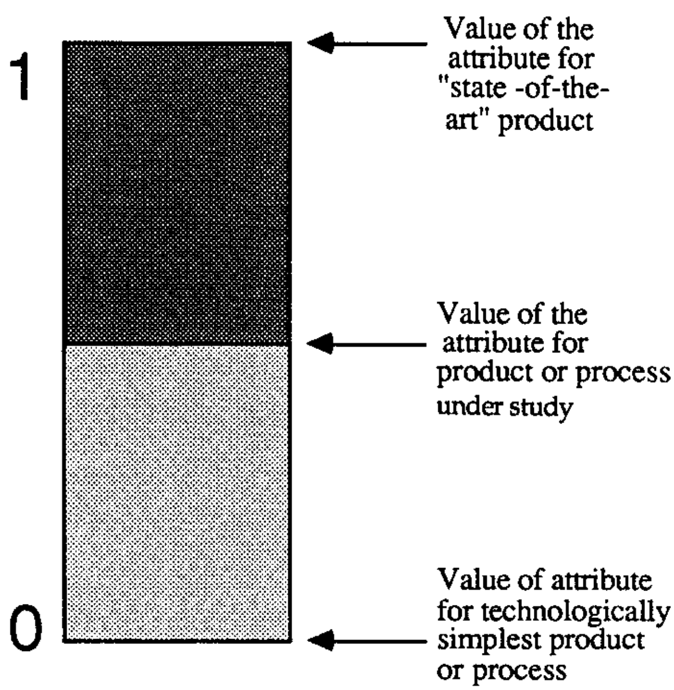
$K_{min}(i,j,k_{min})$ the highest value of product characteristic "j", among all members of subgroup k

Take, for instance, the product "diagnostic kits". One attribute would be "test duration" -- the length of time needed to carry out the diagnostic test. The numerator of [1] would give the difference between the "best" (i.e. shortest) test duration for an Israeli product, compared to the "worst" (i.e. longest) test duration for any of the products under comparison, for several countries. The denominator would give the difference between the best, shortest test duration for the top state-of-the-art product, and the longest test duration for a technologically unsophisticated (and probably, relatively inexpensive) product. What results is a metric, K*, that ranges from zero to one, showing how a product stacks up for that attribute, relative to the state-of-the-art level.

Note that in some cases -- as in this one -- lower attribute values represent *higher* levels of technology, requiring the values in the technometric expression to be inverted.

For a diagrammatic presentation of K*, see Figure 2.

Figure 2. A diagrammatic representation of the technometric index K*



Once key product attributes have been determined and K* values calculated for each, a technological "profile" of the product can be constructed. It is possible to aggregate K* across all key attributes -- for diagnostic kits, that would include sensitivity, intra-assay precision, inter-assay precision, and handling, as well as test duration -- to achieve an aggregate K* measure for the product or group of products. This aggregate technometric measure can then be correlated with other variables to determine the link between technological excellence and, for instance, market success. Results in study by Grupp and others indicate that declines in the technometric quality of a product or process, K*, occur 2-3 years before such deterioration finds expression in declining market share or export sales. [Grupp and Hohmeyer, 1988]. This indicates that K* can serve as a useful "early warning indicator", revealing problems with product quality in sufficient time to take remedial action; generally, by the time it is observed that market share is falling, it is too late to revamp the product and regain sales from competitors. K* can also serve a positive role, indicating products or sectors where a country has competitive advantage, technologically, hence worthy of investment to further marketing and sales efforts in foreign markets and to further improve R&D and production efficiency at home.

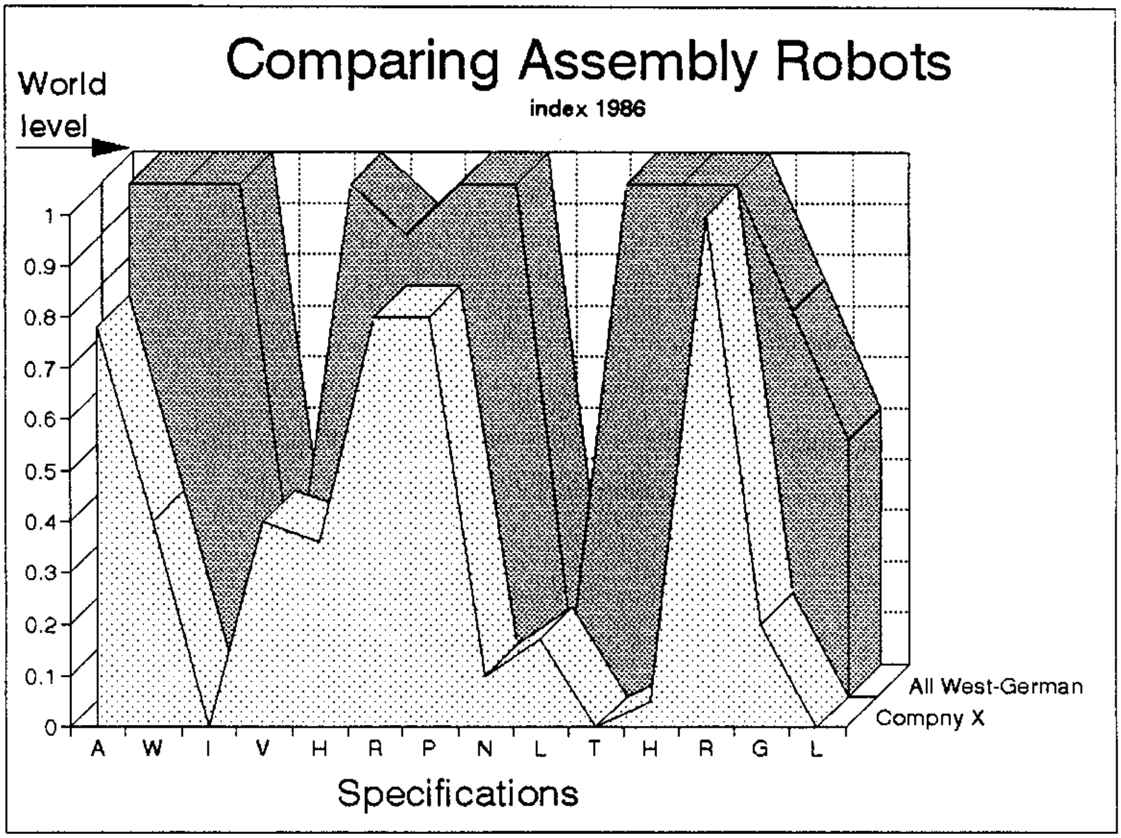
Technometric measures can be used at several levels. At the national level, they can be (and have been) used to identify technology gaps in comparison to other nations, and to shape industrial and R&D policy. At the sectoral level, technometric indicators can serve to identify areas of comparative advantage. And at the firm level, they can be used to construct competitive strategy, determine the optimal "mix" of product attributes, plan new generations of products, guide R&D investment, and form part of feasibility studies. [Grupp, 1989]. Since 1986, FhG-ISI has constructed technometric indicators for the following products: enzymes (immobilized biocatalysts), biogenetically engineered drugs, photovoltaic cells, lazers, sensors, industrial robots, diagnostic kits, and biogenetic water treatment facilities.

Technometrics in Action: "How Good is our Industrial Robot?"

One of the high-tech products for which Grupp and associates constructed technometric profiles was assembly robots used on production lines. To do this, they consulted experts in the field and defined fourteen key specifications of assembly robots, such as: maximum load, position accuracy, lifetime and minimum reach. These characteristics must necessarily be stated in quantitative terms: lifetime (in years), maximum load (in kilograms), etc. By studying catalogues, visiting trade shows and interviewing production and R&D personnel, a value was assigned to each specification, for a) Company "X", b) all other Germany companies, and c) companies in the U.S. and Japan, Germany's leading competitors. Then, K* values (each specification's value in the 0,1 metric, where "0" is the lowest value and "1" is the highest) were assigned for Company X, for each specification, and for all German companies taken together.

The results are shown in Figure 3a. Company X's robot is shown to be technologically inferior, relative to the world "state of the art". It is, in fact, a fairly simple one, priced relatively cheaply. Its relative strengths are in axes, repetition accuracy, position accuracy, and hand rotation. German robots are seen to be "state of the art" except for three or four specifications, including "horizontal velocity", "position accuracy", "drive" and "lifetime".

Figure 3a. **A Technometric Comparison of Assembly Robots**



Specifications		Value for Company X	Value for All West Germany Companies
A	axes	0.78	1
W	maximum reach	0.4	1
I	minimum reach	0	1
V	vertical velocity	0.33	1
H	horizontal velocity	0.3	0.4
R	repetition accuracy	0.8	1
P	position accuracy	0.78	0.9
N	nominal load	0.09	1
L	maximum load	0.1	1
T	drive	0	0.2
H	vertical reach	0.07	1
R	hand rotation	0.8	1
G	angular velocity	0.2	1
L	lifetime	0	0.5

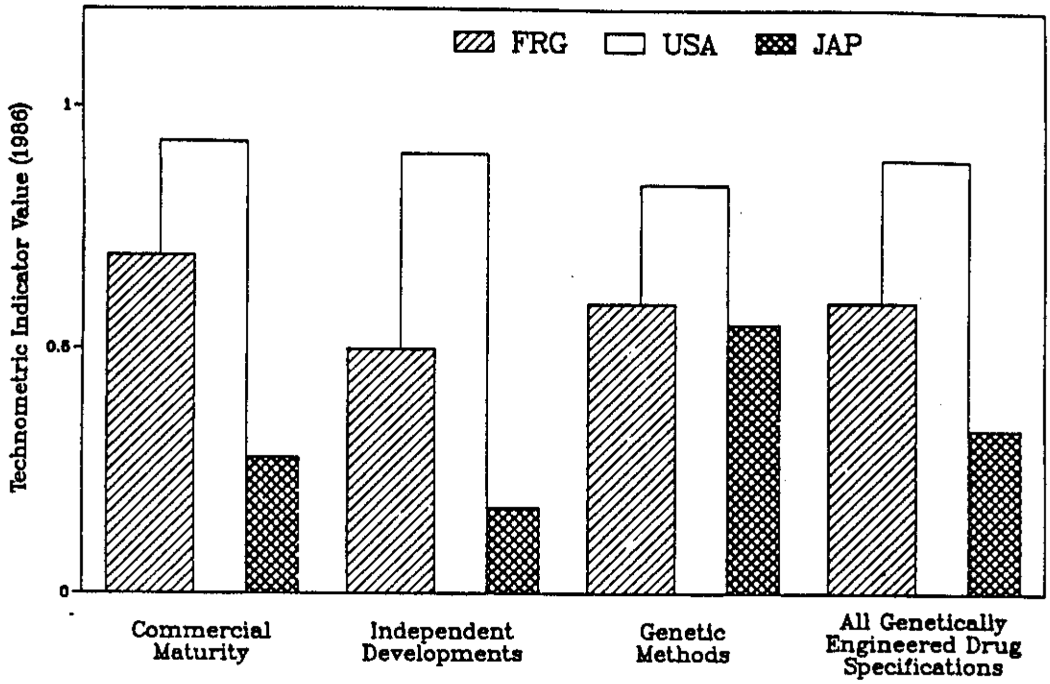
Photovoltaic Cells:

Grupp originally developed his method in response to concern at West Germany's Federal Ministry of Research and Development over reports that Japan's technology had outpaced Germany's. Grupp's 1988 study with Olav Hohmeyer (Grupp and Hohmeyer, 1988), "Technological Standards for Research -Intensive Product Groups and International Competitiveness", showed that contrary to the beliefs of some, German industry had kept pace overall. While the United States was shown to dominate research-intensive products such as gas turbines, aircraft and communication satellites, and Japan ruled consumer electronics, West Germany was positioned squarely in the middle between the technological leader and follower in both markets.

Still, the Grupp-Hohmeyer study laid bare some alarming gaps many managers and government officials were not fully aware of. One of the products Grupp studied was solar cells: large-surface semiconductors that convert light into electric current. The world market for photovoltaic systems is estimated at $300 million and is growing by 50-70 per cent a year. Germany was widely considered to be a world power in photovoltaic cells because such batteries are based on chemical processes; Germany's chemical industry has long been topflight. Germany, for instance, supplied the first solar cells for America's space program.

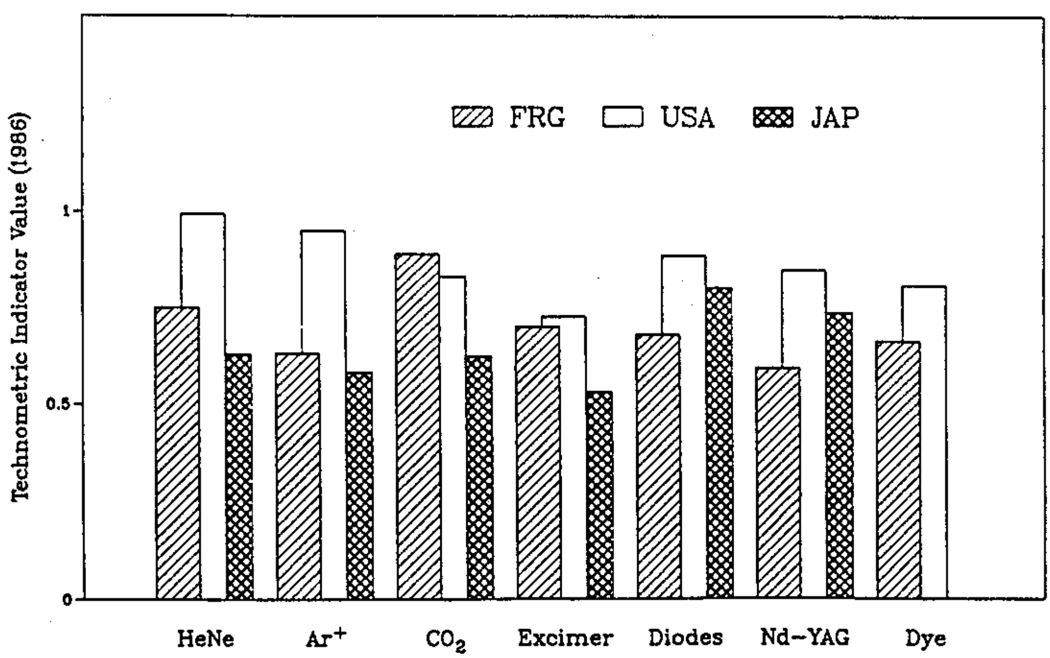
But Grupp's study revealed that Germany lags in a new area of technology in which photovoltaic cells are no longer made from crystalline silicon but rather from so-called thin-film materials, such as amorphous (non-crystalline) silicon, cadmium sulphide and gallium arsenide. The giant German conglomerate Siemens AG has since formed a joint venture with Arco Solar Inc., a subsidiary of Atlantic Richfield and a leader in the new photovoltaic technology. The joint venture has already set up a new production facility in Bavaria. The gap was perceived and steps were taken to close it. (See Figure 3b).

Figure 3b. **Technometric Indicators for Photovoltaic Cells, by Type of Materials**



A similar technometric study was initiated for lasers. This study showed important differentials in laser quality, depending on the nature of the laser media. (See Figure 3c).

Figure 3c. **Technometric Indexes by Active Laser Sources**



Finally, data were assembled to show the relative technometric levels of six key products -- biogenetically engineered drugs, lasers, robots, enzymes, solar cells, and sensors -- in the U.S., Japan and Germany. Figures 3d, 3e and 3f show the technometric indexes for each country, and for all six products, ranked in descending order.

Figure 3d: **Technometric Indicator Values for the State of the Art in Six Selected Areas in the U.S.A. (1986)**

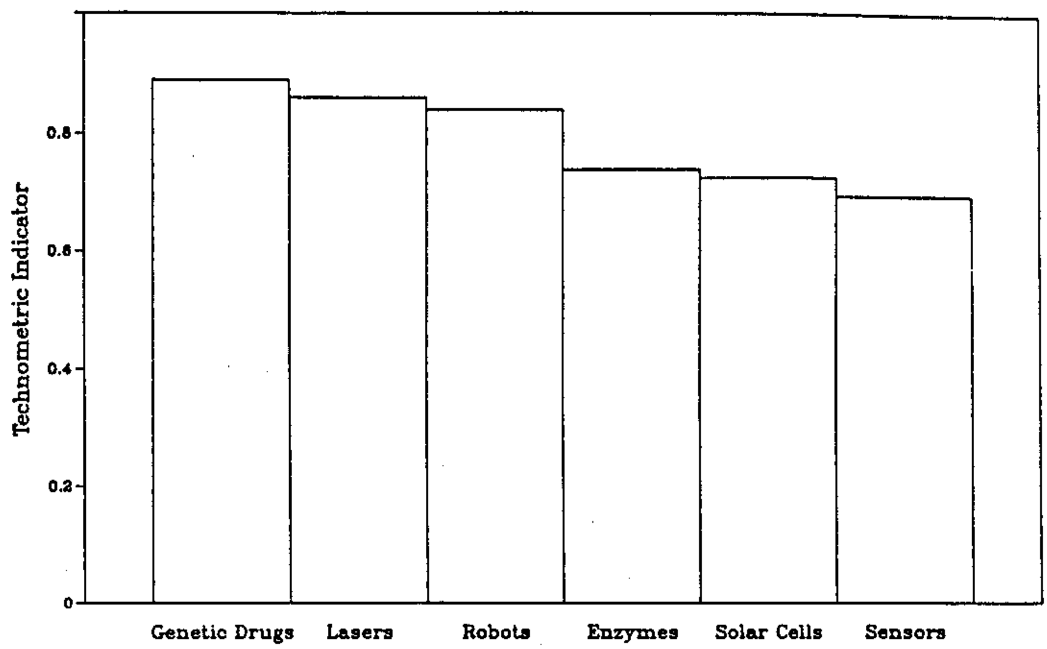


Figure 3e: **Technometric Indicator Values for the State of the Art in Six Selected Areas in Japan (1986)**

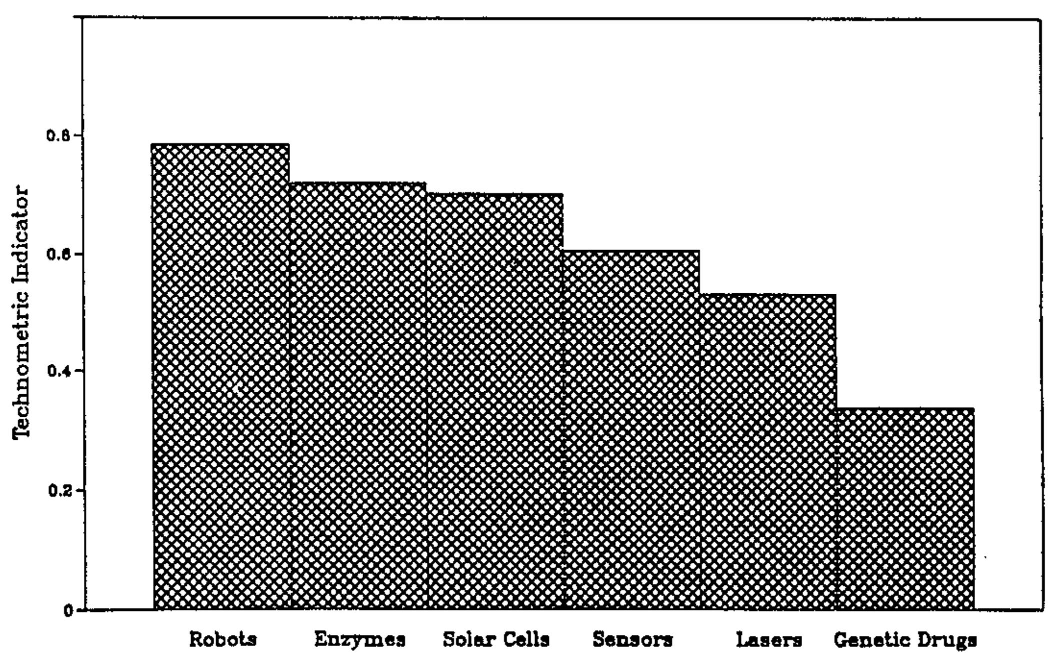
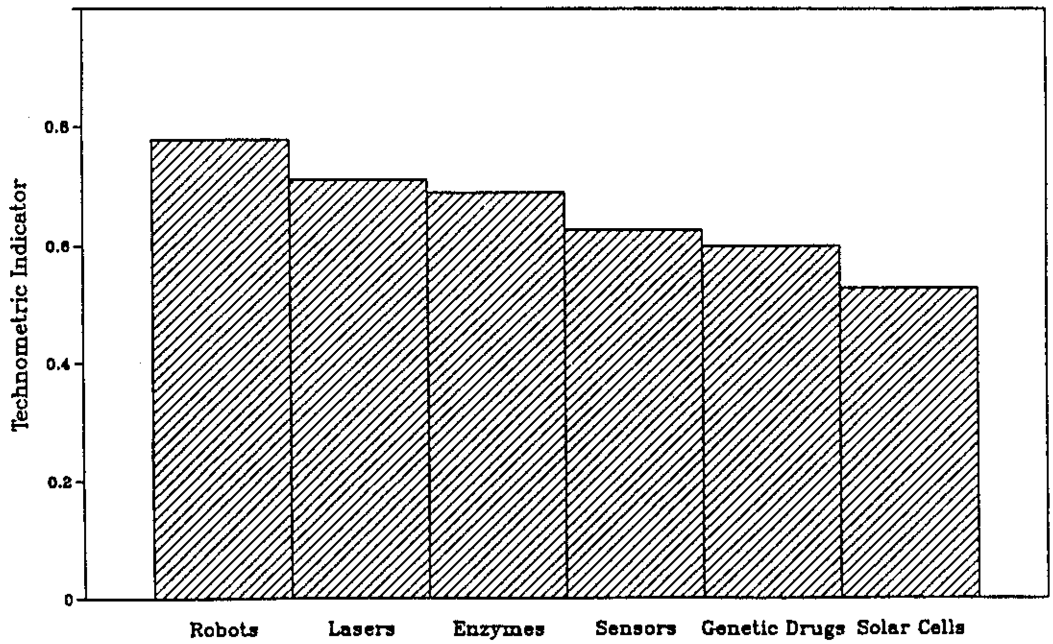


Figure 3f: **Technometric Indicator Values for the State of the Art in Six Selected Areas in West Germany (1986)**



Recently, Frenkel and Maital conducted a technometric survey of eight companies in Israel that manufacture biodiagnostic kits. The objective was to evaluate product quality and to frame policy recommendations. Comparative technometric data were supplied by Koschatzky and Grupp. The results of that survey follow.

III. The Biodiagnostic Industry in Israel

The Biogenetic Industry:

Biotechnology is a branch of technology that seeks to harness biological processes and systems, or biological organisms, in order to create useful products and processes for industry, medicine and agriculture. Using live organisms for the benefit of mankind is an old idea, used long ago for making bread, wine and cheese. In recent years, genetic engineering has permitted scientists to alter the building blocks of life itself. Advances in molecular biology have opened new horizons in influencing cellular processes and have made possible, as a result, development of entirely new products.

Scientists predict that toward the end of this century, biotechnology will be of major importance in production of food for both human beings and animals, in treatment of illness for humans and animals, in supply of new raw materials for the chemical industry, and in treatment of industrial wastes and water. According to various estimates, the market for biotechnological products will amount to between 40 and 100 billion dollars annually [Source: Katzir Committee Report, 1988].

There are four main areas of biotechnology: medical, agricultural, industrial, and ecological. Within medical applications, there are three subsectors: biogenetic engineering of drugs and hormones; production of biosensors and biocatalysts; and production of diagnostic products for determining the nature of illnesses in humans and animals.

In the first stage of this project, we chose to focus on the biodiagnostic industry.

Biogenetic Firms in Israel:

Some 30 biotechnology firms exist today in Israel. Most of them are small, and are based on products or processes developed in research done in academic institutions. These firms employ between 800 and 1,000 workers, of whom 30 per cent are scientists or engineers. Most of the biotechnology firms were set up as subsidiaries of research institutes or universities, and some are subsidiaries of foreign companies. Only a minority are entrepreneurial, established with venture capital and based on technology of an academic researcher and entrepeneur.

Most of these firms are in pharmaceuticals; 19 of the 30 are in this area, of whom 10 produce diagnostic kits and 2 make materials used for diagnostic kits. Seven companies manufacture drugs, hormones and enzymes. In addition, four small firms produce materials used in research labs and in the biotechnology industry. Two companies are in the chemical industry and two are in agriculture.

According to the November 1988 report of the Katzir Committee, set up to determine sectors in biotechnology that merit investment and development, the sales volume of Israel's biotechnology firms amounts to about $20 million. The Katzir Committee identified six constraints that limit development of this industry: lack of venture capital for establishing new firms; lack of venture capital and other forms of risk capital for existing companies; lack of acaemic research centers specializing in biotechnology; lack of trained manpower in biochemical engineering, production and management engineering; lack of technological infrastructure in existing drug and chemical companies that use traditional technology; and the small size of the local market in Israel for biogenetic products, coupled with the large distance from foreign markets.

In order to remedy some of these constraints, a National Biotechnology Program has been established, headed by Prof. Max Herzberg, President of Orgenics Ltd. (one of the companies in our survey).

In the biotechnology industry, diagnostic kits is the market "easiest to enter, with the shortest product life and highest risks" [*Biotechnology Europe*, Oct. 1989, p. 40]. Israeli firms in this industry mainly produce products for human and veterinary diagnosis, based on monoclonal antibodies. Our field survey of Israeli biodiagnostic firms was limited to companies that produce complete kits. We did not include companies that produced onlyh components of such kits. Nor did we include companies that purchased foreign technology under licensing agreements, but only companies with proprietary technology used in developing their own unique products.

A total of 12 biodiagnostic companies were located, of which 8 complied with the above criteria. Senior managers in all of those 8 firms were interviewed, and supplementary material on each firm was collected. Managers were highly cooperative and gave generously of their time. A key part of the interview was a detailed questionnaire, eliciting information on the company and on technometric details of its products.

The nature of biodiagnostic companies in Israel:

Analysis of the data from our field survey revealed that half of the 8 firms are independent, while half are subsidiaries of foreign firms. Most of the companies are privately owned, while some are public companies whose stock is listed on stock exchanges. The companies owned by foreign firms largely began as independent firms but because of difficulties in raising capital or the need to penetrate new markets, were bought out by larger companies abroad. These companies became subsidiaries, but retain their independence in matters of product R&D.

Seven of the 8 companies were established after 1980, while one was established during the 1970's. Despite their youth, all these companies have by 1990 succeeded in producing and marketing their own products. The transition from R&D to production and marketing was relatively swift. This contrasts sharply with the 7-10 years needed to develop and test new drugs, and the estimated $50-$100 million cost, as noted by the Katzir Committee.

Average plant size is small; the eight plants employed a total of 182 workers of all kinds, an average of 23 per firm, with size ranging from 5 workers to 45. (In general, industrial firms in Israel are very small).

As expected, the proportion of workers in this industry comprising highly-skilled and scientific manpower is very high. According to a 1987 Manpower Survey conducted by the Ministry of Industry, biodiagnostics employs a high proportion of scientific personnel, even in comparison to other high-tech industries. (See Table).

Manpower Profile for Biodiagnostic Firms, High-Tech Firms and Industrial Firms in General in Israel

	Engineers & Scientists	Technicians Workers	Skilled Workers	Unskilled Workers	Office (%)	Total
Biodiagnostic Firms	43.4	13.7	27.5	4.4	11.0	100
High-tech Firms	25.1	20.3	34.8	9.0	10.8	100
All Industrial Companies	9.6	7.7	50.1	22.4	10.2	100

R&D: Our survey revealed that fully a third of employees are engaged in R&D, at least part of the time. A third of total outlays of the 8 firms goes to R&D.

Sales and exports: All eight firms export at least part of their output. In aggregate, 75 per cent of the biodiagnostic firms' sales are exported. The heavy reliance on exports stems from the small size of the local market in Israel. Only two of the 8 firms rely principally on the local market; in the remainder, 90 per cent of total output is exported.

Europe is the main market. Two thirds of their exports goes to that market, while one third goes to other destinations. Half of the 8 firms export diagnostic kits to Germany, which absorbs between 10 per cent and 35 per cent of their exports. The United States is not a principal market for Israel-made diagnostic kits, and only about 5 per cent of total exports of this product go to that couantry. In contrast, Japan stands second in importance as an export market, next to Europe. Two firms export to Latin America and one company has a small amount of export sales to Africa.

The survey asked managers to forecast future export sales. Most of the companies predicted a rapid expansion in exports in the next five years, between threefold and fivefold growth.

Marketing and distribution: As in most high-tech products made in Israel, marketing is a major obstacle for biodiagnostic kits. Most of the firms we surveyed sell their products abroad through distributors, who acquire exclusive territorial rights. Some of those distributors belogn to large foreign companies. This approach to distribution is one important way that Israeli biodiagnostic companies cooperate with foreign entities. One of the 8 companies reported setting up its own marketing firm abroad, in order to achieve greater control over distribution.

All the companies responded that their products are "unique", aimed at either narrow market niches where no similar product exists, or broad market niches where some competition exists. None of the products compete on the basis of low price, but rather value-added and quality.

Most of the managers interviewed in our survey emphasized marketing as the main difficulty they face, rather than finance, R&D or technology.

The Single European Market in 1992: All 8 companies reported preparing for the 1992 Euromarket. Two have already set up companies in Europe, and three said they intended to do so. Two other companies reported joint-venture agreements to this end with European firms. Most of the companies felt that the main difficulties facing Israeli biodiagnostic firms, in connection with the Euromarket, would come from product standards. The present situation, in which approval by Israel's Ministry of Health is recognized in, for instance, Germany, will not continue after 1992. It is therefore vital that Israel adopt standards that are consistent with, and comply with, those prevailing in Europe. (A major difficulty in doing this is that European standards in many areas have not yet been agreed upon -- which some see as a deliberate European strategy to hamper imports from other countries).

Technometric Profiles:

Availability of excellent technometric data on biodiagnostic kits for Germany, U.S. and Japan, assembled by FhG-ISI researchers, makes it possible to compare the relative advancement of Israeli kits to those abroad.

Characteristics: Earlier studies of biodiagnostics showed that there are six main attributes of biodiagnostic materials, which together define the quality of those materials. They are:

- sensitivity:

the minimum amount of antibodies needed to product a chemical reaction, or the "threshold". Units of measurement are generally thousandths of a gram per milliliter.

- intra-assay precision:

degree of internal (intra-assay) accuracy: if the same kit is used 100 times, how many times will it correctly diagnose the presence of a hormone or microbe?

- inter-assay precision:

for a 100 randomly-selected kits, how many of them will correctly diagnose the presence of a hormone or microbe?

- measurement:

range over which diagnosis is possible. Units of measurement are the same as with sensititivity.

- test duration:

length of time needed for operating diagnostic test until result is obtained, in minutes.

- handling:

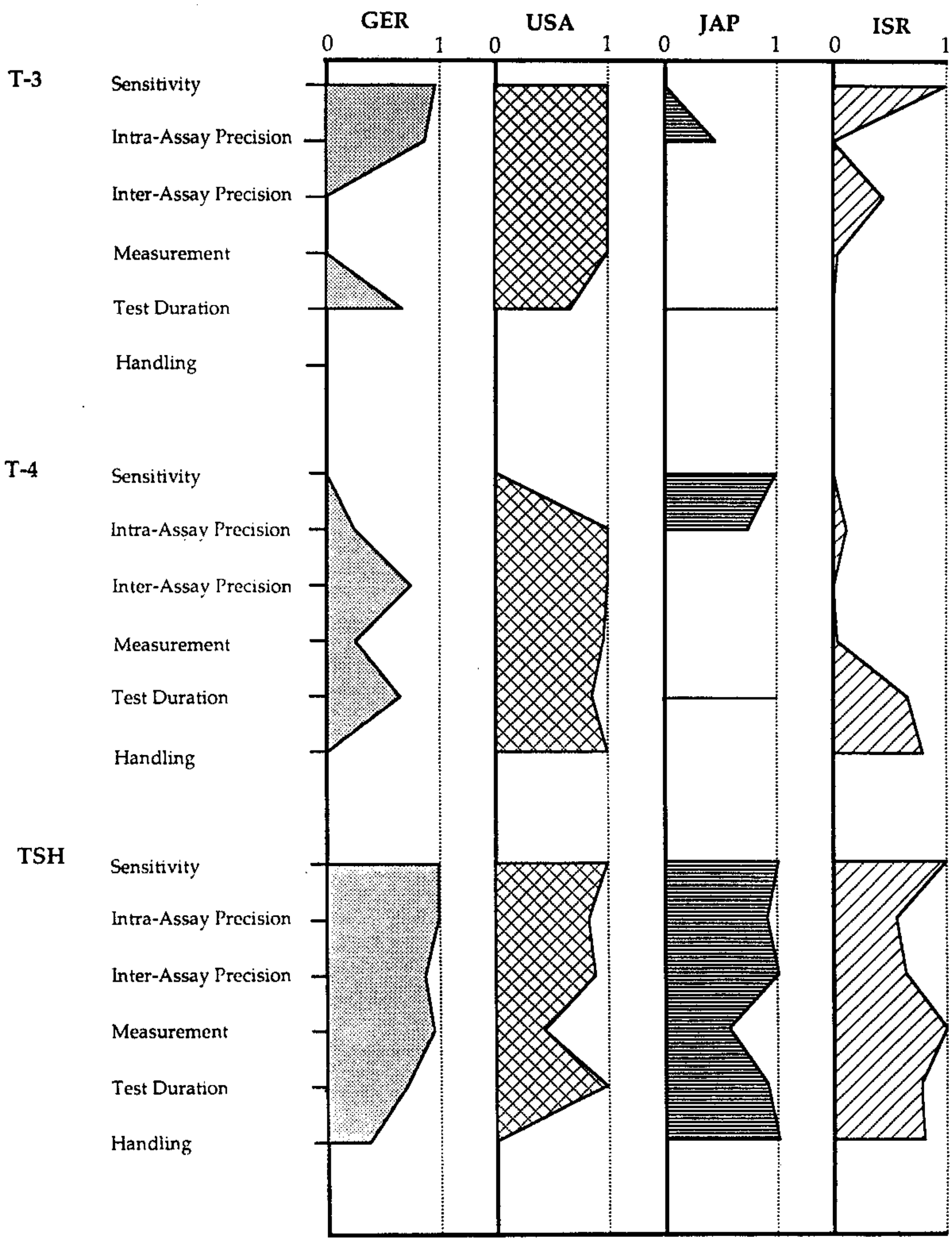
number of steps required.

Diagnostic kits: Data enabled comparison of diagnostic kits for the following: hormonal deficiencies related to the thyroid gland (lack of hormones FT-4, T-4, and T-3), and the sex hormone Prolactin; and tests for presence of the AIDS virus HIV-1. The technometric profiles are shown in Figures 4, 5 and 6.

What emerges is that, as expected, the United States in general holds the lead in the quality of its diagnostic kits. The U.S. pioneered in the field of biotechnology, and still enjoys a technological advantage. This lead is especially pronounced for T-3, T-4, and FT-4. For TSH, Germany enjoys a slight advantage over Japan and Israel, with the U.S. trailing. For prolactin, the U.S. product is superior to that of Israel, with Germany in third place. (See Figures 4 and 5).

Figure 4. **Technometric Profiles of Diagnostic Kits, Israel, U.S., and Germany**

A: Comparative Technometric Profile of Selected Kits Connected with the Diagnosis of the Thyroid Gland (T3, T4, TSH)



B: Comparative technometric Profile of Selected Kits Connected with the Diagnosis **of the Thyroid Gland (FT3 and FT4), and the Sex Hormone (PROLACTIN)**

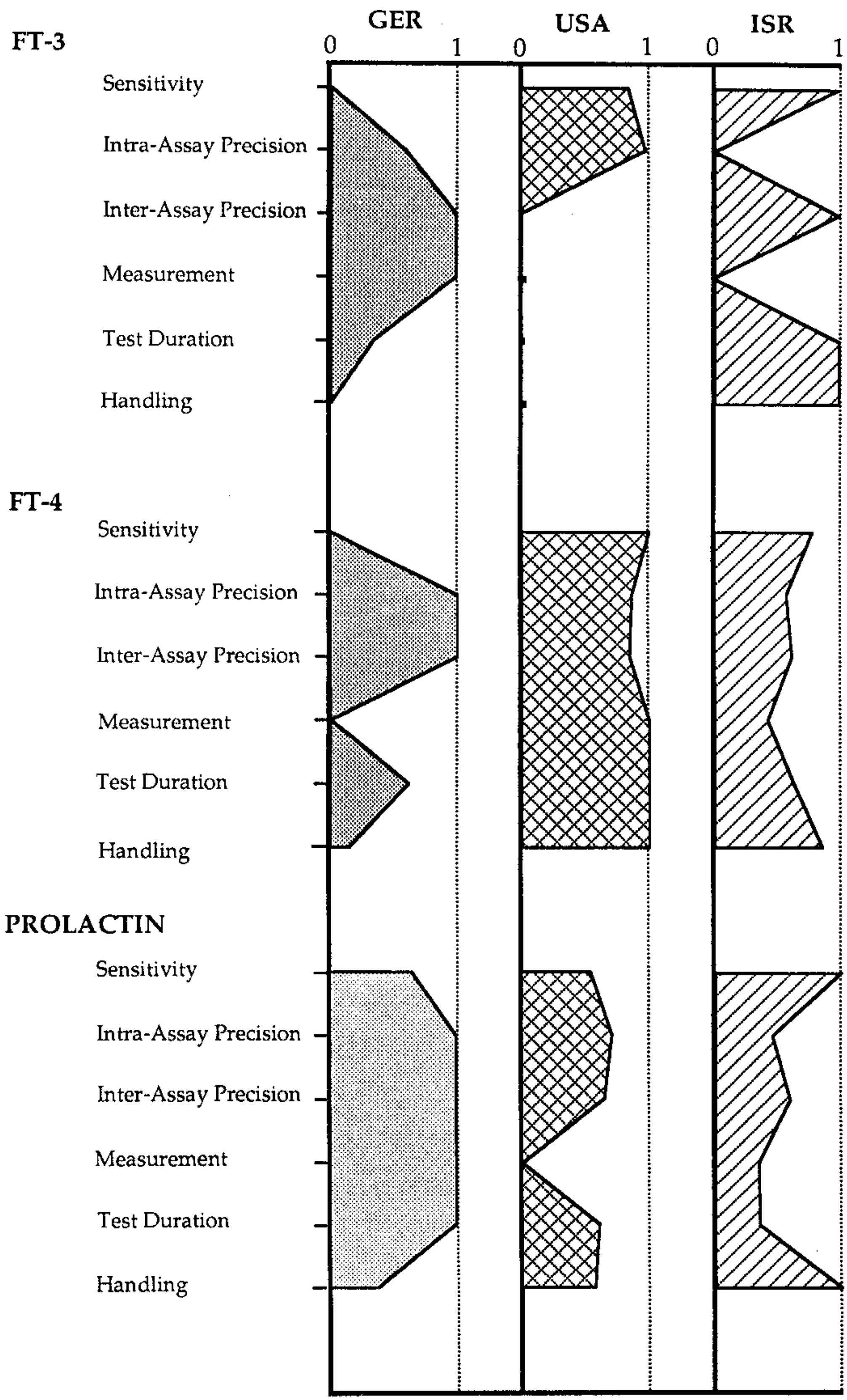
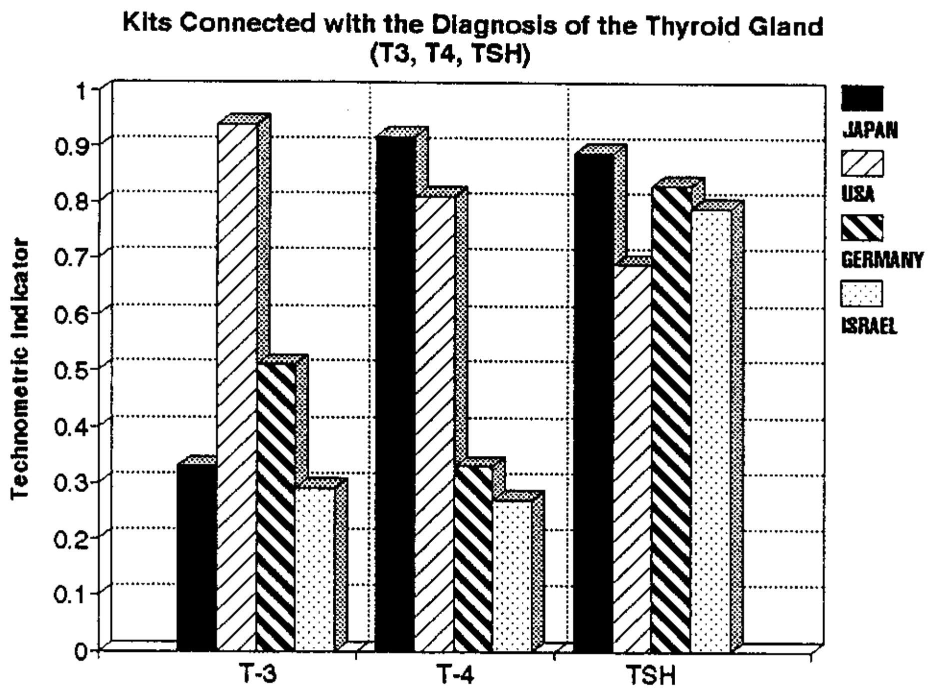
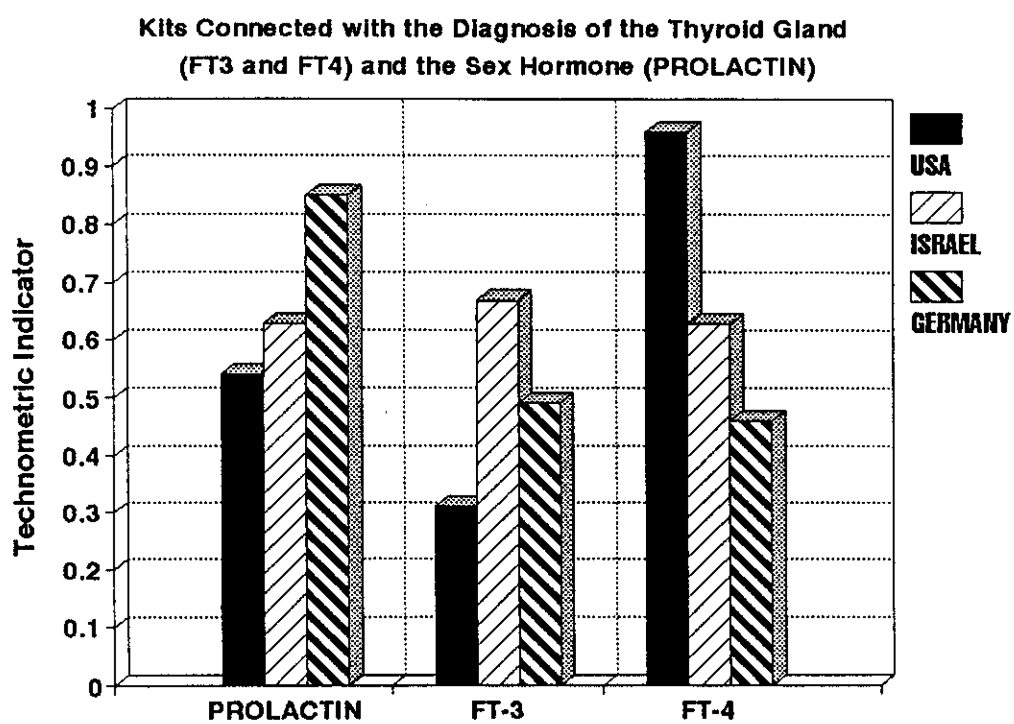


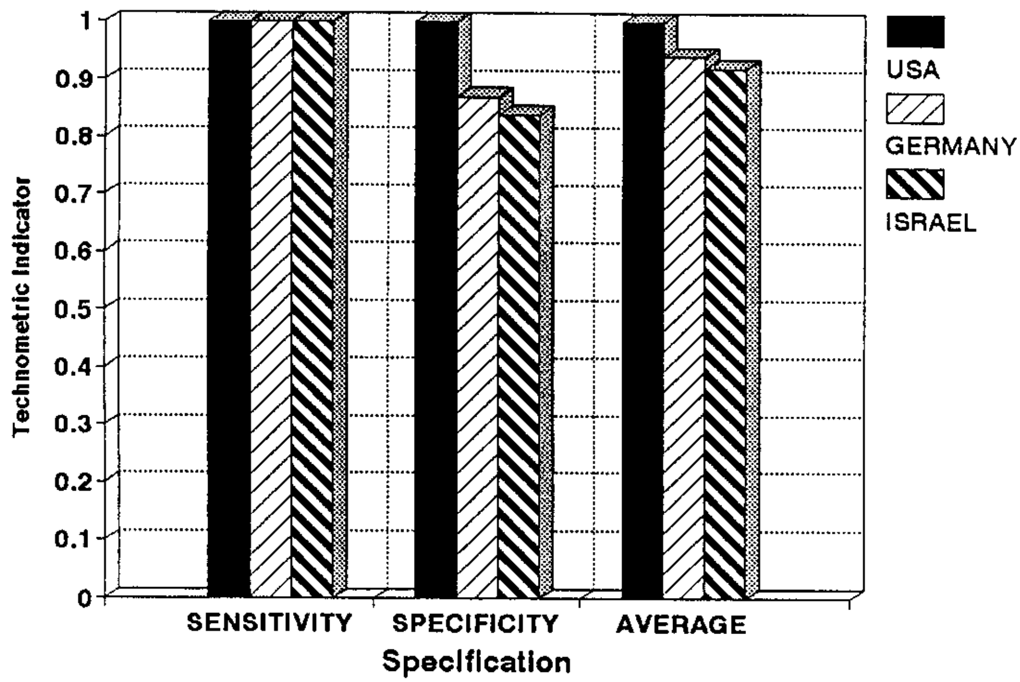
Figure 5. **Aggregated Technometric Indicators for Immunoassay diagnostic kits, Israel, Japan, Germany and the United States**





For AIDS detection [HIV-1], a product for whom the market already amounts to hundreds of millions of dollars and is certain to grow rapidly as the illness itself spreads, kits made in Germany, Japan and Israel are essentially equivalent in quality. (See Figure 6).

Figure 6: Technometric Profiles for HIV-1 Kits, Israel, Germany and U.S



Figures 7a, 7b and 7c present comparative technometric analyses of diagnostic kits for the detection of several infectious diseases: CMV, Rotaviruses and Clamidia, for Israel and Germany. It should be emphasized that for Israel, the technometric profiles are for kits produced by a single producer, while for Germany there are in all cases more than one.

Figure 7a: Comparative Aggregate Technometric Profile of Selected Kits Connected with the Diagnosis of the Infectious Diseases (ROTAVIRUS, CHLAMYDIA and CMV)

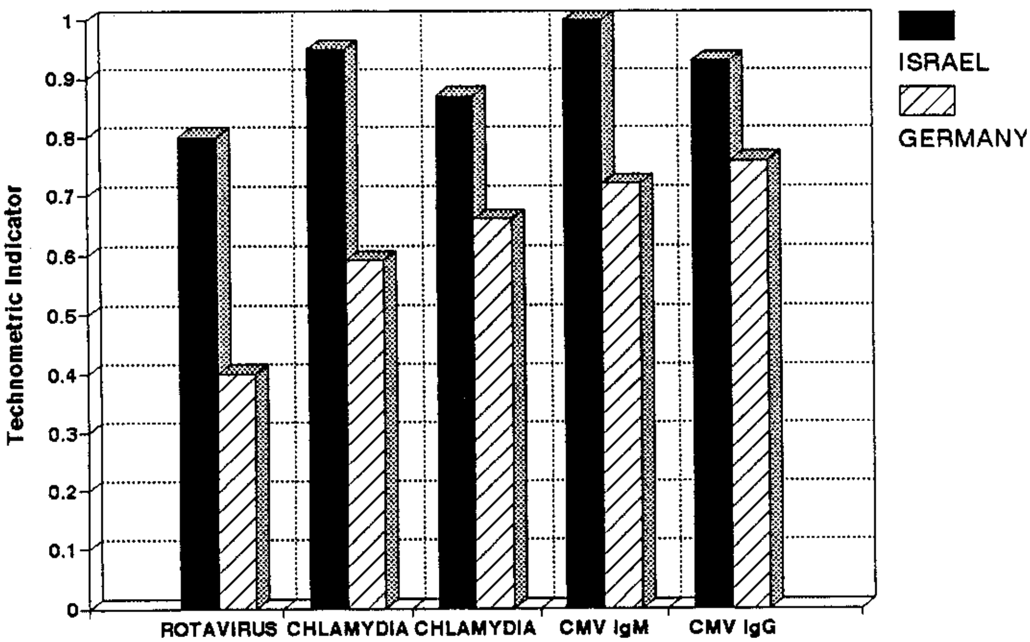


Figure 7b: Comparative Technometric Profile of Selected Kits Connected with the Diagnosis of the Infectious Diseases (CMV, ROTAVIRUS, CHLAMYDIA)

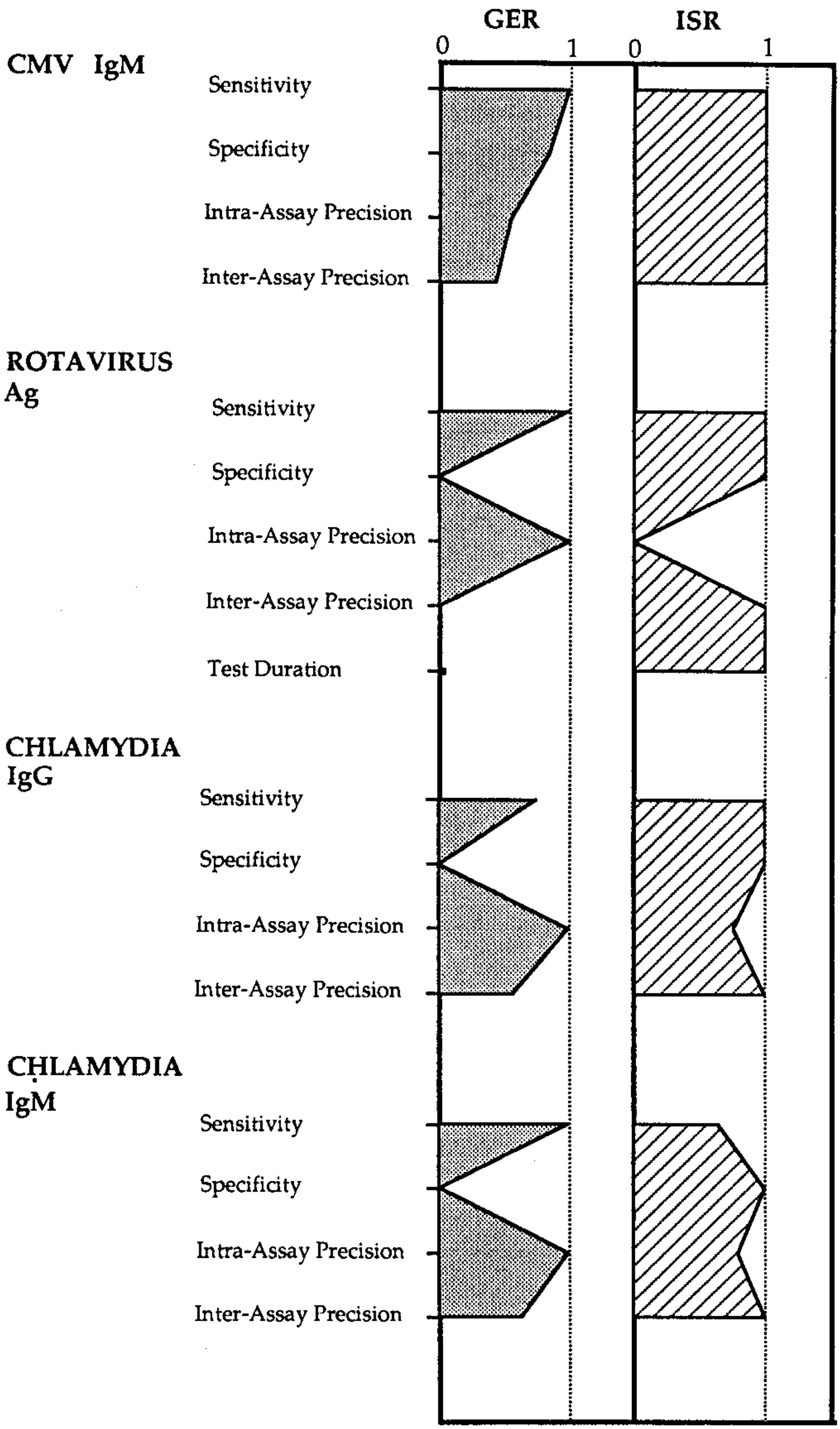
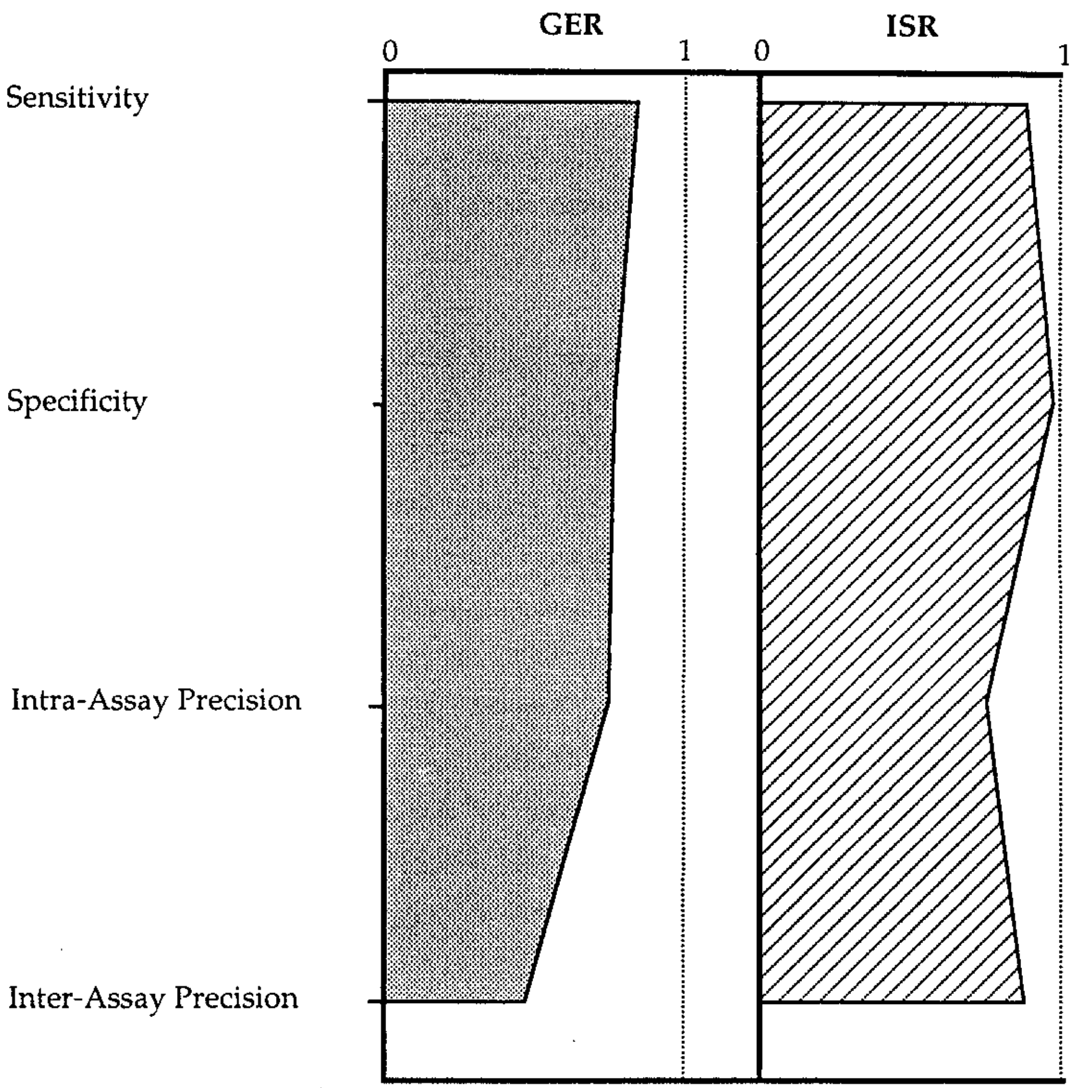


Figure 7c: Comparative Aggregate Technometric Profile of Five Selected Kits

Connected with the Diagnosis of the infectious Diseases.



Preliminary Conclusions and Implications:

These results suggest that for biodiagnostic products, Israel is in some cases at the frontier of technological excellence, according to the technometric index, and in other cases is close to it. This has occurred despite the fact that far less resources have been invested in biotechnology in Israel, compared to the other countries in the comparison, Japan, Germany and the United States.

There is reason for concern that this area of proven technological excellence will not be translated into market share and export sales for Israel. The eight participating firms in our survey report a lack of risk capital, and difficulty in marketing and distributing their products. Four of the eight firms are wholly-owned subsidiaries of foreign companies, suggesting that much of the benefits of excellence at the R&D stage will accrue abroad.

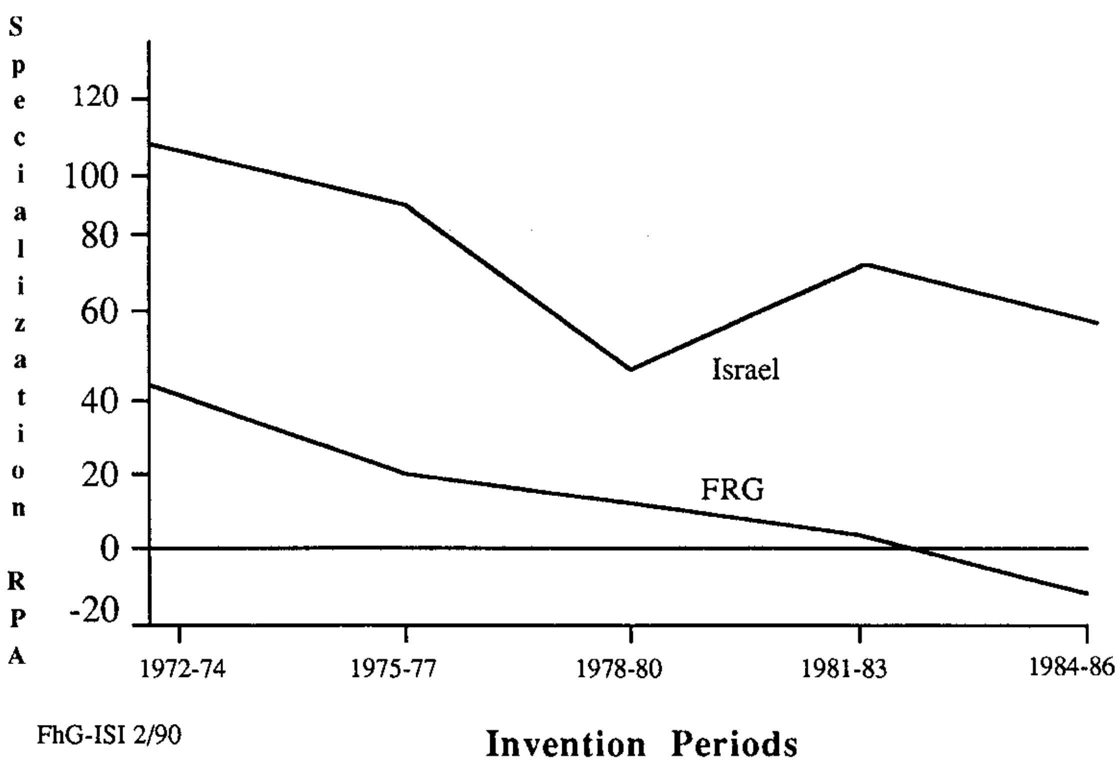
Moreover, Israel's industrial and R&D policy has been slow to implement many of the Katzir Committee recommendations and support biotechnology, and biodiagnostics in particular, as a promising area of excellence. It is estimated that about 80 per cent of budget of the Ministry of Industry's Chief Scientist goes to R&D in electronics, an industry facing ever fiercer competition from newly industrializing countries in the Far East, in particular. The Chief Scientist professes to pursue a "neutral" policy, which examines applications for funds on their merits, rather than initiate or encourage applications in selected areas. Given the predominant weight of Israel's electronics industry, this policy of "neutrality" explicitly favors existing industries like electronics over fledgling industries like biogenetics. As a result, Israel's comparative advantage in biotechnology is not being fully exploited.

Evidence of the decline in interest in the general area of "drugs and medicines" in Israel is given in an interesting chart produced by FhG-ISI. (See Figure 8). This diagram shows the Relative Patent Intensity (RPA) for Israel and Germany, for drugs and medicine. RPA reflects the number of patents in products related to drugs and medicines, compared to the overall number of patents for all products and processes; zero would indicate that patenting intensity for drugs and medicine is the same as for other products. The falling curve since 1972-4, with a brief upturn in 1981-83, suggests that less R&D effort is being expended in this area in Israel (though relatively more than in Germany, where RPA has also been in decline), despite its promise as an export market.

Another reason for the failure of government ministries to support this area is that biodiagnostic companies are small, and the current size of their export sales is also relatively small. Ministries prefer dealing with large companies. Thus, the field of biotechnology is a particular case of a more general problem in Israel -- severe constraints facing nearly all high-tech startups as they make the difficult transition from successful R& D projects to producing, marketing and distributing products and processes in distant markets. There is a danger that Israeli expertise in this area will be recognized by foreign firms than by , who will then purchase it, causing the employment, exports and profits to accrue outside of Israel.

Figure 8.

Figure 8. **Relative Patent Advantage, Drugs and Medicines, Germany and Israel, 1972-4 to 1984-86**



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IV. Further Applications of Technometrics

Our ongoing research on the technometric approach focuses in part on developing it as a quantitative tool for both public policy and managerial decisions.

Linear Programming:

The quantitative nature of the FhG-ISI indexes can be exploited by placing them in the context of a linear programming model. This model uses as outputs *total exports*, and as inputs: *technometric quality; current patenting activity* (in a recent period); and *cumulative patent activity* for all periods. A version of linear programming known as data envelopment analysis is used, which can incorporate qualitative as well as quantitative variables, and which measures "Farrell efficiency" -- the degree of efficiency for a given firm or country in producing a unit of output, compared to other firms or countries. (Charnes, Cooper and Rhodes, 1978, 1981; Sherman, 1984).

For illustrative purposes, the photovoltaic cell industry is used. Two technologies are examined: cells based on crystalline silicon (an older type), and on amorphous silicon (a newer technology). Efficiency in Japan, Germany and the U.S. in generating exports, as a function of technological quality and patent activity, is computed using the model and compared.

What emerges from this study's preliminary results is the following: the Japanese are relatively more efficient at converting technological excellence into experts than the U.S. and to some extent Germany. Moreover, by intense patent activity in new fields (like amorphous silicon photovoltaic cells), they are able to neutralize U.S. and German headstarts in traditional crystalline silicon cells.

Diffusion and Diversity:

A 1982 data set containing technometric attributes for some 42 different products and processes, for Japan, Germany, United States and in some cases other countries, made possible a study of the empirical relation between the level of technological specifications and their variance across firms, for high-tech products and processes. We used these data to attempt to answer the following question:

What is the empirical relation between technological excellence, as measured by the technometric index K^*, for a given country, and the variance of K^* across different firms, for that country?

Our finding is that products characterized by a high value of K* have a *smaller* degree of variance in K* among firms in the industry. This is consistent with a technology-diffusion process, in which new products come to the market with state-of-the-art technology; as the product matures, some firms update and improve their technology, while other companies fail to do so. Contrary to our expectation, Japanese products are characterized by a high degree of technological diversity, as measured by the relatively large range of K* values for most products.

Technometrics as a Managerial Tool: Case Studies for Israel

Two case studies were conducted on high-tech products in Israel, using the technometric approach.

1. A Technometric Study of Electromagnetic Compatibility Labs (EMC)

Several competing laboratories for evaluating electro-magnetic compatibility (the ability or inability to operate several types of electronic equipment, without emissions from one of them interfering with the operation of the others) were evaluated and compared, by constructing a technometric index for each. The study served as a basis for analyzing the competitiveness of one company's facilities compared to competing ones available in the market. (See Figure 9).

2. A Technometric Study of a Hydrogen-based Air Conditioning System for Buses

Generally, construction of technometric quality indexes requires existence of a marketable product on the market or about to be marketed. . However, in principle, the approach can be used to evaluate the marketability of a *prototype* or working model. This study examined a new product under development, under the auspices of the Technion R&D Institute -- a non-freon hydrogen-based air conditioning system for trucks and buses. The technometric index for the product showed graphically its superiority over conventional freon-based products, and proved useful for measuring and portraying these advantages as part of a business plan. (See Figure 10).

Figure 9

Technometric Comparison of Electromagnetic Compatibility Testing Labs

Specifications: I. Physical Characteristics: A. Size. 1. Volume. 2. one-room or two-room. 3. number of cells. B. Performance. 4. cell analysis. 5. internal echo. 6. broadcast power. 7. frequency range. C. Reception. 8. spectrum. 9. sensitivity. 10. frequency range. D. Auxiliary equipment: 11. computerization. 12. computerization of broadcast. 13. computer printout. 14. TV portrayal. II. Lab Services: A. Kinds of Tests. 15. military standard MIL-461; 16. civilian standard FCC: 17. civilian standard VDE; 18. waiting time. 19. waiting time for test. 20. production of final report. III. Reliability . 21. preliminary consultation. 22. consultation during test. 23. reliability of results. IV. Efficiency 24. maintenance time. 25. exploitation of cell. V. Cost. 26. price per test day. 27. price per consultation hour.

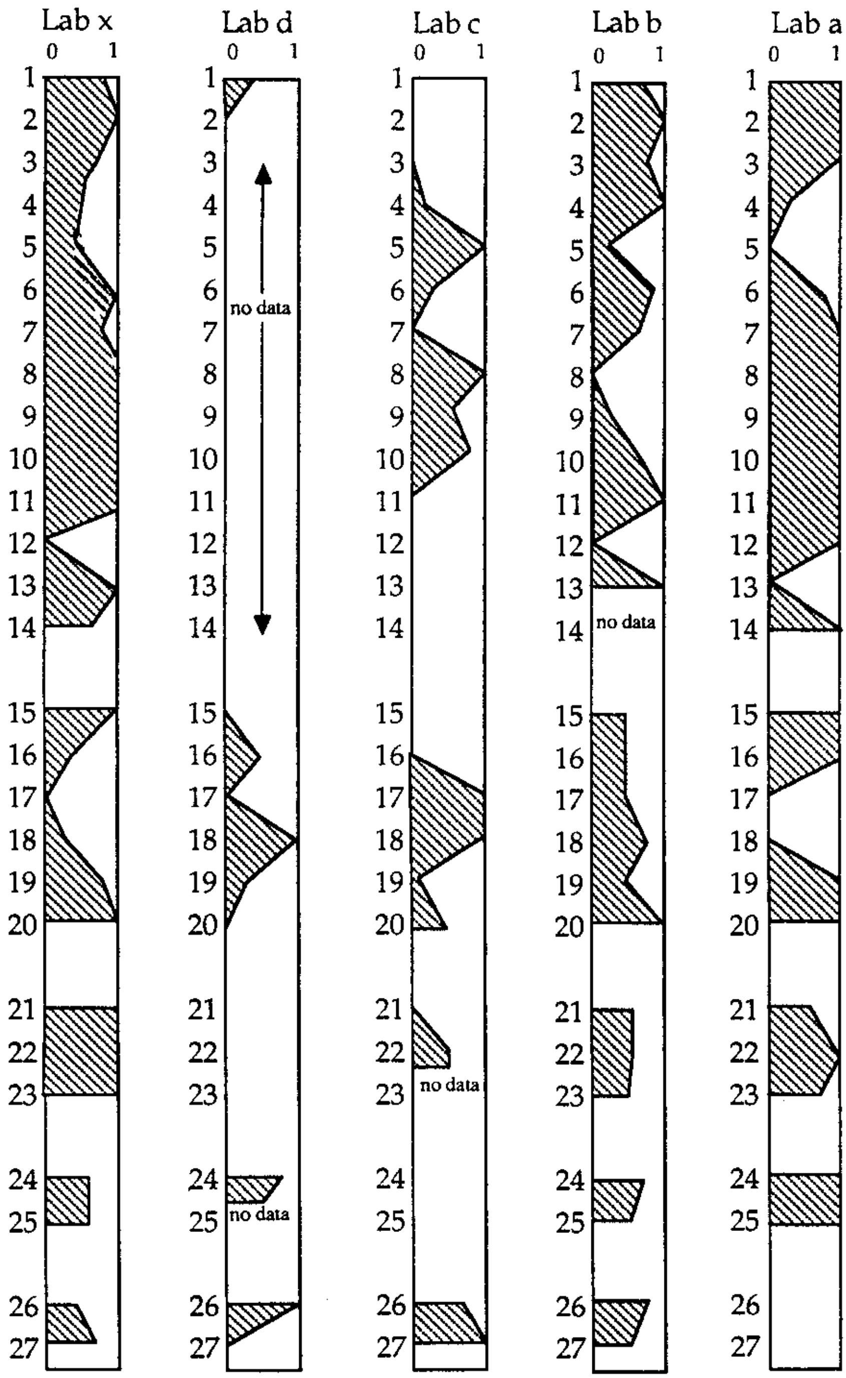
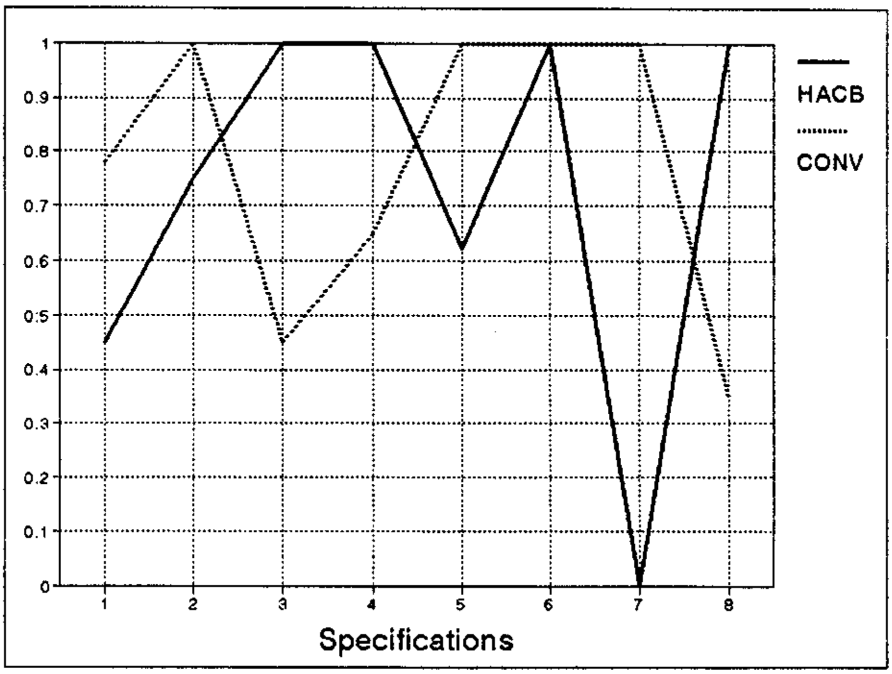


Figure 10

Technometric Profile of Non-Freon based Hydrogen Air Conditioner for Buses (HACB) In Comparison with Best Conventional Freon-Based Product

Specifications: 1. weight of air conditioner. 2. external dimensions of upper unit. 3. additional fuel consumption due to air conditioner. 4. additional horsepower demanded of motor. 5. cooling capacity at 43 degree exterior temperature. 6. temperature differential due to conditioner. 7. lifetime. 8. quantity of freon.



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WORKSHOP ON:

TECHNOLOGY INNOVATION PROCESS:

DOES ISRAEL HAVE COMPETITIVE ADVANTAGE IN KNOWLEDGE-BASED PRODUCTS?

Summary of joint research findings

Seminar, held at the Technion , April 15, 1993

Hariolf Grupp*   Amnon Frenkel**   Shlomo Maital**

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Introduction

Professor Daniel Weihs:

This study -- a technometric study of comparative advantage in selected high-technology industries in Israel-- was funded by the German-Israel Foundation. Its director, Dr. Amnon Barak, will attend this symposium.

This project is a good example of the kind of research that the GIF can and should support. It resulted in a fruitful, direct contact between two working groups and hopefully, as far as I understand from the researchers, may ultimately generate as many as ten published papers.

Professor Shlomo Maital:

Our lecturer today is Dr. Hariolf L. Grupp. His topic is: *From Basic Research to Knowledge Based Exports: An Integrated System of Quantitative Indicators for the Technological Innovation Process.*

Dr. Grupp is not a stranger to Israel. He was a student trainee here as a Physics student from Germany. He came here to work with Professor Zeev Levi at the Hebrew University in 1971. Dr. Grupp got his Ph.D. in Solid State Physics from Heidelberg University, served for two years as an assistant professor in Heidelberg, and then for four years was a senior researcher at the Bundestag, the Parliament of West Germany, in the office of Technology Assessment.

In 1985 he joined Fraunhofer-Institute for Systems Analysis in Karlsruhe. Fraunhofer, as you know, is a chain of independent Research and Development institutes or laboratories. Dr. Grupp's branch, in Karlsruhe, does evaluative research and Dr. Grupp is head of the technological change group. He is also the vice-chairman of the scientific council of all 49 Fraunhofer labs.

Dr. Grupp tells me that as vice-chairman of this scientific council, he has learned a great deal about the process of technological change and ongoing trends in this area. We are very pleased to have Dr. Grupp as the guest of the S. Neaman Institute for Advanced Studies in Science & Technology.

From Basic Research to Knowledge-Based Exports: An Integrated System of Quantitative Indicators for the Technological Innovation Process

Dr. Hariolf Grupp

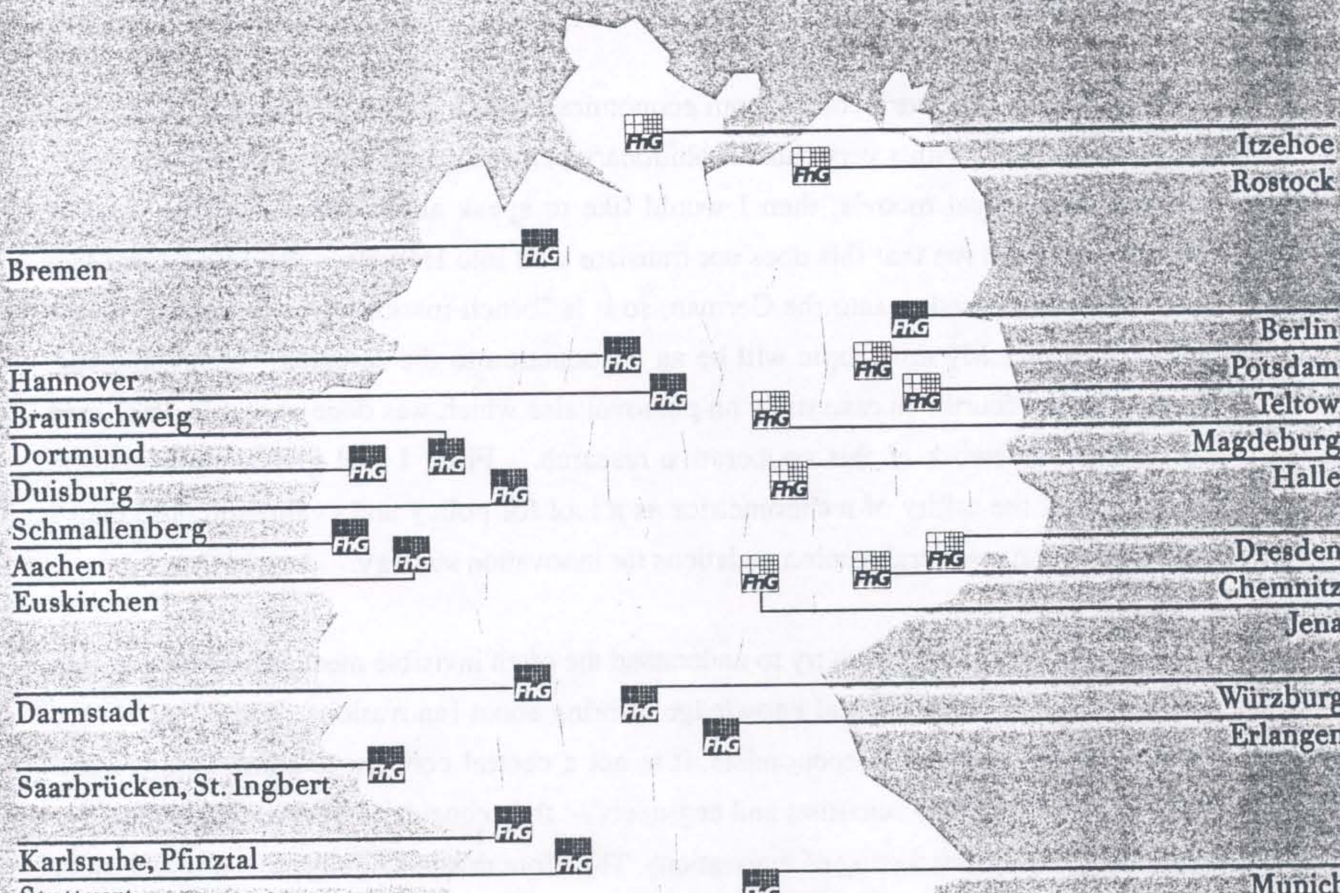
Thank you very much, ladies and gentlemen, for this very warm welcome. It is really my pleasure to speak today at the Technion after several years of joint work and I would like to thank cordially the Neaman Institute, in particular the director, Professor Weihs, for the invitation to speak here today. I also say this on behalf of my colleague, Knut Koschatzky, who participated in this project but was unfortunately unable to attend the workshop this week.

In this symposium, we will devote the next few hours to discussing the results of our joint research with Shlomo Maital and Amnon Frenkel of the Technion. As has already been indicated by Prof. Weihs, the original proposal submitted to the German-Israeli Foundation was drafted by myself and by Prof. Zehev Tadmor, who was then Director of the S. Neaman Institute, and although he is absent and very busy, I would like to thank him as well for stimulating this research. It was a great help that in both countries, Israel and Germany, there was keen interest from the very beginning of this project. But in order to bring it to fruition, one has to have people actively working in each country. I would like to thank all those who were involved in the preparation and in the research itself.

Now I would like provide a introduction describing our methodology. In order to convince you about the usefulness of technometrics, I would like to give you an example -- an historic case. In fact it is not very "historic" -- it related to the year 1987 -- and for this example I can show you what the economic impact of innovation was, from 1987 until now.

Before I start I would like to give you my "coordinates". This is a map of the unified Germany, together with the old borders. You can see that Fraunhofer is a research organization for applied research, private, and non-profit, which is decentralized.

Locations of Fraunhofer-Gesellschaft



Its headquarters are in Munich and there are branches in many cities all around the Germany, dedicated to special fields of applied science and engineering. In the past two years, we have taken over several institutes from the former Academy of Sciences of the German Democratic Republic. My own institute is close to the border with France.

We are very much oriented towards European projects; the share of our collaboration with non-German partners is increasing, and already amounts to about 30% of our work, with only 70% focused solely on Germany. The cooperation with an Israeli institution is always something special and therefore I very much enjoyed and appreciated this cooperation from the very beginning.

The baseline of our work comes from economics, from innovation research, therefore I would like to start with a very short evolutionary perspective on innovation, how it comes about in theoretical models, then I would like to speak about bench-marking, and as Shlomo informed me that this does not translate well into Hebrew, I can also assure you that it does not translate into the German, so it is "bench-marking", in German, Hebrew and in English. My third topic will be an introduction to the so-called "technometrics" approach, and fourth, a case study on photovoltaics which was done earlier in 1987, and not in the framework of this cooperative research. Fifth, I will give you an historic evaluation of the utility of technometrics as a tool for policy and evaluation, and then I conclude with our general recommendations for innovation strategy.

What we do, principally, is to try to understand the often invisible mechanisms for creation or acquisition of technological knowledge to bring about innovations. While this is very much a central concern to economists, it is not a central concern to administrators and managers, nor to many scientists and engineers -- they consider others as responsible for innovation and the marketing of innovations. Therefore this is a non-typical research field lying somewhere inbetween several disciplines. Now, we all know that core disciplines develop faster than side-disciplines and this applies here, to our project as well. It is always very difficult to say to which faculty or part of the sciences it belongs to.

In very general terms -- and here everybody agrees -- *technological innovation is problem solving*. It is nothing special -- you have a problem and you have to solve it. Companies do the innovation. Of course there are other institutions to support it, but without companies, without the intention to achieve revenues or sales or turnover, innovation will not be occur, simply for its own sake.

This is different from other fields of research, which are done for reasons of curiosity or for medical care, or for defence, to have a safer world. Innovation is done for company revenues. Without companies, it is impossible.

So companies pursue innovative activities -- but we know relatively little of what goes on inside companies. Because of competition and rivalry between companies, researchers often cannot learn very much of what is going on inside of companies. So we are dealing with processes which are not as easy to study as processes in the public realm. The private world is private and therefore the right to keep important information confidential is widely accepted.

Statistics collected and published by governments are generally anonymous, in that they do not permit attribution to individual firms. They are aggregated by branches of the industry but not by single companies; whenever fewer than three companies fill one element of the statistics, then the data are not published, so that one cannot attribute them to one company. So we are dealing with a special research problem -- difficulties in data access.

Companies pursuing innovative activities are strongly selective. They do not try to do everything, in all fields. Some innovations come from new companies. But mainly, they come from the really effective companies with good productivity -- input to output relation -- that accumulate knowledge, already have products and revenues and they try to improve them, introduce new ones and so on. So innovation occurs in cumulative steps.

How does one define "innovation?" I will stick to the definition of the OECD, the 24-member Organization for Economic Cooperation and Development, which says innovation is a certain type of research and development activity which results in a product that is introduced on the market. We have invention, we have discovery in research, this is very important. But only if an invention is introduced on the market, we do speak of innovation.

What comes before that are innovative activities, but innovation essentially requires that a product is introduced on markets for the first time. For some companies, their innovation is really imitation, because their product already existed, they put green instead of blue color on it, and that is fine, but it is not innovation in our terms.

I know that business people say that innovation is what is new to us, to my company, I don't care what is going on in American and Japan, when it is new for us it is innovation. We have to live with these different uses of the word, but the OECD says innovation is R & D processes which lead to the first introduction of new products, services, and processes, in international markets.

What we have to study is not just the appearance of innovation on the market, but how the production of new products occurs. The question that is most interesting to researchers is, how do innovations come about? How do companies manage to get the relevant knowledge, and is it from internal or external sources, or maybe from university sources, in order to bring about an innovation. The problem is well known. But analytic instruments to study it are not so widespread.

I would like to read a sentence from a publication of 1962. There an American economist wrote: "The production of knowledge is an economic activity." In 1962 people said, that is not right. The production of knowledge is indeed an economic activity, an industry if you like, but economists have largely neglected to analyze the production of knowledge. In mainstream economics, capital and labor are most important and what you cannot explain with labor and capital, you may explain, as a residual, as the influence of technology. As a result, economists never put the question of technology at the center of their interest.

After that introduction, I begin my presentation by describing what we wanted to accomplish in this project --to illuminate this process of knowledge generation and its conversion into innovative products. And above all we wanted to *measure* this process. That is our starting point. We are modeling, in a very simple and quantitative way, the innovative process.

There is theory and model development, mostly in universities. This is very important, but not every theory and not every model leads to an innovative product. Some of them are of such a nature that they can be realized in technological artifacts and prototypes. Some cannot. This is neither good nor bad, just a matter of fact.

Some of the technically realized effects are suitable for industrial development but not everything which is possible is suitable for industrial development. For instance, it may be too expensive, too dangerous, and so on. Among those items susceptible of industrial development, some are realized on the market -- this is innovation in the strict sense, and other companies then try to imitate, it which is a very difficult task. But a follower should not be regarded as an innovator.

Utilization is a very important part of innovation. some problems are created by utilization. To cite one example -- waste disposal. Sometimes only when you think of how to get rid of products, do you ask new questions for research, such as recycling, how can you recycle cans and so on. Utilization as a source for innovative activities is very important and is of growing importance.

What is written in scientific papers is mostly oriented towards more basic work. A company planning to introduce a new product will not disclose it in a scientific paper. There are of course patent applications, sometimes basic ones, but often more applied knowledge is protected as intellectual property through secrecy. Certainly imitation is impossible to protect by patents because when something is already known, any further patent application will be rejected by the patent offices. At the end of the process, there is diffusion of knowledge.

In studying innovation, we found that a key, vital piece of information is missing, between data on scientific papers, citations and patents, and economic statistics from statistical offices on exports and output -- information which throws some light on the direct outcome of innovation. Therefore we started in the mid-'80s to develop the technometrics method in order to get some information directly on the outcome of the innovation process before it wends its way through the economic system and finds expression in the marketplace.

The data on inputs in innovation are far better known than data on outputs-- statistics on persons, on money, on technical consultants, on expenses for know-how fees, royalties and so on, on investment. All these are input figures. They are good but not good enough, because in statistics they are anonymous, you cannot attribute them to a specific company, so therefore these input data are important but do not tell you what is the *result* of innovation but only what resources were invested in it.

This is not intended to mean that innovation works like a pipe-line, outputs flowing from inputs. That is not the intention. The intention is to say, if we want to create understanding about what is going on, we need certain tools for observation, for monitoring, and the tools should throw light on selective parts of the whole process. Technometrics is such a tool.

The Case of Photovoltaic Cells:

Let us take the case of photovoltaic cells -- cells that convert solar energy into electricity -- in order to explain technometrics.

First of all, we have to outline what types of innovations occurred in the last 10 years. Here I must say that there are many technological solutions and only a few of them are realized. These are called dominant configurations, or some say, trajectories. In photovoltaics there is a lot of laboratory work going on, and many ideas and discoveries and inventions. But in the market-place only three principal types of products have appeared as of now. They are, first, cells based on mono-crystalline silicon, very durable but quite expensive to produce. It is a wasteful product. You have to cut a lot of silicone and this is wasteful and expensive.

The second of the three principal solutions to the problem is poly-crystalline modules, with high durability, somewhat cheaper, somewhat less wasteful. Then, third, there are the amorphous silicone modules. There are a lot of other materials -- thin films for instance -- but they are not successful in mass applications, they are less durable, and the material degrades after some years of use. These are the three principle technological solutions to the problem of how to generate electricity from solar energy.

The case of photovoltaics (solar cells)

Distorted markets while governments intervene by subsidies.
Societal interest since oil price adjustments 1973.

Three remaining technological trajectories:

Mono-crystalline modules (space).

Poly-crystal modules (high durability).

Amorphous modules (thin films; mass applications).

Eight important features (measuring units):

Peak power (W)

Power variety (W)

Voltage (standard conditions; V)

Voltage stability (Uoc Isc/P)

Area-specific power (cm cm/W)

Weight-specific power (kg/W)

Life time (warranty time; a)

Production technology (DM/W)

Table I: **World's Photovoltaic module production by dominant design configuration (in percent)**

	Monocrystal	Polycrystal	Amorphous	Others
1983	50.2	14.3	14.3	21.2
1988	37.2	22.4	39.5	0.9
1989	42.5	25.5	31.1	0.9
1990	35.3	32.9	31.6	0.2
1991	35.6	37.8	24.9	1.7
1992	37.1	34.9	25.6	2.4
Breakdown 1990:	100	100	100	100
USA	43.9	35.3	14.3	100
Europe	18.9	38.6	8.2	0
Japan	15.2	22.9	73.5	0
Other than triad	22.0	3.2	4.0	0

There are many more feasible solutions to the problem, but on the market we have just these three basic ones. Table 1 shows world production of photovoltaic cells, according to the three principle types. First came the monocrystalline silicone. That was the early market. The polycrystalline modules came later. The amorphous materials for mass application of consumer products, pocket calculators and in watches and so on, came even later, had a very strong increase, but now the problem is diminishing consumer markets, there are fewer products sold, so this type of phovoltaic cell its going down in terms of its share. And what is very interesting, the companies in the principal countries have different strengths. All companies in the world can draw from on the same science and technology , but although they can, there is obviously something like a national system or tendency --in the United States, the most important share of photovoltaic cells is the mono-crystalline type now, Europeans are in the poly-crystalline field and the Japanese did most of the production in the amorphous technology.

This is somewhat astonishing -- the distribution of principal solutions of companies in different parts of the world is very different. So the selection processes of the companies, what to market, apparently function very differently. Among many technologically feasible solutions, only a very few come to the market.

These data refer to production, not to exports. For exports there are no precise export figures because of original equipment manufacturing. Some of the photovoltaic cells produced are then exported as part of other equipment, so there are no good data. But in principal we have no indication that the export shares depart from the production figures. The Japanese export their photovoltaic products as part of their pocket calculators and watches and the customs officials say: that is a watch, that is not a solar cell, and then you have lost the track of it. By the way, this is measured in mega-watts, not in dollars or yen because it is hard to know how to convert yen into dollars at an appropriate rate of exchange. So the unit for the percentage is megawatts of electricity to be produced.

Technometrics involves collecting detailed data on the principal specifications of those three types of solar cells. By consulting export experts in various countries, we were told that the most important specifications are: Peak Power, Power variety, Voltage, Voltage stability, Area-specific power, Weight-specific power, Lifetime, and Production technology. All can be measured quantitatively, in physical units.

There are more specifications than that but those are the relatively few specifications which matter for the customer. That is power, small for a watch, large for a central electricity producing station; the variety, how can you tune it or not; voltage conditions, you have different conditions for a watch than for a satellite; stability and so on. Then there are questions of weight and size when you want to mount the equipment.

So these are the most important specifications of these types of cells and the problem remains to collect data on the photovoltaic products. This is a time consuming task but not so difficult. The next problem is, how to compare the data. In economics we are used to quantities like dollars or labor hours but here we have watts, voltage, something like voltage under normal conditions, power, cm^2, kg and so on, and you can not compare them one to another. Fraction mathematics does not allow us to calculate any index from properties which are measured in different units.

Here the technometrics model comes in, this is not a metrics in a mathematical sense, but it is an n-tuple for the mathematicians. So one has to have a recipe in order to transform the original technical data into a metrics, in terms of mathematics, that we can calculate and compare. These are the details of the special technometrics used here which converts original data and physical units into zero-one intervals of data. In effect, without formula, the following happens. We have here, physical or technological specifications for many products, a distribution and a mean value. Some are above the mean, some are below. We cannot compare them as the units are difference. The technometrics converts them into a type of index, without units, normalized on a scale of zero to one.

TECHNOMETRIC MEASUREMENT CONCEPT

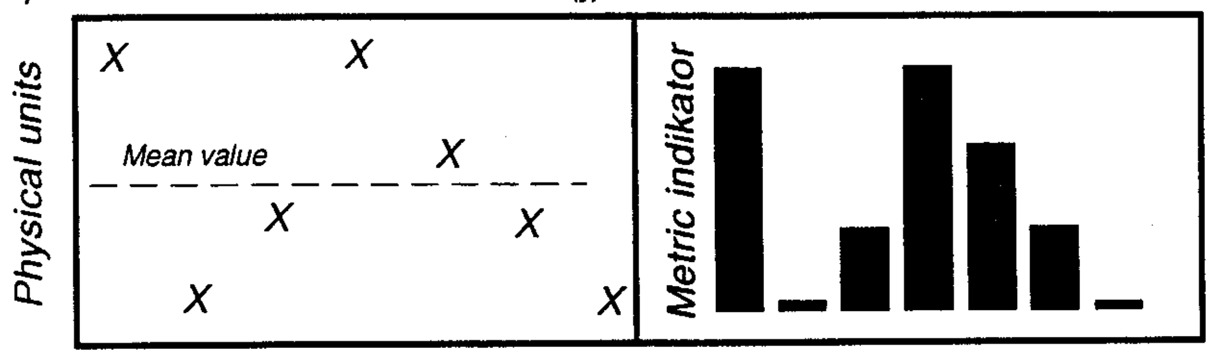
(Or: tacit judgements by indicator measurement)

Evolutionary principle: Derive norms for goodness from existing variety.
Avoid introduction of externally given norms (as for self-regulated systems).
Little variety (i.e., small variance in technical specifications) means stronger distinction in metric values.

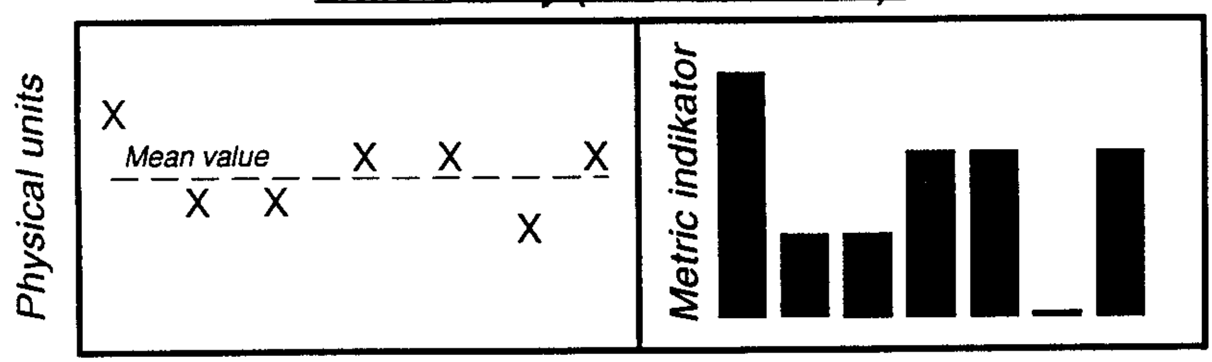
EXAMPLES

Standard case:

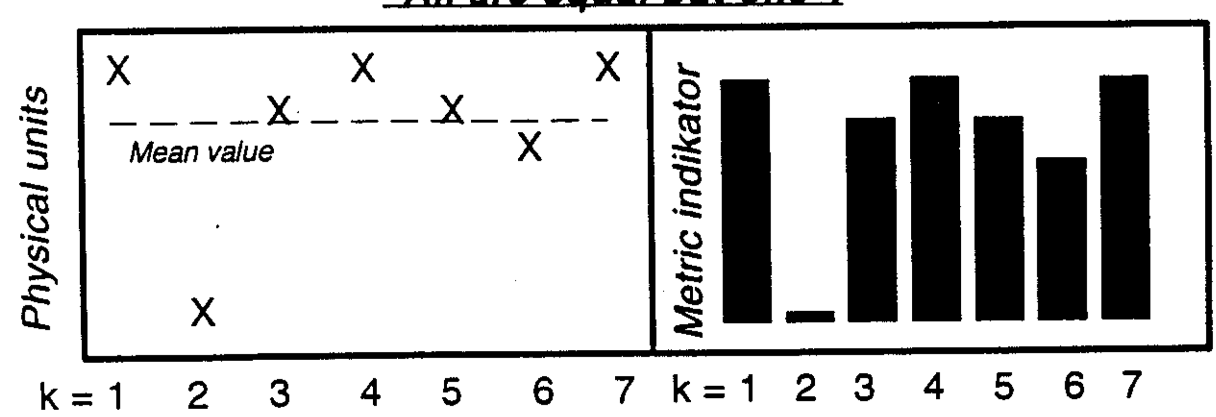
Specifications for characteristic (j):



Little variety (small variance):



"All are equal but one":



Question: As I understand it, you must have a variety of products in order to compare them.

Dr. Grupp: Yes.

Question: So these are all actually imitations ?

Dr. Grupp: If there is only one product developed, we cannot use the technometric index. We need several products that can be compared.

Question: So a product has to be in the market for several years.

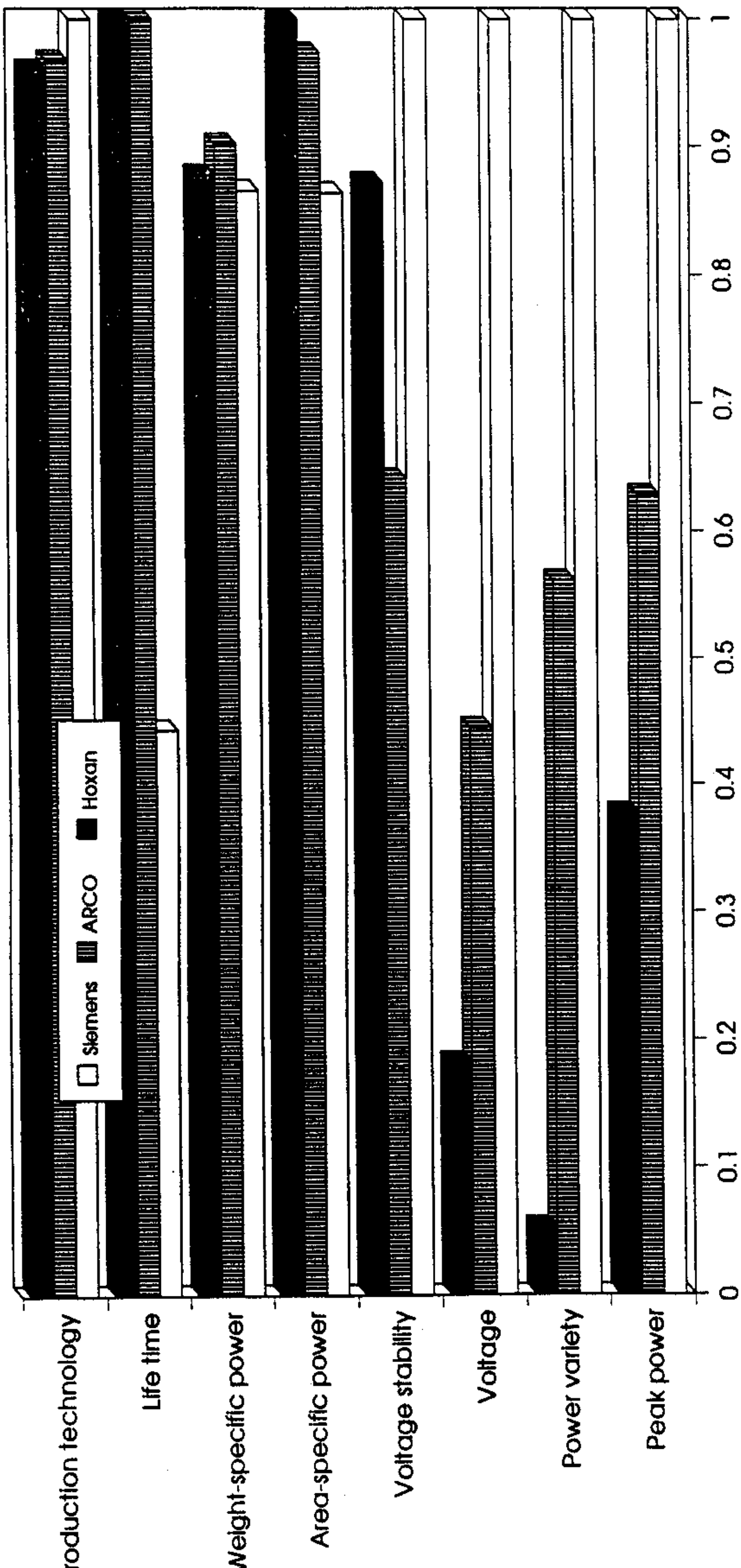
Dr. Grupp: In principal yes, but think of substitution. There already exists, for several years, an older product, and it performs all the customer wants to a sufficient degree. Then an innovation occurs. You can compare one innovation in all its aspects to the older, substituted technology. Therefore you can always measure one innovation in comparison to an earlier product used before for the same purpose.

The question, for any given technology, is whether the experts for this technology can define you a set of basic specifications which are sufficiently detailed to really define the new technology.

Question: If there is no existing product how can we check if the new product fits the new demand, when it is simply not in the same frame of reference?

Dr. Grupp: Yes. That is a basic consideration. Can we define such a set of specifications in order to compare the new product vs. the old one or is it impossible. If it is impossible, then I must say yes, the method fails.

This was an explanation with artificial data. Now let us take a a real case. We compared for the year 1987 photovoltaic solar cells based on mono-crystalline technology for three leading companies. Hoxan Company from Japan, Arco Solar from the United States and Siemens from Germany and what you see here in Figure 4 is this technometric index.


Siemens
ARCO
Hoxan
Production technology
Life time
Weight-specific power
Area-specific power
Voltage stability
Voltage
Power variety
Peak power
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

So the value "1" is world level specifications, and "0" is the lowest marketed specification -- this might have good reasons, it might be cheaper and so on. It is not bad, but just lower in sophistication and probably in price.

What we can learn from this technometric profile? First of all, the Siemens product is strong and is leading only in some specifications -- that is power, voltage, voltage stability and the variance, can you tune it. Here it is most sophisticated. The rival products are less sophisticated here, in these specifications, but on the other side, in electricity rate, life-time and so on, this Siemens product is less sophisticated and the others are leading. These are the facts. Now we have to explain them.

The explanation goes in the following direction. Siemens aimed its products at central grid electricity production because it was done by an affiliate of the company active in nuclear power and they wanted to offer, aside from nuclear products, also renewable products, so they aimed at central grid applications -- so here you have to have voltage stability and so on, while other specifications were not so important.

The other companies aimed at mobile stations for isolated houses and so on, where the stability and voltage factors are not so important, but failure, rate of output and life-time, if the site is remote, matter a lot. So because they aimed at different applications, their products were designed from the same technology with different emphasis.

The interesting question then shifts to markets -- *which are the more interesting and significant markets, which are the growing markets*? If the mobile electricity generator markets are more important than the other ones, how can a company with Siemens' specifications compete there?

The market information is available to everybody. But what we would like to fill in is information on the quality of the product and on this there is little objective, quantitative information. Our method addresses exactly this point. Later, I will come back and explain how this race between different types of photovoltaic cells was ultimately decided.

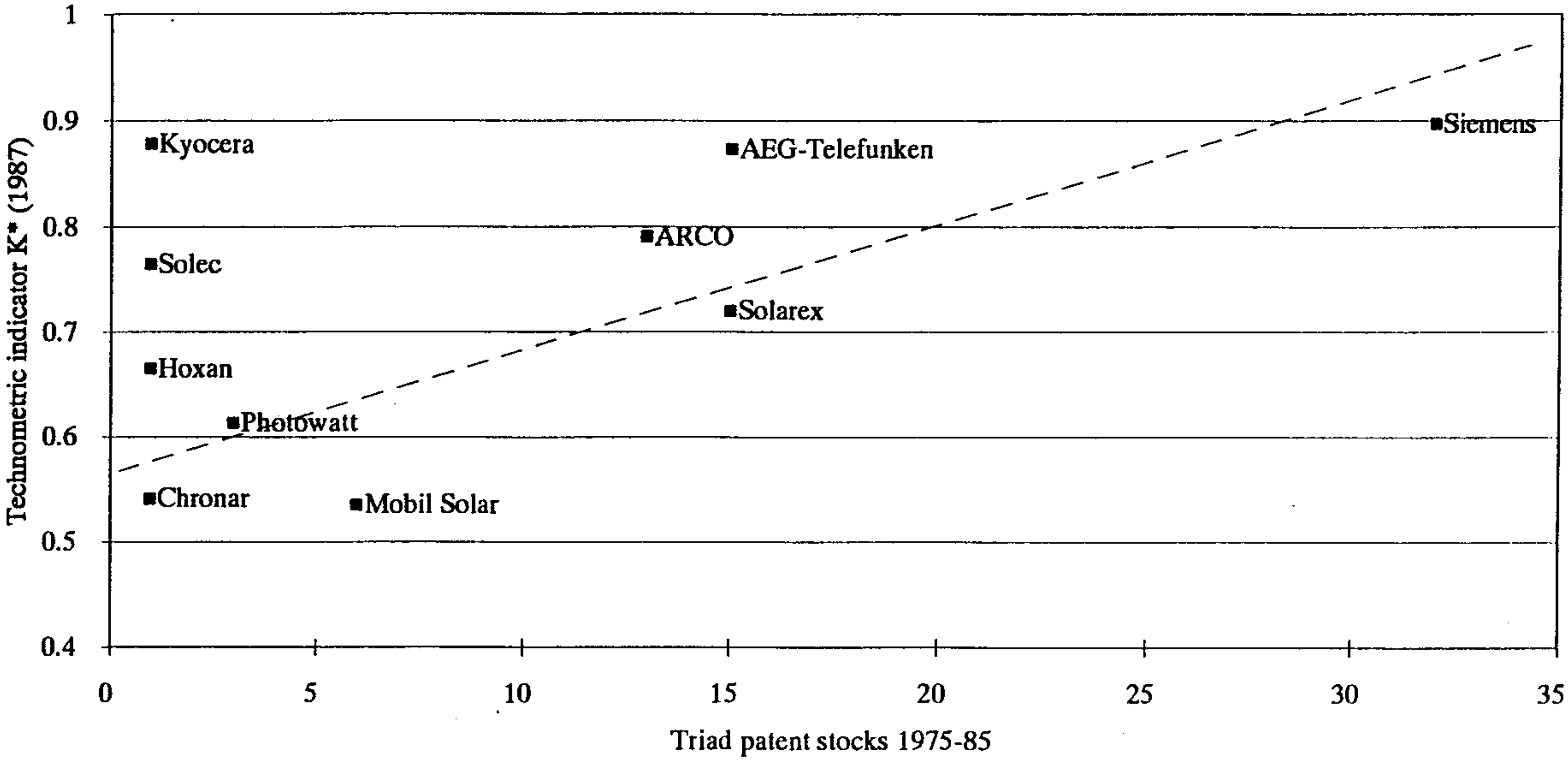
Question: These properties or specifications -- are they the result of innovation or not? I mean, you have a basic innovation of the multi-cell. Now these properties that you are talking about, can you define them in terms of some innovation within the area? Because then your distribution would make sense.

Dr. Grupp: Yes I can. First of all, you have the information that the products which were on the market in 1987 were introduced less than two years earlier, later than 1985, not at the beginning of the 1980s. Not all of those products are introduced in 1987, but all were introduced between 1985 and 1987.

We now come to the next piece of information which is information about inventions, via patents of those three companies. Patents are theoretical intellectual property, so when we look at the U.S. market, compared with the European market, you get different figures. That is normal -- that is, scientific publication is always world wide, you publish once, and it is forever.

Patents have to be duplicated because the legal validity is just for one market. So US and European rankings are different. But what is interesting, the companies listed here, that is the top five in each case, are different from the innovators. Now I take out my red pen and cross out some. First of all the leading US corporation, RCA -- a lot of inventions, a lot of work done, but the result does not appear on the market. Why? RCA as a company did not go for marketing its products, but its photovoltaic activities were taken over by Solarex; so acquired, the technology was marketed by this company.

Next, energy conversion devices. This company was strongly engaged in amorphous technology but the firm performed contract research for others, not for its own marketing: contract research for IBM, Arco Solar, which is not in here, but it was on the market, and even the Japanese Sharp Company, so own products were never marketed, the company did contract research for others.



Technometric indicator K* (1987)
1
0.9
0.8
0.7
0.6
0.5
0.4
Kyocera
Solec
Hoxan
Photowatt
Chronar
Mobil Solar
ARCO
AEG-Telefunken
Solarex
Siemens
0
5
10
15
20
25
30
35
Triad patent stocks 1975-85

Next is Exxon. Exxon intended to supplement its oil business by a solar business but then gave up and sold its technology inventory in its laboratories to Solarex, here, so Exxon is also gone. The US Government did not go for commercial products but was active in researching and developing the technologies. And I can go through the list for the Japanese and German companies. This is a chemical company for basic materials, not for solar products, they have a lot of technology but don't manufacture solar cells; this an affiliated company of Hertz, the same -- silicone substrate but no final products. Finally, AEG was taken over by NVB.

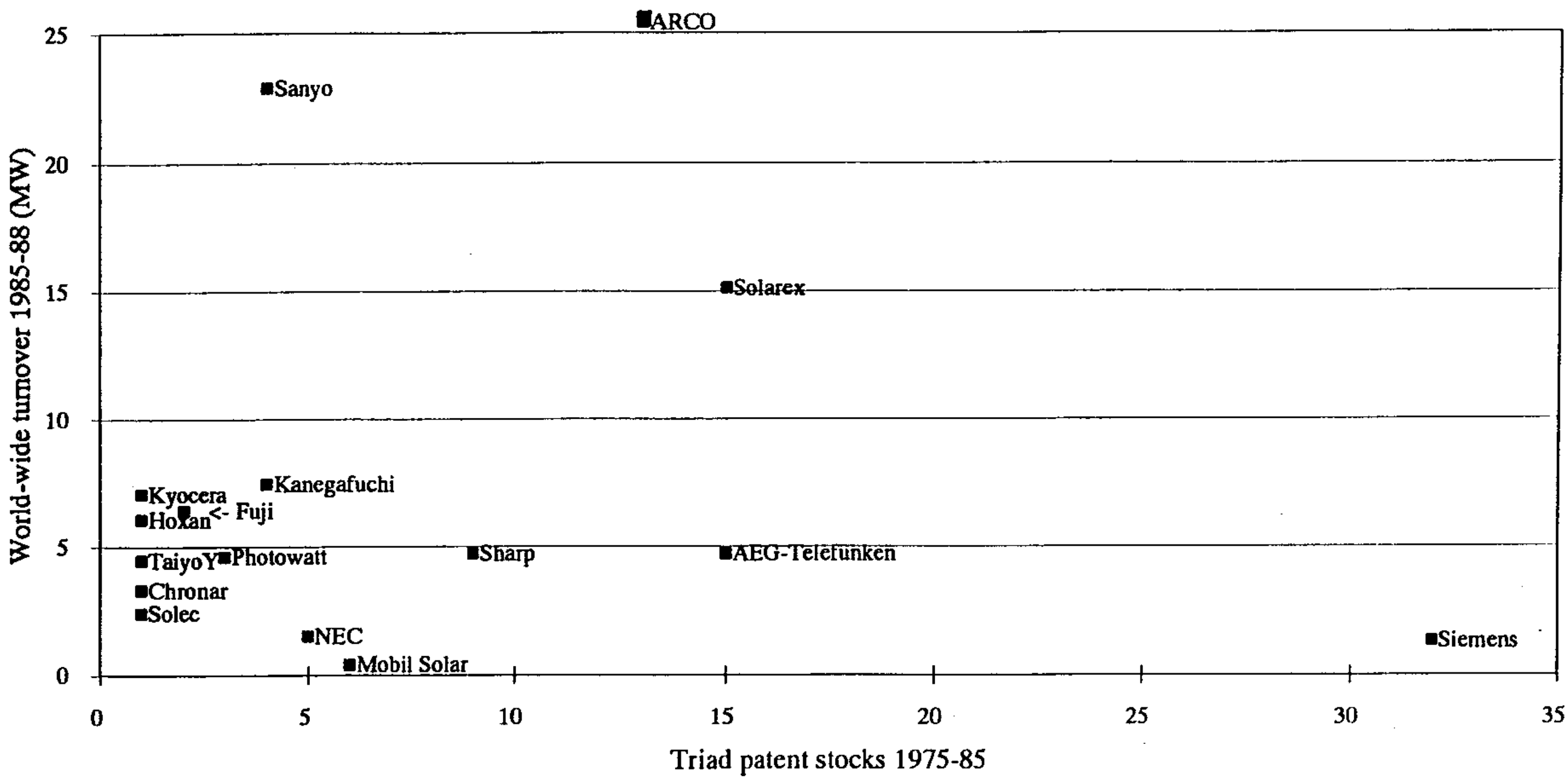
So the inventors of the technology and the company holding the trademark of the product are different. There always has to be a conversion of this type, a transfer from the one who holds the technology and generated the technology, to the one who markets it, this is innovation, not imitation, and by which means technology becomes effective in the markets.

Therefore, the information on products through technometrics and the information on inventions and scientific activities, which universities are active, are all important information, but they are not the same, they are complementary. Each piece of information contains a different part of the picture.

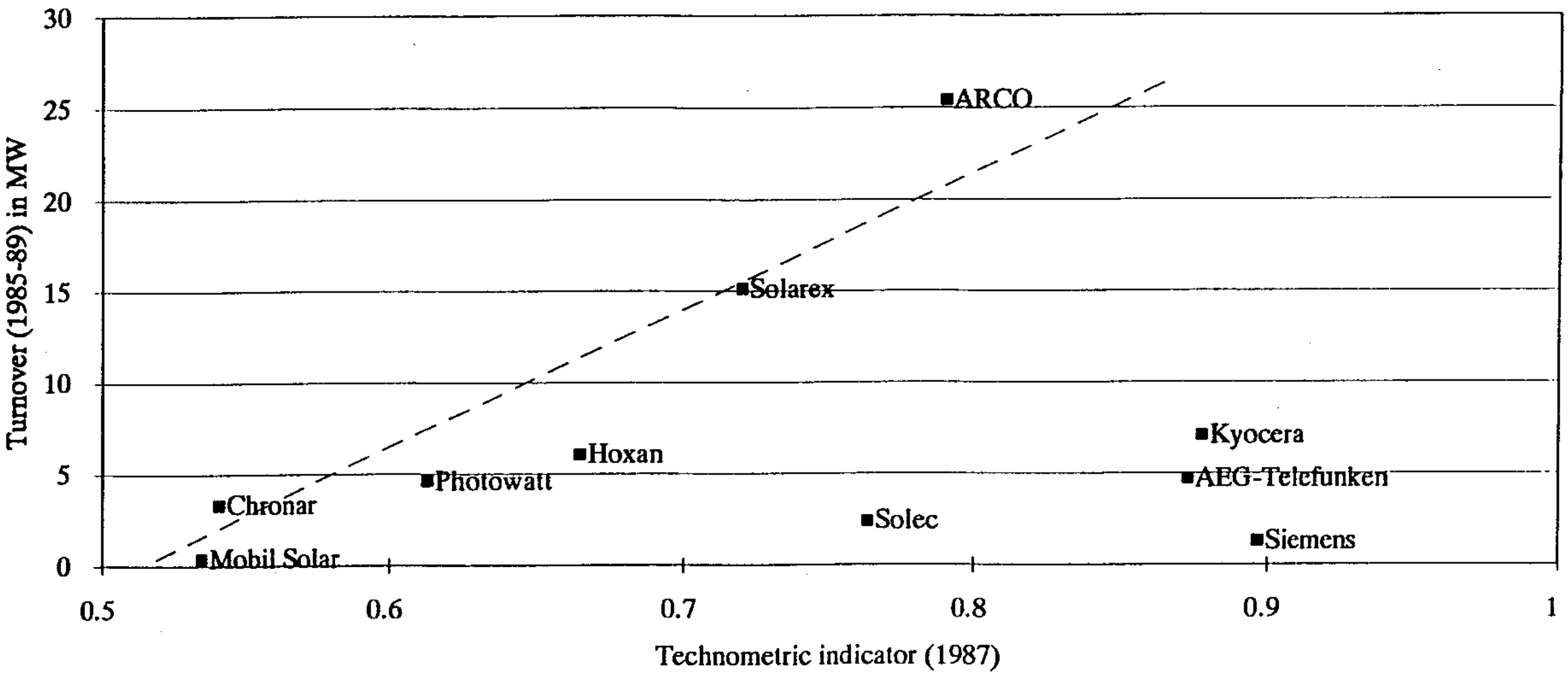
Now I come to the conclusion -- What happened to all of those companies? I will first show you a correlation which failed.

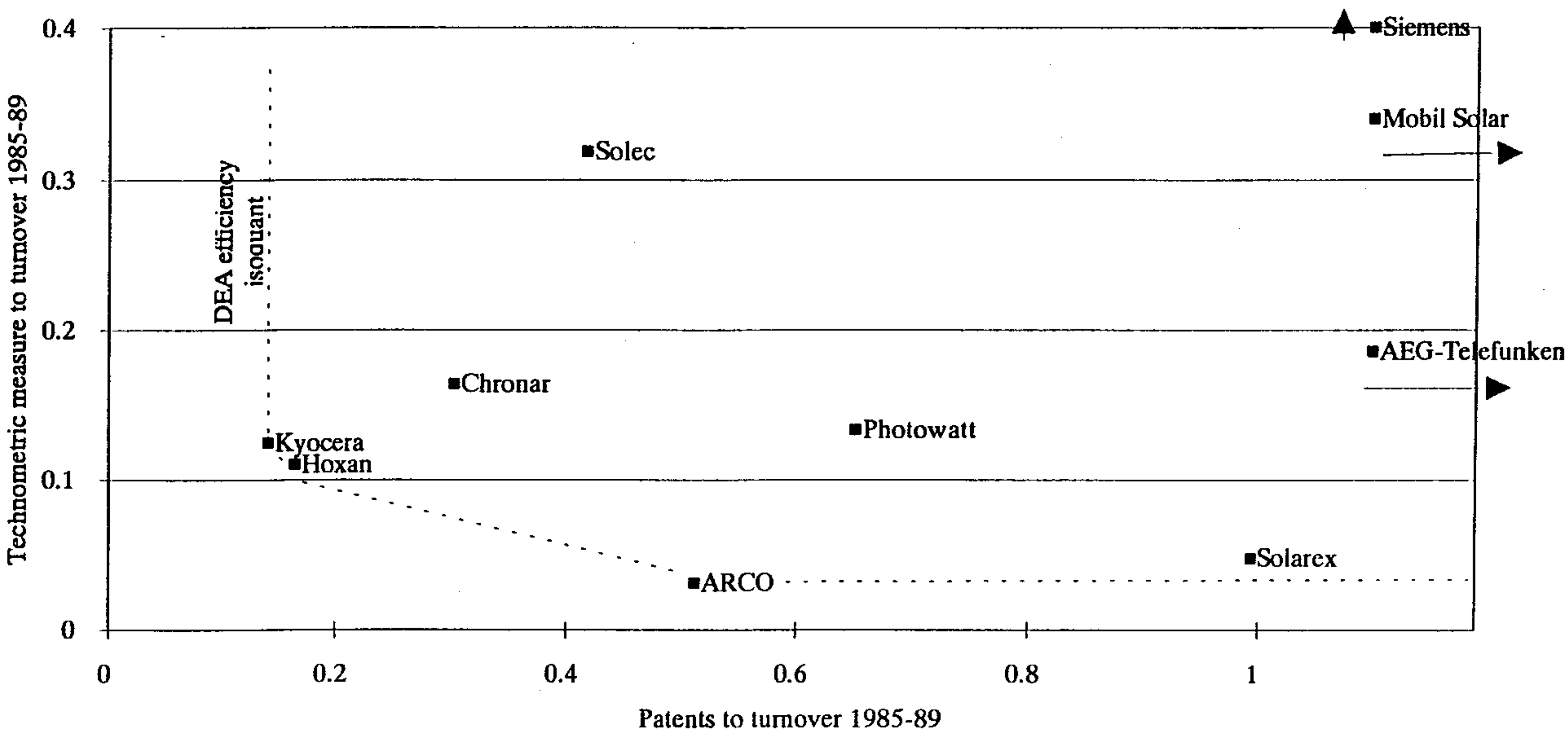
Here on the ordinate turnover the world wide turnover, 1985-1988, by those same three companies and here on the abscissa are their patents. The patents are in all of the trial countries. You see that this is the "Milky Way". There is nothing like a clear correlation, because some companies have patents but no products and others have products but patents from another side. So you get nothing like a simple correlation.

We expect however, that the technometrics data do give a real correlation, because there you have good products, good specifications, you should have pay-off from the markets. And indeed this was true for most of the companies. Here again is the turnover in '85, plotted against the technometric indicator value. The higher the index, the more sophisticated the product. For most of the companies there is a correlation between more sophisticated products and larger market shares. But then there are some cases which fall apart. This applies to AEG, Siemens, and Kyocera.



World-wide turnover 1985-88 (MW)
Triad patent stocks 1975-85
ARCO
Sanyo
Solarex
Kyocera
Kanegafuchi
Hoxan
<- Fuji
TaiyoY
Photowatt
Sharp
AEG-Telefunken
Chronar
Solec
NEC
Mobil Solar
Siemens


Turnover (1985-89) in MW
30
25
20
15
10
5
0
0.5
0.6
0.7
0.8
0.9
1
Technometric indicator (1987)
ARCO
Solarex
Kyocera
Hoxan
Photowatt
AEG-Telefunken
Chronar
Solec
Siemens
Mobil Solar


Technometric measure to turnover 1985-89
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
Patents to turnover 1985-89
DEA efficiency isoquant
Siemens
Mobil Solar
Solec
AEG-Telefunken
Chronar
Photowatt
Kyocera
Hoxan
Solarex
ARCO

Siemens was a company with excellent technology for central grid application, but unfortunately this market did not expand. Nobody wanted to have it. There were so many nuclear and coal plants in Germany and nobody wanted solar plants; lack of space was also played a part.

AEG-Telefunken company, now part of an aerospace company, was dedicating its product towards space application. That is the original space-solar company, even for the US satellites in their early phases, and it was successful there. But as compared to the terrestrial applications of photovoltaics this was just a dead end market. The number of satellites did not increase to the same amount as the number of pocket calculators. So that is good technology but the market did not increase to such a size.

Kyocera, a Japanese company, has excellent technology but not like other Japanese companies, not for the consumer markets, but for street lamps, which is also good technology, but also this part of the market did not expand to such an extent as the consumer market. So most of the Japanese were in the amorphous silicone technology, but in consumer products, while this company was different. They went for mono-crystalline products, for street lamps and so on, and safety calls and highways and so on, and this is a good business, but it is not as powerful, in terms of the past 5-6 years, as the others.

Question: Were your weights for the technometric indicators equal?

Dr. Grupp: Yes the weighting can be constant or specifications can be wighted differently according to priorities. We used equal weights.

Question: Equal weights, even for different products?

Dr. Grupp: Yes. Because I want to show that precisely this point matters. If you go for one market then another part of technology is more important than for another market. But for most of the companies it does not matter. For most of them which are not so specifically tuned to a market need, it is right that more sophisticated technology correlates positively with a larger share of the market, however you weight the specifications.

Question: How will this analysis change if you put in non-technological specifications, such as price, or kind of supply, availability, things like that. That might be a big influence.

Dr. Grupp: Lets say for those three companies, I speak now based on statistics, the variance is explained only by the technometrics specifications to such a large extent that there is little room for other explanations. You put in a dummy variable for the rest of non-technological factors and it is very small. Most of the problems companies had are explained by the technological factors.

Photovoltaics is perhaps a special market because of the government programs and the government interference in those markets; delivery times are not so important as in a very competitive market. But in this case I think technological factors and market size here are sufficient for the explanation, then there might be some third order effects also. You will hear of other examples today where the result is different.

So I would like to conclude from this analysis of an historic case: I tend to show that traditional information on markets combined with relatively new information on the sophistication level of products -- technometrics -- can provide some new pieces of information to explain phenomena which are difficult to explain otherwise.

Some people we talked with stated their opinions in a very general way. But when they are forced to provide data, quantitative information, things become clearer for both sides -- the expert talking about things and the researcher trying to understand things. Of course I will not deny that one can do a very intelligent study on what is going on in an industry, market or product, without any data. But it is much more difficult.

How can you assure that you mean the same thing, when you speak the same words. Whether the meaning of what you are saying is the same. So the compulsion to quantify makes information which may be acquired otherwise, more reliable, or at least it can be checked by others. When you speak to a company in terms of technometric or patent data, you can understand that company much better than if you use only words and elicit only opinions.

I do not want to say this is the solution to every problem, but this type of approach, based on data, looking for qualitative explanations, of course, makes understanding of innovation a bit easier or a bit more reliable. Some of this work is done for government, some is done for companies. For companies the advantage is that they can take action more precisely -- knowing precisely where a competitor is better in technology is good.

For a company it is important to have general information, of course, but "harder" quantitative information is easier to transfer into action, into operational measures. I do not want to say this is a method which beats everything else - that is not true. But we think that the quality of assessment in terms of more objectivity is more improved if you try to supplement your qualitative findings -- which are always important --by quantitative type of data.

This was just the introduction to our method, and the data were not part of our cooperative study. I wanted to start with an historic case that was easy to understand, and that served to explain the technometric methodology that was used in our joint research on Israeli products.

סדנא בנושא

תהליך החדשנות הטכנולוגית:
האם לישראל יש יתרון יחסי במוצרים עתירי מדע?

סיכום ממצאי מחקר משותף

הסמינר התקיים בטכניון בתאריך 15.4.1993

הריולף גרופ*   אמנון פרנקל**   שלמה מיטל**

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הקשר שבין מצוינות מדעית וטכנולוגית לבין יצוא מוצרים עתירי-ידע: ישראל בהשוואה לאירופה

פרופ' שלמה מי-טל
הטכניון

המשפט המסכם בהרצאתו של דר' גרוף, היה חשוב מאוד. הוא אמר שכאשר ניתן לזהות מדד טכנומטרי גבוה המעיד על איכותו הגבוהה של מוצר, ניתן לצפות בוודאות רבה לתוצאות כלכליות טובות שיתבטאו ביצוא, במכירות, בפדיון, בפלח שוק וכדומה. כעת אני רוצה להציג בפניכם, בקצרה, ממצאים מתוך מחקר שביצענו ואשר ממצאיו מטילים ספק במסקנה אשר הובעה, בהקשר של ישראל.

טענתי היא שיש לנו בארץ מצוינות טכנולוגית ומדעית. הצרה היא שמצוינות זו מובילה ליצוא של ידע ולא ליצוא של מוצרים ושרותים. על פי מימצאי המחקר שלנו, אנחנו בישראל, לא ממצים את היכולת הטכנולוגית הגבוהה, יכולת שעלתה בעקבות קליטת הון אנושי עצום מעולי ברית המועצות, וביחד נעלה כמה תהיות לגבי השאלה, מה ניתן או אפשר לעשות? ראשית אתאר בפניכם את המדדים בהם השתמשנו במחקר ואת מימצאיו, ולאחר מכן נדון בפתרונות אפשריים.

כפי שידוע לרובכם, שביל המדע אינו ישר, אלא מתפתל. במחקר שלנו, לא התכווננו לבדוק נושא זה, אך מאחר שד"ר גרוף הציג בפניכם את המערכת המשולבת של אינדיקטורים המכמתים את תהליך החדשנות, ומאחר והיו בידו נתונים כמעט לכל שלב ושלב של התהליך, חשבנו שיהיה זה מעניין לבחון את מצבה של ישראל בכל אחד מן השלבים. כלומר, לאבחן מהו מצבה של ישראל על בסיס מדדים אלה בהקשר של: מדע ומחקר בסיסי וישומי, המוצרים, החדשנות ולבסוף היצוא. בדיקה זו כאמור התאפשרה לאור קיומו של מידע כמותי אודות המדדים שנקבעו לכל אחד מן השלבים, עבור מדינות אירופה וגם ישראל.

הרעיון פשוט, ותכליתו היה לאפיין את תהליך החדשנות כתהליך דו-שלבי. בשלב ראשון מושקעים משאבים בתקציבי מחקר ופיתוח, הכוללים משאבי זמן, כוח אדם וכסף על מנת לייצר ידע. בשלב השני מושקע הידע על מנת להפכו למוצרים עתירי ידע לשם יצוא. הרעיון היה לבחון בשלב הראשון את מידת היעילות של הפקת הידע ומצוינות מדעית, כתוצאה מהשקעת משאבים במחקר ופיתוח. אם נניח ש-X מייצג את המדד באמצעותו אנו מודדים את כמות המשאבים המושקעים במחקר ופיתוח, ו-Y מייצג את את התפוקות הטכנולוגיות והמדעיות המושגות, הרי שאנו בוחנים את יעילות הפונקציה המובילה מתשומות המו"פ X, לתפוקות מדעיות Y :

$$Y = F(X)$$

בשלב השני, בחנו את מידת היעילות שבהפיכת המצוינות המדעית שהושגה בשלב א', למוצרים עתירי ידע לצורך יצוא. התשומה היא כעת - Y, כלומר מה שהיה תפוקה בשלב הקודם הופך להיות תשומה בשלב השני והתפוקה Z הוא יכולת היצוא.

$$Z = F(Y)$$

כך באמצעות הפשטת המודל הרב שלבי (שהוצג על ידי דר' גרופ בהרצאה הראשונה), למודל דו-שלבי, בדקנו באיזו מידה ישראל יעילה בהפקת ידע על בסיס השקעת משאבים, ובאיזו מידה אנחנו יעילים בתרגום הידע ליצוא. יכולת התאמת הנתונים עבור X, Y ו-Z, מאפשרת לבחון את רמת היעילות המושגת בשלב I ובשלב II במדגם של מדינות. ניתוח שכזה, מאפשר על כן להפריד בין מדינות המציגות יכולת ביצוע מרשימה של יצוא, לעומת כאלה בעלות יכולת נחותה ליצא בין שלב I לשלב II, וכפועל יוצא מניתוח זה, לעצב מדיניות לעידוד היצוא אשר תטפל בשורש הבעייה.

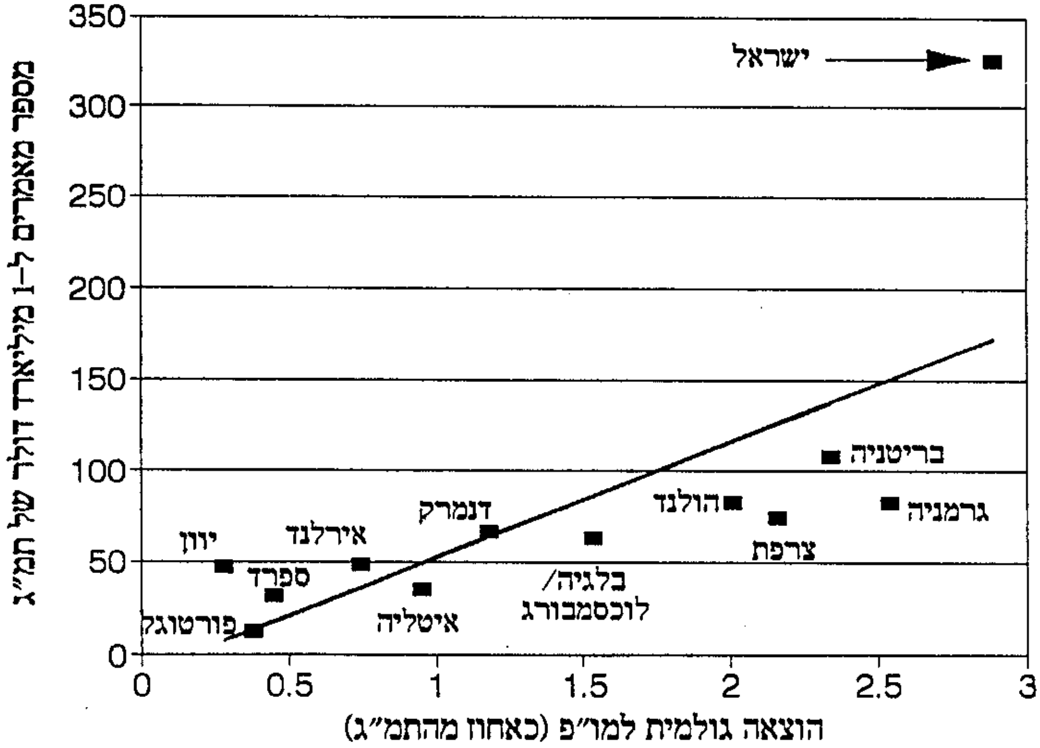
המסקנה שהגענו אליה, שבשלב ראשון אין לישראל מתחרות בין מדינות הקהיליה האירופאית שנכללו במחקר. אף אחת מהן אף לא מתקרבת לישראל מבחינת הפקת ידע, אם מדובר בכמות הפירסומים המדעיים, או מספר ציטוטים של הפירסומים, או אפילו בשלב רישום פטנטים. אולם, בשלב השני, היעילות שלנו נמוכה מאוד. מסקנה זו מחדדת את הקביעה של נושא ההרצאה הזאת שאנחנו מייצרים את הידע, אך לא מייצאים מוצרים על סמך ידע הזה.

כיצד בדקנו זאת. אם נחזור למודל השלבים שהוצג על ידי דר' גרופ, נראה כי שלבי תהליך החדשנות כוללים את השלבים הבאים: מחקר, מימוש המחקר בצורה טכנולוגית, פיתוח אב-טיפוס, עריכת חדשנות, פיתוח מוצר בשוק על סמך האב טיפוס, יצור, הפצת המוצרים ויצוא. כל שלב מוגדר על ידי אינדיקטור המאפשר מדידתו. בשלב המחקר מודדים את היקף המחקר על ידי מספר הפירסומים המדעים המופקים על ידי החוקרים בכל מדינה, ומספר הציטטות למאמרים אלה כאינדיקציה לרמתם המדעית. בהמשך מודדים את מספר הפטנטים הרשומים. איכות המוצרים נבדקת באמצעות השימוש במדד טכנומטרי (יוצג בהרצאה הבאה). השלב הבא הוא שלב היצוא ולשם כך פיתחנו מדד המצביע על יכולת היצוא. מן הראוי לציין כי לישראל הישג אדיר בתחום היצוא. היצוא התעשייתי בארץ הוא בהיקף של כ-12 מיליארד דולר לשנה. בהתחשב בסביבה העויינת בה מצוייה ישראל והקשיים האחרים שיש לנו, ניתן לראות בכך הישג גדול מאוד. חצי מהיצור הזה הוא יצוא עתיר ידע. לפיכך, כיצד ניתן לטעון שאנחנו לא יעילים בתחום זה? תשובה לכך תינתן בהמשך ההרצאה. נחזור כעת לממצאי הבדיקה שנעשתה באמצעות מודל של רגרסיה, לבחון אמפירית את הקשר שבין X ו-Y, וכן להשוות את היכולת האינדווידואלית של המדינות ביחס לקו מגמת הרגרסיה.

תוצאות השלב הראשון מוצגות באיור מס' 1. ציר ה-X מייצג את המשתנה הבלתי תלוי במודל הרגרסיה שהוא ההוצאה הגולמית על מחקר ופיתוח, אשר נמדדה כאחוז מהתוצר המקומי הגולמי בישראל וב-12 מדינות הקהילה האירופאית. ציר ה-Y מבטא את המשתנה התלוי במודל - מספר מאמרים שהתפרסמו בכתבי עת הנדסיים ומדעיים, כולל מדעי הטבע. נתון זה נלקח מתוך בסיס הנתונים של ISI בפילדלפיה, הבונה מסד נתונים ממוחשב מתוך סריקת העיתונות המקצועית בעולם, ומיון המאמרים שנכתבו ופורסמו על ידי חוקרים מהמדינות השונות. ברור שיש כאן הפשטה וישנם משאבים נוספים הקשורים ליצוא ידע, כמו גם תפוקות נוספות מחוץ למאמרים. יחד עם זאת, אלה בהחלט משמשים כאינדיקציות.

התוצאות המתקבלות הן שלמרות שחלק גדול מהמחקר ופיתוח בישראל הוא צבאי - יותר מ-50% וחלק ניכר מממצאים הקשורים במו"פ זה הינם חסויים, דהינו לא באים לידי ביטוי בפרסומים מדעיים, עדיין ישראל מצוייה הרבה מעל לקו הרגרסיה, לאורכו ניתן לראות את מדינות אירופה. כלומר, לו היינו מפרסמים בקצב האירופאי, היינו מצויים בהמשך הקו. היקף הפירסומים בפועל הוא בסדר גודל של פי שניים מעל לתפוקה האירופאית.

איור מס' 1: מספר מאמרים במדעים המדויקים וההנדסה כפונקציה של ההוצאות על מחקר ופיתוח בישראל ו-12 מדינות אירופאיות, בשנים 1985-1981



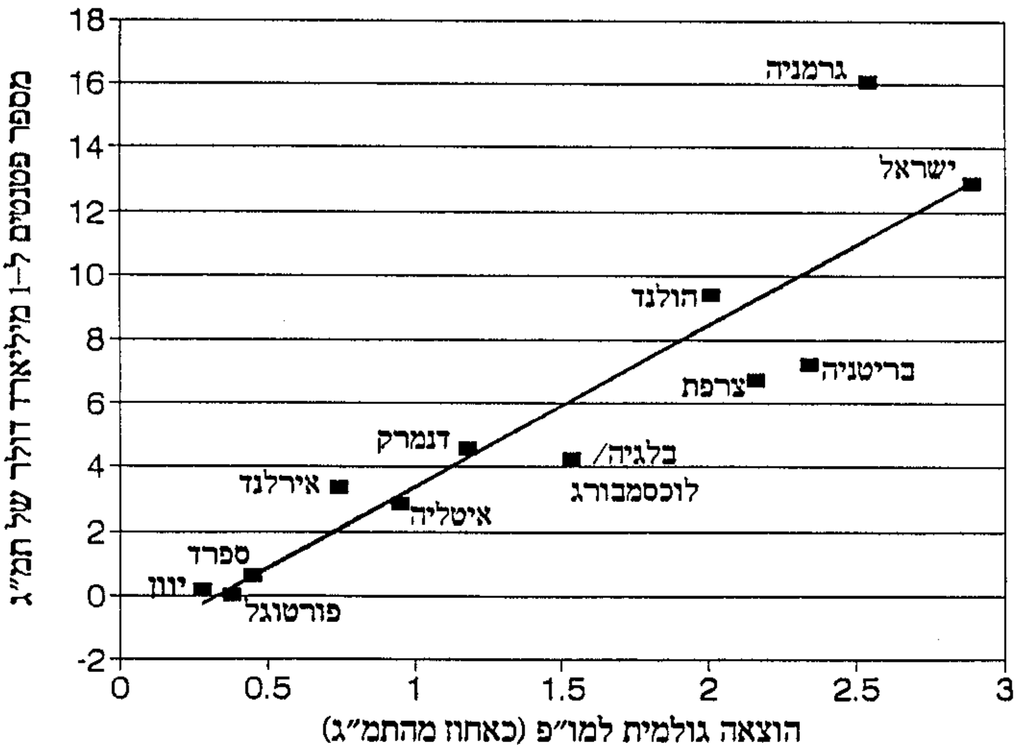
יפן לא נכללה בבדיקה שביצענו, אך ממה שידוע לנו ניתן לציין כי יפן מצוייה נמוך מקו הרגרסיה, מאחר והיא איננה מצטיינת במדע בסיסי. יפן מצטיינת בלימוד הטכנולוגיה הקיימת ובישום מהיר מאוד בפיתוח מוצרים. לגבי השאלה האם המצוינות המדעית של ישראל אינה תוצאה של הכרח וחוסר ברירה? לי אין ספק שיש בכך אמת. מידע אישי שצברתי עקב ישיבתי בועדות מכינות בהם דנים בקידום אקדמי, מתברר כי היום יש דוקטורנטים שעוד לפני קבלת התואר כבר צברו ארבעה, חמישה פרסומים טובים. ישראל היא מדינה תחרותית. מכל מקום אין אני מנסה כעת להסביר מדוע אנו מצויים גבוה מעל קו הרגרסיה, אלא רק מציין זאת כעובדה.

בישראל כמות הפרסומים היא מאוד גבוהה. נכון שיש להתייחס לכך בזהירות משום שיתכן שמספר מאמרים מתפרסמים על אותו נושא מבלי שהם מחדשים? עובדה זו נכונה, ויתכן שחלק מהמאמרים חסרי ערך. אילו הייתי מראה את תוצאות הרגרסיה המתקבלת כאשר המשתנה התלוי הוא מספר הציטוטים, מה שמעיד טוב יותר על הרמה של מצוינות מדעית, כי אז הינו רואים שגם במקרה זה ישראל מצוייה במצב דומה. במקרה זה מדובר לא על סתם מאמרים, אלא על מאמרים שמצוטטים בספרות שאנשים מוצאים בהם שימוש במדע.

נמשיך למטה בשלבי תהליך החדשנות שהוצג על ידי ד"ר גרופ, לשלב של פטנטים ונציג את הממצאים המתקבלים באיור מס' 2 הנראה בשקף הבא. ציר ה-X שוב מייצג את המשתנה הבלתי תלוי במודל הרגרסיה, שהוא ההוצאה הגולמית על מחקר ופיתוח כאחוז מהתוצר המקומי הגולמי. ציר ה-Y מבטא כעת מספר פטנטים מנורמל בגודל התמ"ג. ישנן מספר דרכים למדוד את היקף הפטנטים. אנו השתמשנו במספר הפטנטים שנרשמו במשרד הפטנטים האמריקאי על ידי המדינות שנבדקו במחקר.

אלה מהווים אינדיקציה של הנכונות להשקיע במדינה זרה ברישום פטנט. תוצאת הבדיקה מראה כי ישראל מצוייה כעת ממש על קו הרגרסיה, לא מעליו ולא מתחתיו. כלומר, מצבנו דומה לזה המאפיין את ארצות הקהיליה האירופאית. כמובן שהפיתוח הצבאי שהוא גדול בארץ, לא בא לידי ביטוי בנתונים אלה ולכן ניתן לומר שמצבינו טוב יותר ממה שמשתקף כאן.

איור מס' 2: מספר פטנטים רשומים (1884-1986) כפונקציה של ההוצאות על מחקר ופיתוח בישראל ו-12 מדינות אירופאיות, בשנים 1981-1985



הועלתה השערה כי קיימת הטיה מסויימת בממצאים הנובעת כתוצאה מן העובדה שלמדען הישראלי בפועל, אין ברירה אלא לרשום פטנט על המצאתו בארה"ב, בה בשעה שמדענים בארצות אחרות רואים את מדינתם כמכובדת דייה לרשום את הפטנטים שלהם בה. להערכתי דווקא הנושא של ארצות הברית מחזק את הטיעון שהוצג. במוסד נאמן בוצע מחקר על מידת שתוף הפעולה בין חוקרים ישראלים וחוקרים מחו"ל (בעיקר מארה"ב) בכתיבת פרסומים מדעיים. מתוצאותיו מתברר כי ישנם פירסומים רבים של ישראלים אשר לא משוייכים לישראל ולכן לא נכללו בתוצאות המיפוי שהראתי באיור מס' 2. הסיבה לכך נובעת מן העובדה שהמאמרים פורסמו על ידם בעת שהותם של החוקרים הישראלים בחו"ל, תחת כתובת זרה, ולכן לא שוייכו לישראל. הרבה מהמחקרים שלנו נעשים בחו"ל במימון אמריקאי ולכן יש לכך משמעות. אגב, המחקר הראה כי איכות הפרסומים הללו (על פי מדד של מספר הציטוטים), גבוהה יותר מאשר של המחקרים המקומיים שנעשו רק בישראל. הבאתם של אלה בחשבון היה מחזק את הטיעון שלי, שישראל מגלה מצוינות ויעילות רבה בייצור ידע על סמך המשאבים הדלים שקיימים, אולי בין היתר משום שמשתמשים גם במשאבים של אחרים.

איור מס' 3 מצביע על מה שמכונה ה"שלב השני" של תהליך החדשנות. באיור זה ציר ה-X מייצג את מספר הפטנטים מנורמל בגודל התמ"ג, וציר ה-Y את מה שאנחנו מכנים מדד ה-RCA. זהו מדד שפיתחנו על מנת למדוד את כושרה של המדינה ליצא מוצרים עתירי ידע, מוצרי הי-טק או להחליף יבוא של מוצרי הי-טק בייצור מקומי, פעולה הדומה ליצוא. ביטויו של המדד הוא כדלקמן:

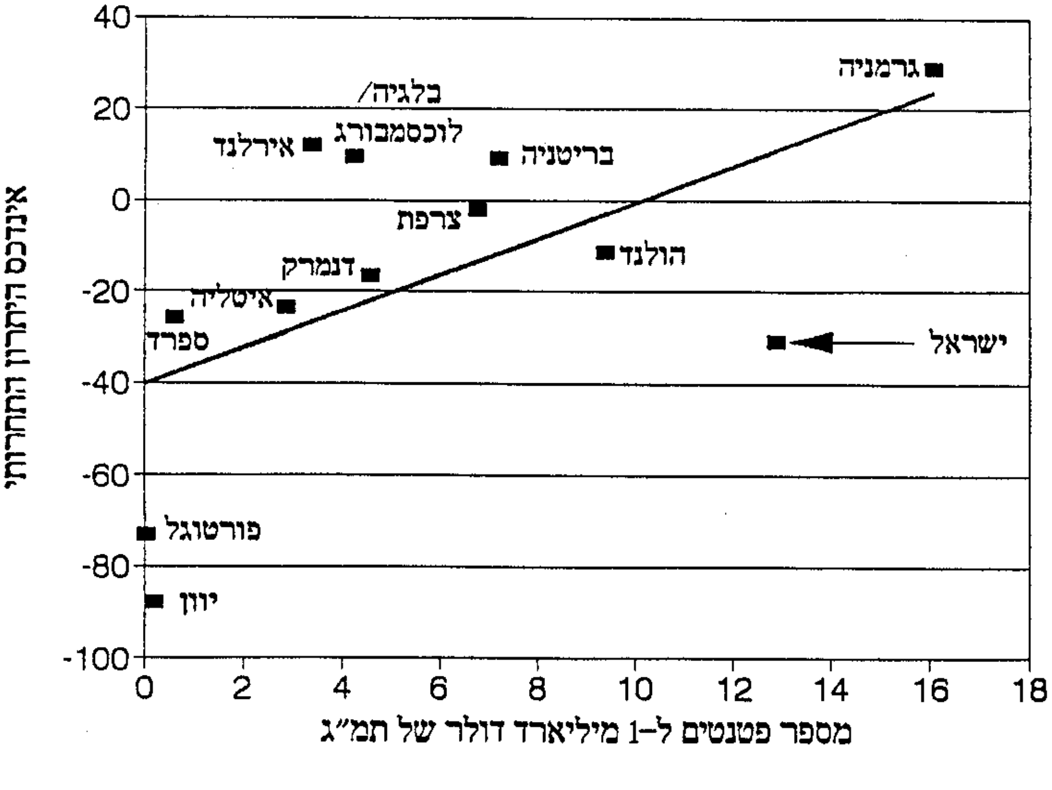
$$RCA = 100\ \{(ES^2-1)/(ES+1)\},\ -100 < RCA > +100$$

כאשר חלוקת היצוא

$$ES = \frac{EX/IM}{EXTOT/IMTOT}$$

EX הוא סך כל היצוא של מוצרי LE על ידי המדינה, IM הוא סך כל היבוא במוצרי LE למדינה, EXTOT הוא סך כל היצוא הכולל של מוצרים על ידי המדינה ו-IMTOT הוא סך כל היבוא הכולל של מוצרים למדינה.

איור מס' 3: אינדכס היתרון התחרותי (1988) כפונקציה של מספר פטנטים רשומים בישראל ו-12 מדינות אירופאיות, בשנים (1984-1986)

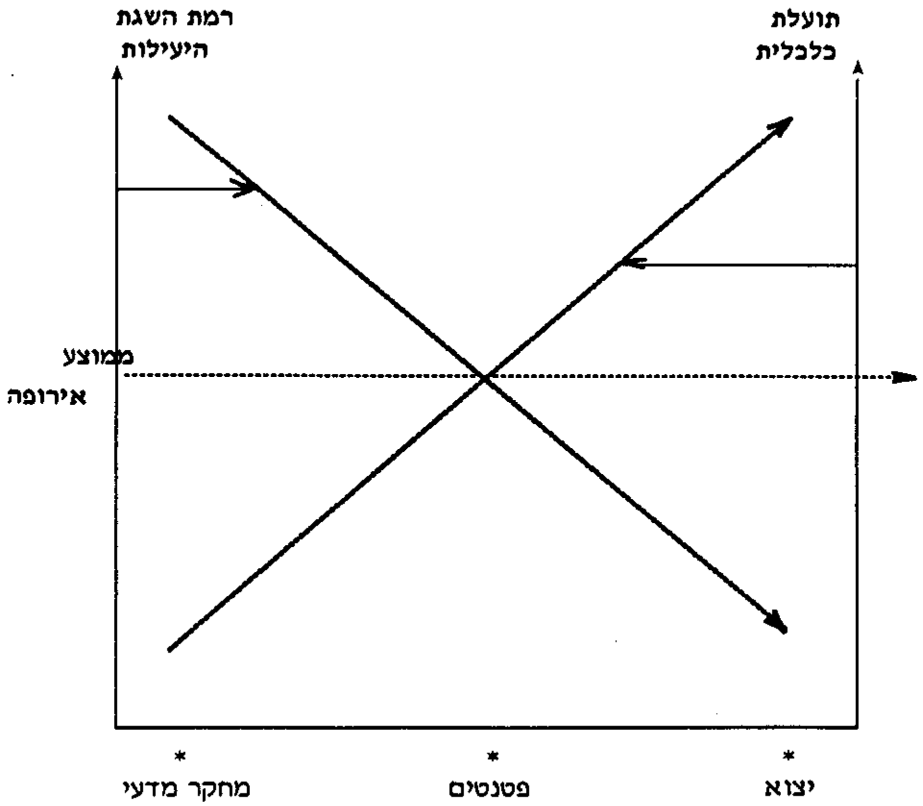


אינדכס ה-RCA נבנה על ידי ד"ר גרופ כאשר ההגדרה של מוצר הי-טק לצורך השימוש במדד, היה כל מוצר שההוצאות על המו"פ שלו היו מעל 3.5% מהיקף המכירות. בארץ זה כולל לדוגמה את ענף אלקטרוניקה ועוד מספר ענפים. תוצאות ניתוח הרגרסיה מראים כי קו המגמה מאפין את ארצות אירופה, בעוד שישראל מצויה מתחת לקו, בסדר גודל הייתי אומר של כ-30%. כלומר, לו ישראל היתה ממוקמת ביבשת אירופה והיו לה תנאי פתיחה טובים יותר, הינו מיצאים על אותו בסיס ידע

ב-30% יותר ממה שאנו מצליחים היום. פירוש הדבר, ביטול הצורך בסיוע האמריקאי בכלל, או הרבה מאוד תוצאות טובות אחרות. מן הראוי לציין כי תוצאה זו נשארת תקיפה גם אם נחליף את המדד של היתרון היחסי (RCA) במדד אחוז יצוא מוצרי הי-טק מכלל היצוא התעשייתי. כאמור היקף יצוא ההי-טק בארץ מהווה כמחצית מכלל היצוא התעשייתי, לאור הבסיס המדעי המוצק שלנו, זה יכול היה להיות גבוה יותר.

סיכום הממצאים הללו מוצג באיור מס' 4. ציר ה-X מייצג את שלבי תהליך החדשנות - ממדע ומחקר בסיסי, למחקר ישומי, פטנטים, פיתוח מוצר וכו'. ככל שנתקדם לאורך ציר שלבי תהליך החדשנות, נמצא את ישראל יורדת בציר ה-Y המצביע על מידת המצוינות בתהליך. הבעייה של ישראל היא שהערך הכלכלי של השלב הולך וגדל. ממחקר ופיתוח שום מדינה בעולם לא מתפרנסת, כך שמבחינת הערך הכלכלי, ההצטיינות במחקר מדעי מניבה ערך כלכלי יחסי נמוך לעומת הערך הכלכלי של יצוא מבחינת תפוקה, הכנסה ותעסוקה, שהוא גבוה. לכן, יש קשר הפוך בין ההצטיינות שלנו לבין הפירות הכלכליים שנוכל להפיק משלב החדשנות.

איור מס' 4: רמת היעילות המושגת בשלבי החדשנות והתועלת הכלכלית המופקת מכל שלב בישראל לעומת מדינות אירופה



הערה: התרשים סכמטי בלבד.

אני רואה בממצאים אלה בעיה גדולה במיוחד לאור המבול המבורך של הון אנוש שקיבלנו מבריה"מ. ראוי לציין כי מספר המהנדסים שסיימו את לימודיהם בטכניון מאז 1925 קטן יותר מאשר מספר המהנדסים שקלטנו מרוסיה בשלוש השנים האחרונות. הגיעו לארץ בגל העלייה הגדול מאה שלושים אלף מהנדסים. אמנם ישנה אי בהירות בהגדרת התואר מהנדס בין המגיעים משם, יחד עם זאת המספר העצום שהגיע, מדבר בעד עצמו.

לסיכום, האם קיימת בעיה אמיתית? ומה עושים? לדעתי ישנה בעייה אמיתית הבאה לידי ביטוי באופן בולט בכך שחלק מחברות ההי-טק הגדולות בעולם, הקימו מרכזי מחקר ופיתוח בארץ, לדוגמה: נשיונל סמיקונדקטורס, מוטורולה, אינטל, אי-בי-אם, דיגיטל. חלקן מייצרות גם בישראל אך רוב רובו של היצור הוא במקום אחר כמו סינגפור. ידוע שבישראל לא זול ליצר. השכר שלנו בתעשיה הוא כ-8.5 דולר לשעת עבודה. במזרח הרחוק הוא כ-4 דולר לשעה. אין זה אותר שעה, מפני שיקר ליצר בישראל. הבעייה של ישראל טמונה בעובדה שבאסיה התפוקה לעובד דומה מאוד לתפוקה לעובד בישראל כאשר השכר שלנו כפול. השכר בגרמניה בתעשיה הוא פי שניים ויותר מאשר השכר אצלנו, אבל הפער בערך מוסף לעובד אף הוא גדול מפי שניים. כלומר יש לנו מצוינות טכנולוגית ומדעית, פוטנציאל גדול וצורך גדול מאוד למצות את הפוטנציאל אשר כעת אינו ממוצה. השאלה מדוע זה קורה וכיצד ניתן להפוך את היתרון שיש לנו בשלב א' של תהליך החדשנות, למימוש ביצוא בתפוקה בשלב ב'? אני מעמיד את השאלה לדיון.

ישום השיטה הטכנומטרית למדידת איכות טכנולוגית (Benchmarking) השוואת מוצרים עתירי ידע: ערכות דיאגנוסטיות וסנסורים תעשייתים בישראל בהשוואה לאירופה וארה"ב.

אמנון פרנקל
מוסד שמואל נאמן

אנסה יחסית בקצרה לתאר מימצאים שהושגו באופן אמפירי במחקר המשותף שלנו יחד עם הקבוצה הגרמנית מ-ISI שבקרלסרוה. בשנת 1990, כאשר התחלנו את המחקר הגדרנו מספר סוגים של תעשיות היכולות להצביע על כיוון לגבי אפשרות ההשוואה בין ישראל למדינות אחרות, תוך ישום מודל הטכנוטמטריקה אשר פותח על ידי הגרמנים ויושם שם על מוצרים דומים בשנים 1986-1989.

שתי התעשיות אשר התמקדנו בהן במסגרת המחקר שלנו, המהווה מחקר השוואתי של ישראל ביחס למדינות אחרות, בעיקר גרמניה אך גם ארצות הברית, יפן ומדינות נוספות באירופה, הן תעשיית הסנסורים ותעשית הדיאגנוסטיקה הרפואית. ענפי תעשייה אלה לא נבחרו באקראי אלא כתוצאה מהיותן אחת או שתיים מתוך קרוב לשש או שבע סוגי תעשיות אחרות שנבדקו על ידי הקבוצה הגרמנית בשנים 1986-1989. שיתוף הפעולה איפשר שימוש בנתונים קיימים שנאספו על ידי הגרמנים אודות חברות יצרניות בעולם. מן הראוי לציין כי הקושי הגדול ביותר ביישום מודל הטכנוטמטריקה ואשר ד"ר גרופ דיבר עליו במקצת בהרצאתו בפניכם, הוא שלב איסוף הנתונים. זהו השלב בו נדרש החוקר להשיג את הנתונים מכל החברות. בדרך כלל נתונים אלה לא מצויים על המדף, והשגתם כרוכה בביצוע ראיונות אישיים עם מנהלי החברות ואנשי הפיתוח והשיווק שלהם. תהליך שכזה הוא יקר ומשתרע על פני תקופת זמן ממושכת.

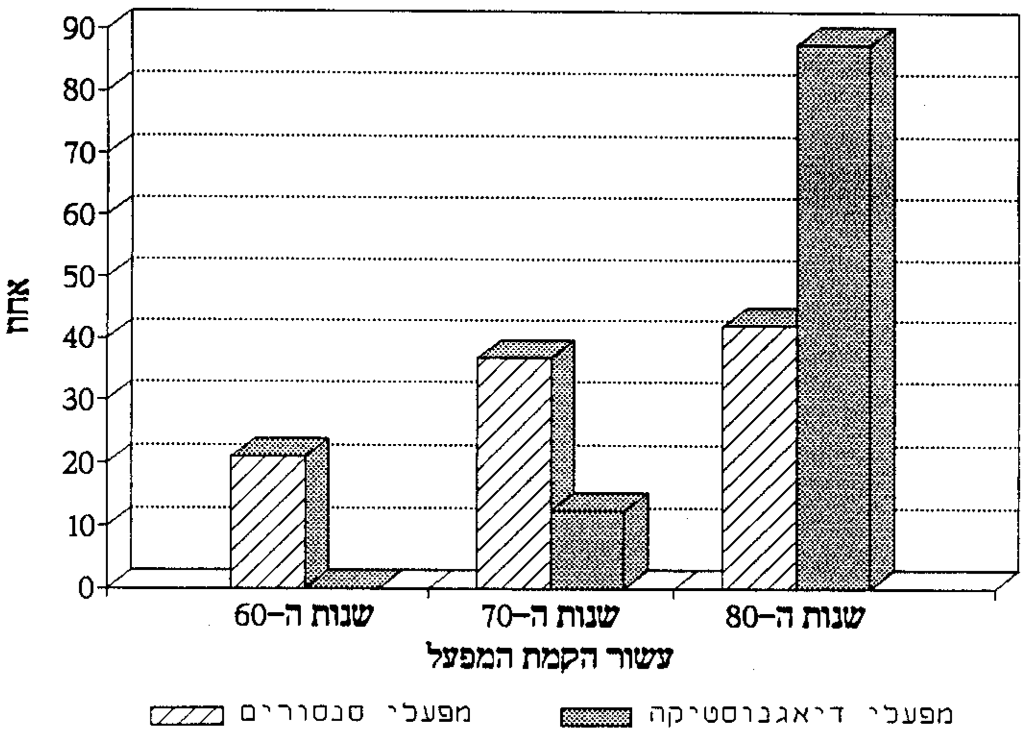
שתי התעשיות שבחנו באמצעות המודל, ואשר את ממצאי הבדיקה אציג בפניכם, שונות עד מאוד במאפיניהן. שתיהן תעשיות קטנות יחסית במדינת ישראל ושתיהן מאופינות בעתירות ידע גבוהה הבאה לידי ביטוי במאפינים שונים של עתירות ידע. להלן אציג מספר מאפינים של שתי תעשיות אלה בהשוואה בינהן ובהשוואה לכלל התעשיה בארץ.

באיור מס' 1 מוצגת התפלגות המפעלים בשתי התעשיות על פי מועד הקמתם. הממצאים מורים כי תעשיית הדיאגנוסטיקה היא תעשייה צעירה מאוד, אשר התפתחה בארץ בעיקר החל משנות ה-80. לעומתה תעשיית הסנסורים בישראל היא תעשייה ותיקה ומרבית המפעלים המשתייכם לה, הוקמו בשנות ה-60 וה-70.

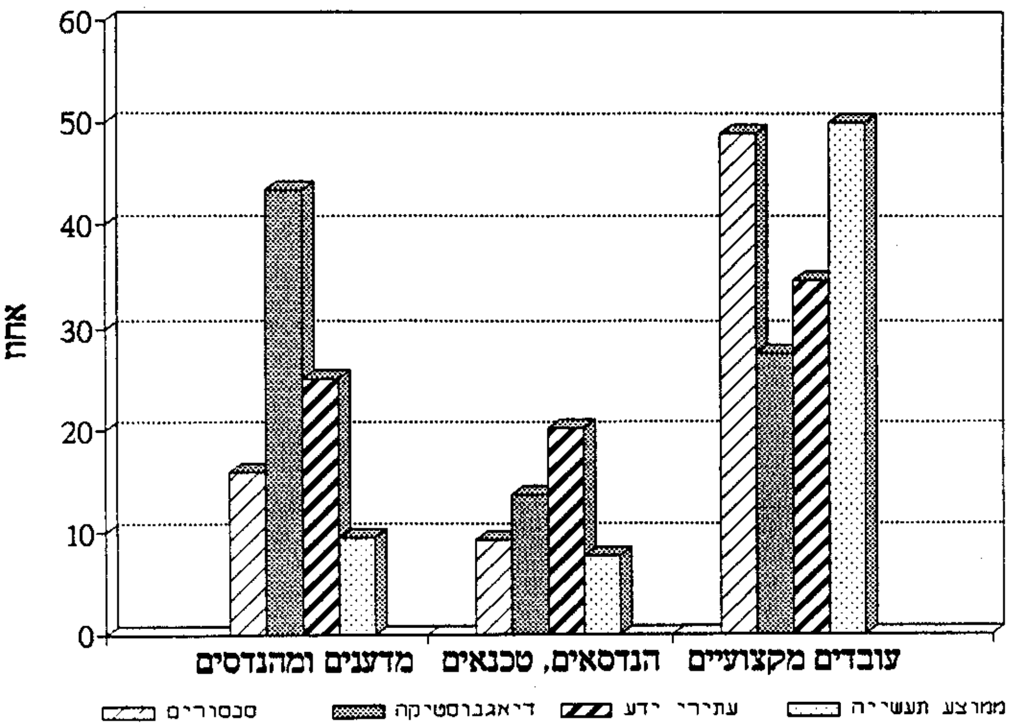
באיור מס' 2 מוצגות התעשיות על פי הרכב כוח האדם המועסק בהם, בהתפלגות לקבוצות על פי המיומנות המקצועית. הממצאים מצביעים על העתירות הגבוהה של ההון האנושי המועסק בתעשיית הדיאגנוסטיקה, בהשוואה לשאר קבוצות התעשייה שבתרשים. שיעור המדענים והמהנדסים מהווה למעלה מ-40% מהמועסקים בתעשייה זו, לעומת פחות מ-20% בתעשיית הסנסורים. בתעשיית הסנסורים הוא אף נמוך מהממוצע לכלל התעשיות עתירות הידע בישראל. בקבוצת ההנדסאים והטכנאים, הפערים קטנים יותר. בקבוצת העובדים ברמת המיומנות הנמוכה (עובדים מקצועיים), בולט השיעור הגבוה של המועסקים בתעשיית הסנסורים, הדומה לזה של כלל התעשייה בארץ.

בהשוואה לכך השיעורים נמוכים בהרבה מהנתונים המקבילים בתעשיית הדיאגנוסטיקה ובממוצע של תעשיות היי–טק בארץ.

איור מס' 1: התפלגות המפעלים לפי מועד הקמתם



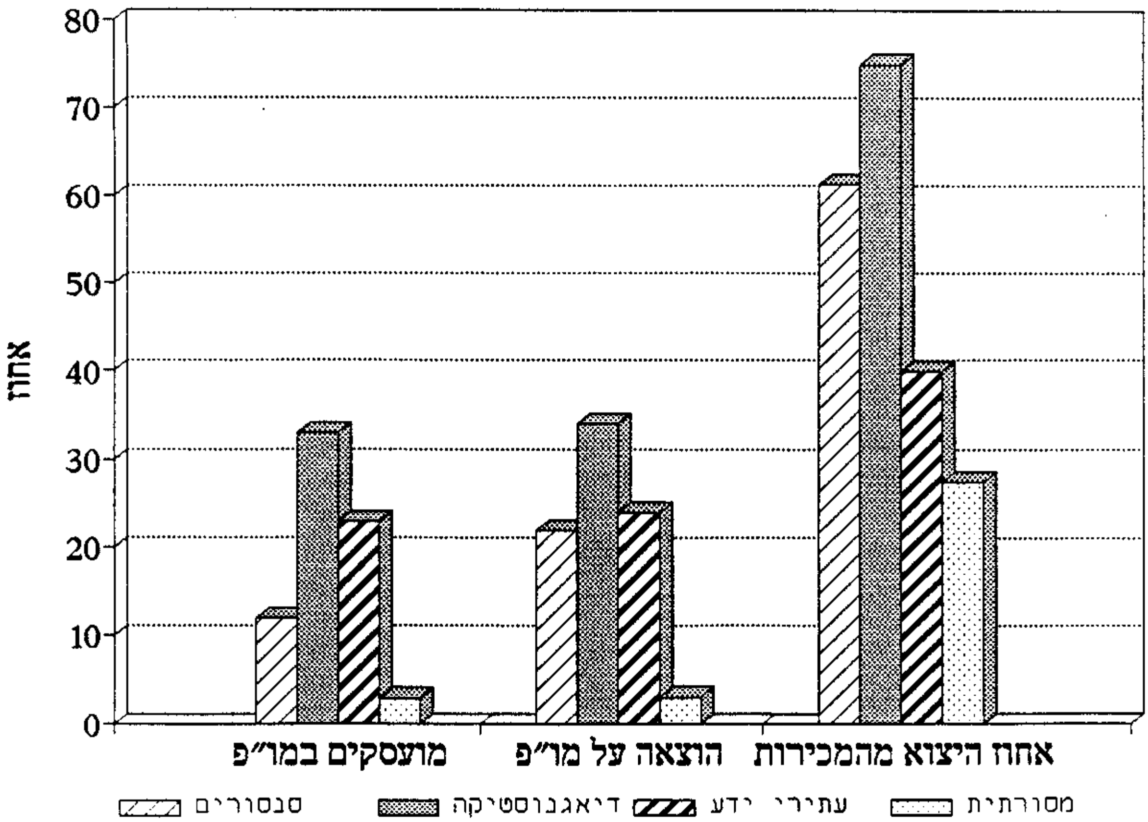
איור מס' 2: הרכב כוח האדם בתעשיות לפי רמת המיומנות המקצועית



לבסוף, אציג אינדיקטורים על העתירות המדעית של תעשיות אלה. הנתונים מראים כי תעשיית הדיאגנוסטיקה הרפואית בולטת בכל שלושת המדדים. בתעשיית הסנסורים ההוצאה על מו"פ מכלל הוצאות המפעל אף היא גבוהה, ודומה לזו המאפינת את ממוצע תעשיות עתירות הידע בישראל. תעשיית הסנסורים בולטת בהשוואה לתעשיות עתירות הידע, באחוז יצוא גבוה של מוצריה (60% לעומת 40%).

מהנתונים שהוצגו עולה כי תעשיית הדיאגנוסטיקה מצוייה בקצהו העליון של מדרג התעשיות עתירות הידע, כפי שמשתקף בשיעור המועסקים במו"פ, וההוצאה על מו"פ. יחד עם זאת, סביר להניח כי לעובדה שתעשייה זו התפתחה רק בשנים האחרונות, ומרבית המפעלים מצויים בשלבי התפתחות ראשוניים, יש השפעה על היקף העיסוק במו"פ. עם התפתחותה של התעשייה ומעבר לשלבי יצור סטנדרטים יותר, צפוי שהיקף זה יקטן.

איור מס' 3: מדדי מו"פ ויצוא בתעשיות

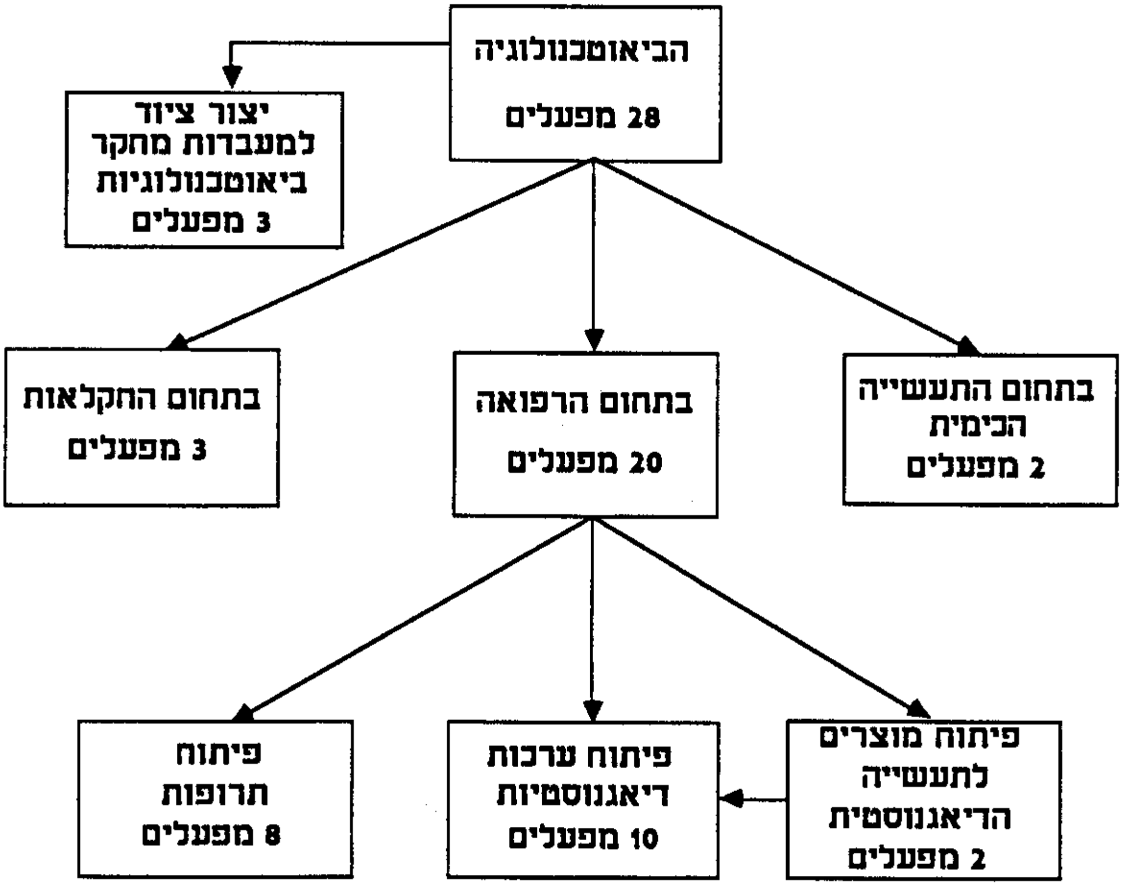


נעבור עתה לסקור את הממצאים מבדיקת הרמה הטכנולוגית של שתי התעשיות תוך השוואה ברמת המדינה באמצעות מודל הטכנומטריקה. המטרה להדגים באמצעות חקרי הארוע אשר בדקנו, את אופן היישום של המודל ואפשרויות השימוש בו. לכן אציג בפניכם מספר בודד של דוגמאות מהיישום אשר ביצענו.

תעשיית הדיאגנוסטיקה הרפואית

ענף הדיאגנוסטיקה הרפואית הוא תת ענף של ענף הביוטכנולוגייה. כאמור זו תעשייה צעירה בישראל ומספר המפעלים בארץ העוסקים בתחום קטן למדי. באיור מס' 4 המוצג לפניכם, מובאת התפלגות המפעלם הביוטכנולוגים בארץ בחלוקה לתחומי משנה של עיסוק. ניתן לראות כי מתוך כ-30 מפעלים ביוטכנולוגים, 12 מפעלים עוסקים בדיאגנוסטיקה רפואית, מהם 10 עוסקים בדיאגנוסטיקה רפואית, אך רק ב-8 היה פיתוח של ידע מקומי ולכן נכללו רק אלה בסקר המפעלים שביצענו.

איור מס' 4: התפלגות המפעלים הביוטכנולוגיים בישראל לפי תחומי עיסוק



סקר המפעלים שביצענו העלה מספר יתרונות מול חסרונות של תעשייה זו בארץ כפי שניתן לראות ברשימה שלהלן:

יתרונות	חסרונות
* קיומה של קהיליה מדעית גדולה בתחום מדעי החיים	* העדר הון סיכון בהרחבת הפיתוח, הייצור, והשיווק.
* רמת הידע הישראלי בתחום האימונולוגיה בין הטובים בעולם	* השוק בישראל קטן והתחרות גדולה
* רמה גבוהה של שיתוף פעולה בזמן אמת בין החברות ומוסדות המחקר	* קושי בחדירה לשווקים ותחרות בשיטות אבחון זולות
* יכולת קבלת החלטות מהירה	* פיגור בשיווק גורר התיישנות הידע במהירות
	* שיווק על ידי מפיצים בחברות הקטנות חסרות ההון
	* ריחוק משווקים ואספקה של רכיבים טכנולוגים
	* ריחוק המקשה על חשיפה לטכנולוגיות חדשות

במחקר נבחנה הרמה הטכנולוגית של כל אחת מן המדינות שנכללו תוך השוואה יחסית באמצעות מודל הטכנומטריקה. השיטה הופעלה לגבי שתי טכנולוגיות ידועות של פיתוח ערכות לאבחון מחלות והן: ערכות המבוססות על נוגדנים מונוקלונליים (חד שבטיים) ופיתוח ערכות על בסיס של גלאי DNA. אסביר בקצרה כל אחת מן השיטות.

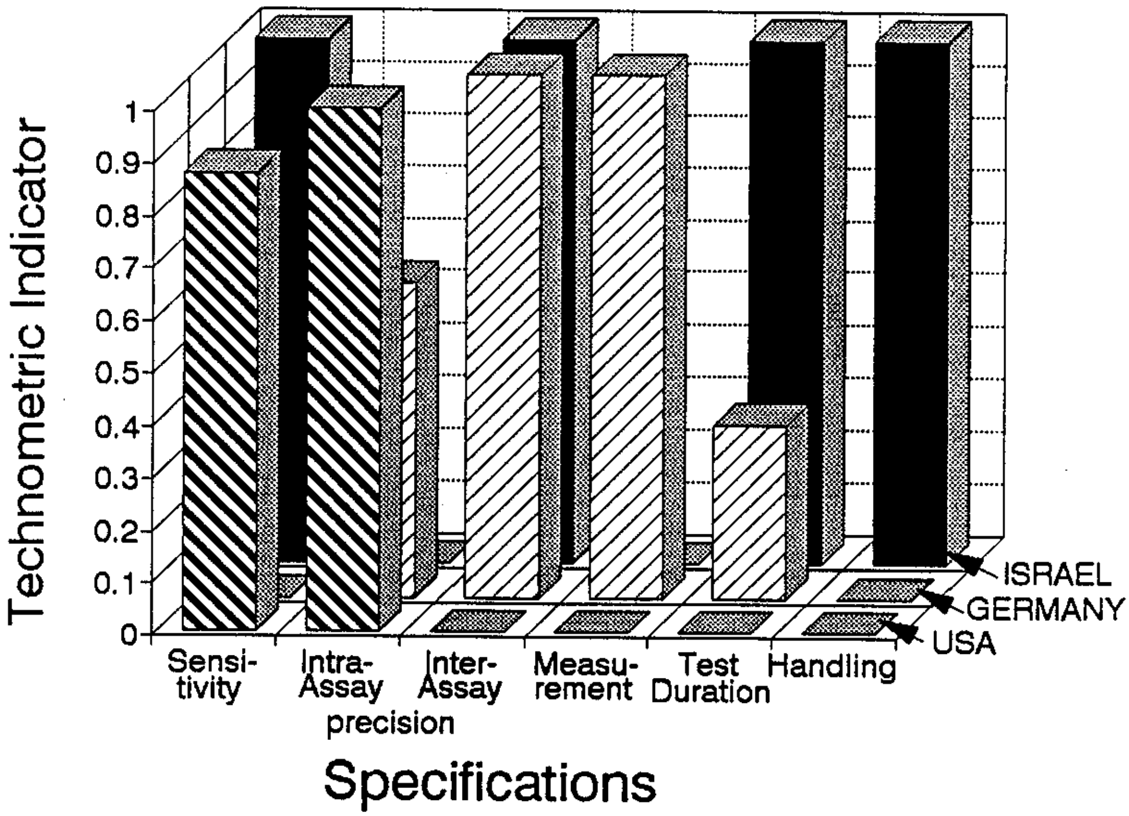
השיטה הראשונה של שימוש בנוגדנים חד שבטיים, היא ותיקה יותר ומבוססת על עיקרון פעולתה של מערכת החיסון של הגוף. מערכת זו אחראית על פיתוח וייצור נוגדנים המותאמים ספציפית להילחם בפולשנים (אנטיגנים) החודרים לגוף וגורמים למחלות. ערכות האבחון מבוססות על זיהוי רמת הנוגדנים הספציפים הקיימת בגוף, באמצעות בדיקת נוזלי הגוף ואשר ממצא חיובי בהקשר זה, מהווה אינדיקציה לקיומה של המחלה. השיטה מופעלת שנים רבות והפיתוחים השונים שנעשו בה קשורים לשימוש בטכניקות סימון משובחות ויעילות, מהירות ביצוע האבחון, רמת האוטומציה שבביצוע הבדיקה, או פשטות הביצוע ויכולת הפשטה עד כדי מתן אפשרות של שימוש בערכות בקליניקות פרטיות של רופאים ועוד.

השיטה השנייה היא חדשנית יותר והשימוש בה בעולם מצומצם עדיין. היא מבוססת על התאמה חד ערכית הקיימת בין קטע של DNA המסומן באופן רדיואקטיבי או אנזימטי לבין DNA של בקטריות, או וירוסים, או רצפי DNA פגומים. השיטה מאפשרת שימוש בבחוני DNA (DNA Probe) לגילוי קיומם של אנטיגננים פולשנים. שלב הגילוי עשוי להיות מוקדם מיכולת הגילוי באמצעות הטכנולוגיה המבוססת על נוגדנים, יחד עם זאת השיטה מסובכת יותר, דורשת מיומנות טכנולוגית גבוהה יותר ומצוייה עדיין חלקית בשלבי פיתוח. בסקר שביצענו התברר כי שלב הפיתוח של ערכות המבוססות על טכנולוגית ה-DNA, עדיין לא מאפשר מיפוי של צלליות המוצרים באמצעות מודל הטכנומטריקה. לכן צלליות שכאלה מופו אך ורק לגבי ערכות האבחון אשר מבוססות על טכנולוגית הנוגדנים החד שבטיים.

בסקר המפעלים שערכנו בארץ זוהו כ-50 ערכות לאבחון מחלות שונות אלה הצטרפו לבסיס הנתונים אשר נאסף במקביל על ידי הקבוצה מגרמניה ואשר הכיל נתונים אודות כ-150 ערכות. בסופו של התהליך ניתן היה להשוות רק חלק קטן מן הערכות, כאשר ההשוואה כללה את ישראל, גרמניה, ארה"ב ויפן. הערכות אשר באמצעותן ניתן היה להשוות את הרמה הטכנולוגית של המדינות שנבדקו, נחלקו לשתי קבוצות: הראשנה, ערכות המשמשות לאבחון מחלות הקשורות לפעילות הורמונלית של בלוטת התריס והורמוני מין; והשנייה, ערכות המשמשות לאבחון החיסון של מחלות זיהומיות. להלן אדגים תוצאות משתי קבוצות אלה.

איור מס' 5 מראה מיפוי השואתי של צללית מוצר של ערכה לאבחון FT-3 (Trijodthyronin חופשי) הקשורה בפעילות של בלוטת התריס. על ציר ה-X מוצבות 6 תכונות המאפינות את הפרופיל הטכנולוגי של ערכת האבחון. ציר ה-Y מראה את הציון שנקבע על פי המדד הטכנומטרי לכל אחת מתכונות אלה בכל אחת משלוש המדינות שנבדקו - גרמניה, ישראל וארה"ב (ציר Z).

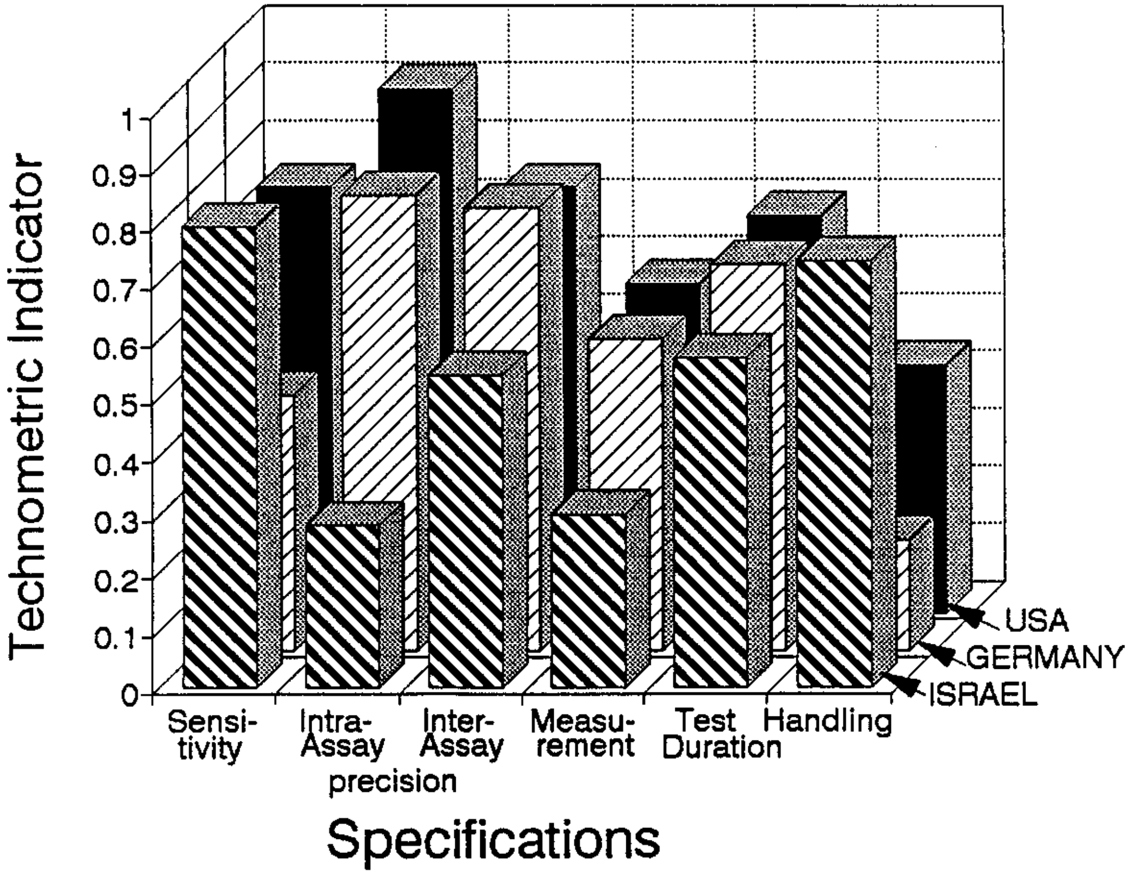
איור מס' 5: פרופיל טכנומטרי של ערכה לאבחון פעילות הורמונלית של בלוטת התריס (FT-3), לפי תכונות המוצר, בישראל, גרמניה וארה"ב



מיפוי צללית המוצר בהשוואת הרמה בין המדינות, מראה כי ישראל מובילה ברמה הטכנולוגית הכללית. הערכים המושגים בישראל בהקשר לערכה מסוג זה, מצטיינים במיוחד ביחס לתכונות בודדות כמו רגישות (Sensitivity) דיוק בין מבדקי (Inter-Assay Precision) משך המבדק (Test Duration) ושלבי הביצוע (Handling). שתי התכונות האחרונות מעידות על יעילות מערכות המבדק בישראל המהווה אינדיקציה לרמת אוטומציה גבוהה יחסית למתחרות. הצד הטכנולוגי החזק של גרמניה מתבטא אף הוא בדיוק הבין מבדקי (Inter-Assay Precision) ובטווח המדידה (Measurement Range). הפיגור נובע מרמה טכנולוגית נמוכה במיוחד בתכונות של טווח מדידה. משך המבדק ושלבי הביצוע, כפי שאלה באים לידי ביטוי בפרמטרים הטכנומטריים. ככל הנראה דרגת האוטומציה של המבדקים הללו בארה"ב נמוכה באופן יחסי. לעומת זאת עושים שם שימוש בנוגדנים מאיכות מעולה כפי שהדבר מתבטא בתוצאות הגבוהות של רגישות המבדק ושל הדיוק הפנים מבדקי.

כפי שהוצג בהרצאה הראשונה, אחת ממעלותיו של המודל הטכנומטרי, היא האפשרות לחשב ציון מיצרפי עבור המוצר הנבדק, כציון ממוצע או משוקלל על פי הרכב כל התכונות גם יחד. דוגמה לכך ניתן לראות באיור מס' 6, המדגים את הפרופיל המצרפי של קבוצת הערכות ההורמונליות שכלל 6 סוגי ערכות שונות בכל אחת משלושת המדינות.[1]

איור מס' 6: פרופיל טכנומטרי מיצרפי של 6 ערכות לאבחון פעילות הורמונלית לפי תכונות המוצר, בישראל, גרמניה וארה"ב



הממצאים העולים מניתוח מיצרפי זה מעידים על כך שארה"ב מובילה בראש (עם ציון טכנומטרי של 0.72) ואילו גרמניה וישראל מצויות מאחוריה (עם ציון כולל של 0.58 ו-0.55 בהתאמה). חולשתה של גרמניה ביחס למתחרותיה, מצוייה בתחום הרגישות והמניפולציה הטעונים שיפור. ההישגים הטכנולוגים של ארה"ב בתחום הרגישות והדיוק, מעידים על שימוש בנוגדנים מאיכות טובה. גם הרמה אשר הושגה בתחום טווח המדידה ומשך המבדק, מעידים על אוטומציה גבוהה ויכולת תחרותית גבוהה של המבדקים האמריקאים בשוק.

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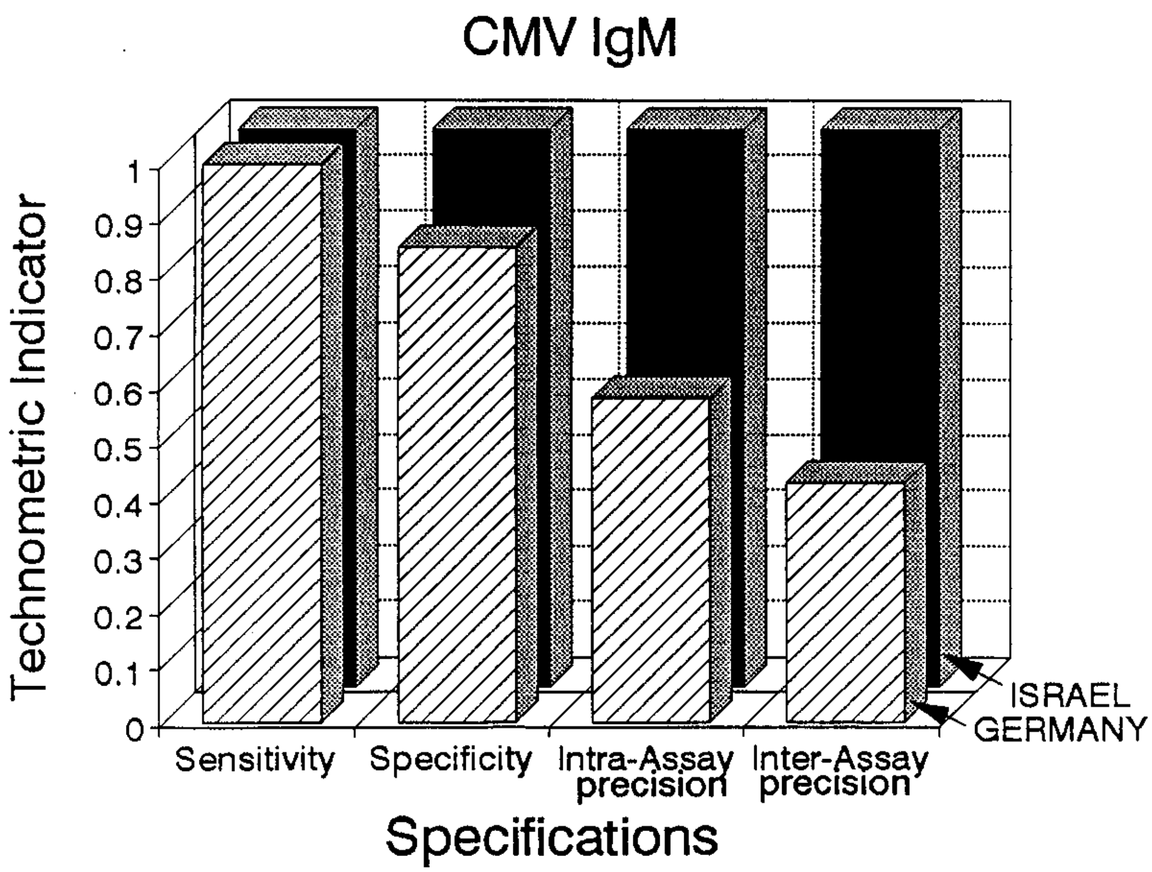
1. הערכות הכלולות בחישוב המיצרפי הן: T-3, T-4, TSH, FT-3, FT-4 ו-PROLACTIN.

הפרופיל המיצרפי של המבדקים הישראלים, אינו מאוזן. הושגו ערכי שיא בשתי תכונות: רמת הרגישות ומספר שלבי הבדיקה. לעומת זאת בשאר התכונות, התוצאות נמוכות יחסית בהשוואה למתחרות ויש מקום לשיפורים. נראה כי תשומת לב צריכה להינתן לשיפור הדיוק של המבדקים, תחום בו הושגו הישגים נמוכים במיוחד בהשוואה למתחרות. תחום זה יש לו חשיבות רבה בעיני המעבדות בבואן לשקול בין האפשרויות המוצעות בשוק.

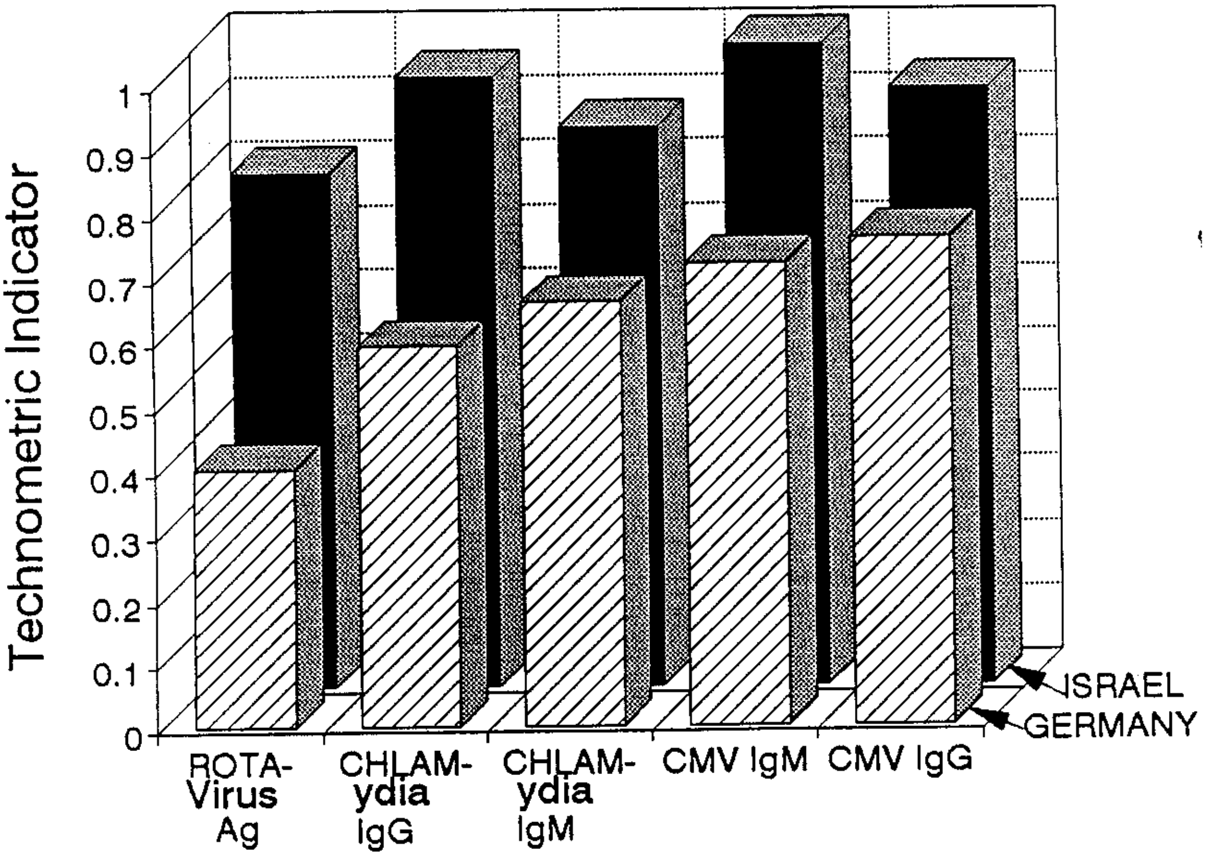
נעבור עתה להדגים את השימוש במודל הטכנומטריקה לגבי ערכות לאבחון מחלות זיהומיות. כאן בחרנו להדגים את הפרופיל ההשוואתי בין ישראל לגרמניה על גבי ערכות לאבחון מחלת ה- CMV (Cytomegalovirus). בפרופיל המוצג באיור מס' 7 שלפניכם (אשר בדק את הערכות המאבחנות נוגדנים מקבוצת IgG) בולטת הרמה היחסית הגבוהה של המבדקים הישראליים ביחס למבדקים מגרמניה. בכל הפרמטרים הנבדקים הושגו בישראל ערכי שיא, לעומת זאת בגרמניה הושג ערך מקביל רק בפרמטר של מידת הרגישות (Sensitivity). חולשתה של גרמניה נובעת בעיקר מרמה טכנולוגית נמוכה בפרמטר של מידת דיוק הפנים והבין מבדקי (Intra & Inter-Assay Precision).

איור מס' 7: פרופיל טכנומטרי של ערכה לאבחון מחלת CMV
לפי תכונות המוצר, בישראל, גרמניה וארה"ב



חישוב פרופיל מיצרפי באמצעות מודל הטכנוטמטריקה לגבי קבוצת ערכות האבחון של המחלות הזיהומיות נעשה בשתי רמות. הראשונה מודגמת באיור מס' 8, המראה את הציון המצרפי של ישראל וגרמניה, בנפרד לגבי כל אחד משש סוגי הערכות של המחלות הזיהומיות שנבחנו.

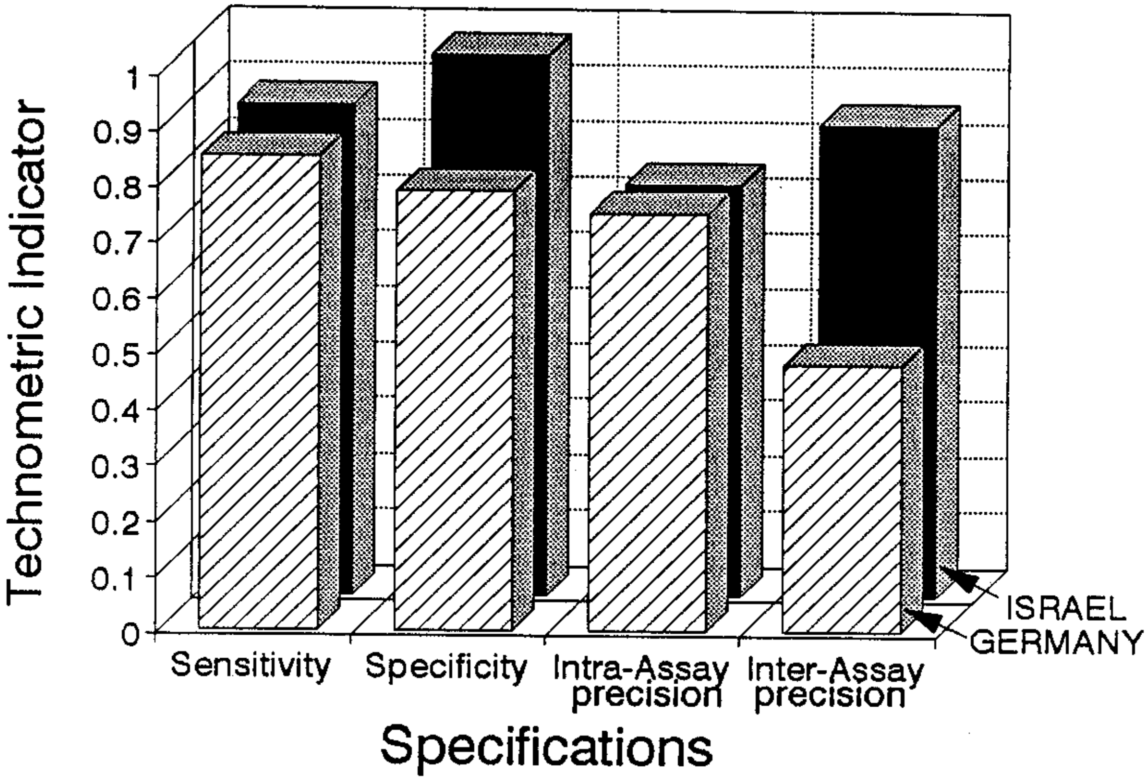
איור מס' 8: פרופיל טכנומטרי מיצרפי השוואתי של 6 ערכות לאבחון מחלות זיהומיות, ישראל מול גרמניה



מן הפרופיל המוצג באיור, ניתן לראות כי ישראל מובילה בציון המיצרפי הטכנולוגי בכל אחת משש סוגי הערכות לאבחון המחלות הזיהומיות שנבדקו. סוג אחר של חישוב מיצרפי באמצעות המודל הטכנומטרי הוא חישוב הציון המיצרפי המתקבל בכל אחת מן התכונות המאפינות את המבדקים, בחתך לרוחב. תוצאות אלה מוצגות באיור מס' 9.

הפרופיל המוצג מראה כי הרמה הטכנולוגית המיצרפית של המבדקים המיוצרים בישראל גבוהה מהמקבילה לה בגרמניה. הציון הטכנומטרי המחושב של האינדיקטור הכולל שהושג בישראל, הוא 0.87 ואילו בגרמניה 0.75. חולשתה של גרמניה מתבטאת בעיקר במדד הספציפיות ובמידת הדיוק

איור מס' 9: פרופיל טכנומטרי מיצרפי של 6 ערכות לאבחון מחלות זיהומיות לפי תכונות המוצר, בישראל וגרמניה



הבין מבדקי, בהם לישראל יתרון טכנולוגי בולט. בשני המדדים האחרים: מידת הרגישות ומידת הדיוק הפנים מבדקי, ההישגים הטכנולוגים בשתי המדינות דומים. יתרונה של ישראל הבא לידי ביטוי ברמת הרגישות והספציפיות של הערכות המיוצרות בארץ, מצביע על שימוש בנוגדנים מאיכות טובה במיוחד.

מן הראוי לציין כי ההישג הישראלי בולט במיוחד לאור העובדה שמרבית הערכות בתחום המחלות הזיהומיות אשר פותחו בישראל, החלו להופיע בשוק רק מאז 1988. נתון זה מצביע על כושר למידה מהיר של התעשייה הדיאגנוסטית בישראל.

תעשיית הסנסורים

בהשוואה לתעשיית הדיאגנוסטיקה, תעשיית הסנסורים איננה ענף מוגדר חד. משמעי. זו תעשייה המשתייכת לקטגוריות שונות של ענפי תעשייה רבים, ולכן קשה מאוד היה לזהות בשלב הראשון של המחקר מי הם המפעלים במדינת ישראל שעוסקים ביצור סנסורים. תעשייה זו לא נמצאה מוגדרת

כענף או תת ענף בקטלוג כלשהו, או פורמט של איגוד התעשיינים וכיו"ב.

הסנסורים הוא שם כולל למגוון רחב מאוד של מוצרים אשר בא לידי שימוש במרבית תהליכי הייצור בתעשייה ובחלק מהמוצרים המוגמרים. לכן, ישנן חלוקות רבות של מוצרים אלה לקבוצות המשוייכות לתעשיות שונות. כך לדוגמה, הביו-סנסורים משוייכים בדרך כלל לתעשיית הביו-טכנולוגיה, סנסורים אופטיים בדרך ימצאו תחת ההגדרה של תעשיית האופטיקה ו/או האלקטרוניקה, סנסורים המודדים לחץ, כות, תאוצה, טמפרטורה וכו' ימצאו תחת תעשיית המכונות וכו'.

עם תחילתו של המחקר ב-1990, זיהינו בישראל כ-46 מפעלים העוסקים ביצור עצמי של סנסורים תעשייתיים. באלה כלולים רק מפעלים שמייצרים סנסורים בידע ישראלי, כלומר לא כללנו מפעלים שרכשו את הטכנולוגיה מבחוץ, וכל תרומתם מתמצת בעטיפה של המוצר ושיווקו. בסקר בו איתרנו את המפעלים ואשר ארך מספר חודשים, ניתן היה לחלק את המפעלים לשלוש קבוצות:

א. מפעלים שמייצרים את אלמנט החישה כמוצר לשיווק, או כאלה הכוללים בייצור את השיטה הסנסורית כולה - 27 מפעלים.

ב. מפעלים שרוכשים את האלמנט הסנסורי בחו"ל אולם משפרים אותו טכנולוגית על בסיס ידע מקומי - 13 מפעלים.

ג. מפעלים שבהם הסנסור הוא חלק מתוך מערך יצור של מוצר כולל גדול יותר. הסנסור מהווה מרכיב במערכת מתוחכמת המיוצרת במפעל, ואינו מוצר המשווק בנפרד - 6 מפעלים.

הסנסורים מהווה קבוצת מוצרים מגוונת מאוד ומתחלקת לסוגים רבים. ניתן לחלקם על פי מטלות המדידה שלהם וכן לפי העיקרון הפיסיקלי שבו הם פועלים. אנו הגבלנו את תחום הבדיקה לחלק מסך כל סוגי הסנסורים הקיימים בשוק וחלק ממטלות המדידה, כאשר האילוץ הקובע היה מסד הנתונים אשר עמד לרשותנו. סוגי הסנסורים ומטלות המדידה אשר נכללו במחקר מוצגים ברשימה להלן:

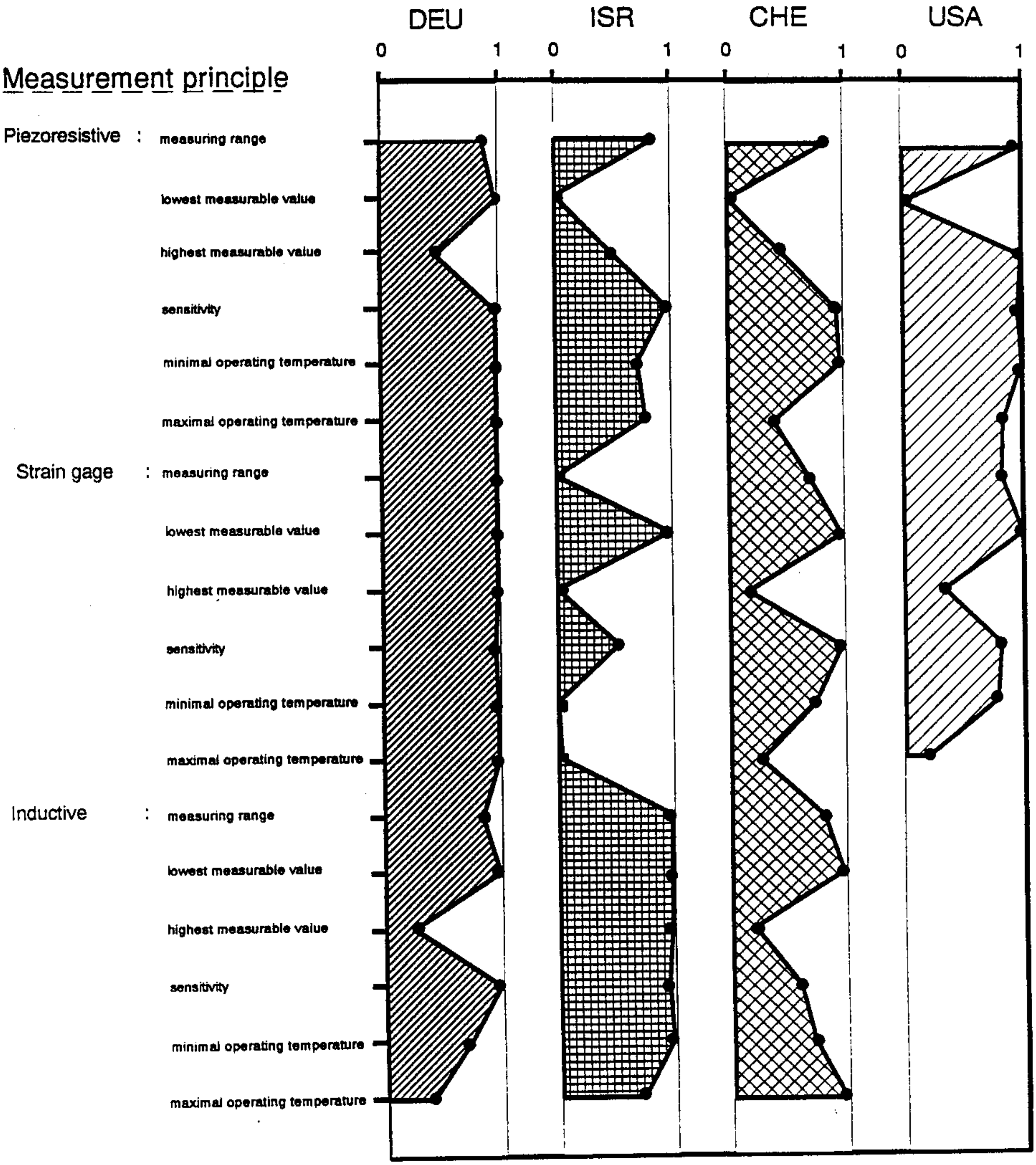
מטלת המדידה	**העיקרון הפיסיקלי**
מדי לחץ	- פיאזו התנגדותי (Piazo-resistive)
	- רצועות מדידה (Strain gage)
	- השראתי (Inductive)
מדי טמפרטורה	- טרמו חשמלי (Termo-electic)
	- התנגדותי (Resistive)
	- אינפרה אדום (Infra-red)
מדי תאוצה	- פיאזו-חשמלי (Piazo-electric)
	- השראתי (Inductive)
מדי כוח	- רצועות מדידה (Strain gage)
	- השראתי (Inductive)
מדי לחות יחסית	- קיבולי (Capacity)
	- התנגדותי (Resistive)

מסד הנתונים אשר לגביו הופעל מודל הטכנומטריקה, נבנה באמצעות איסוף נתונים בתערוכה בינלאומית לסנסורים אשר התקיימה במאי 1991 בנירנברג שבגרמניה. זו תערוכה הנחשבת לגדולה מסוגה בעולם בתחום הסנסורים ומתקיימת אחת לשנתיים. בתערוכה הציגו כ-400 חברות מארצות שונות את מוצריהן. מתוכם פנינו ל-268 חברות אשר מייצרות סנסורים ממטלות המדידה אשר הוחלט לבחון במחקר. כ-150 חברות נענו לפנייתנו והעבירו אלינו קטלוגים מפורטים בהם נתונים על התכונות הספציפיות של הסנסורים. לאלה צורפו הנתונים אותם אספנו בסקר השדה של מפעלי הסנסורים בישראל. על בסיס הקטלוגים נקבעה הרמה הטכנולוגית המירבית של כל אחת מהחברות. בהתאם להשתייכות של החברות למדינות השונות, מיפינו פרופילים שונים אשר איפשרו להראות את הרמה הטכנולוגית של כל אחת מהמדינות הנבדקות, בחלוקה לסנסורים על פי מטלת המדידה והעיקרון הפיסיקלי של טכנולוגיית המדידה. להלן אראה מספר דוגמאות לפרופילים שנבנו, על מנת להדגים את השימוש במודל הטכנומטרי וסוג המסקנות שניתן להסיק מן התוצאות המתקבלות. המיפוי הגרפי נעשה בצורה שונה מזו אשר הראתי לגבי המוצרים הדיאגנוסטיים.

באיור מס' 10 מוצגות תוצאות המיפוי של סנסורים המודדים לחץ. באיור שלהלן, מופו שלוש קבוצות של סנסורים המופעלים בכל קבוצה על בסיס עיקרון מדידה שונה: סנסורי לחץ אשר מופעלים על פי עיקרון הפיאזו-התנגדותי (Piazo-resistive); סנסורי לחץ הפועלים על פי עיקרון של רצועות מדידה (Straim gage); והקבוצה השלישית היא של סנסורי לחץ הפועלים על פי עיקרון השראתי (Inductive). בכל אחת מן הקבוצות מופה פרופיל תכונות הסנסורים אשר הורכב מ-6 תכונות מאפיינות. כמובן שקיימות תכונות נוספות, אולם המטרה היתה להשוות את הרמה הטכנולוגית של מוצר זה על בסיס מיפוי תכונות בהן ניתן להשיג מידע ממרבית החברות במדינות השונות. כמו כן תכונות אלה המוצגות באיור, היו גם התכונות אשר אותרו על ידי מומחים כרלבנטיות ביותר לתחום הנחקר. המיפוי באיור מס' 10 מצביע על הערך של K^* הוא המדד הטכנומטרי של כל אחת מהמדינות לגבי כל אחת מתכונות המוצר. ההשוואה באיור היא בין 4 מדינות: גרמניה, ישראל, שוויץ וארה"ב. (במחקר נבחנו מדינות נוספות שלא מוצגות באיור שלפניכם). לגבי ארה"ב לא נמצאו חברות אשר יצרו סנסורי לחץ המשתמשים בעיקרון ההשראתי.

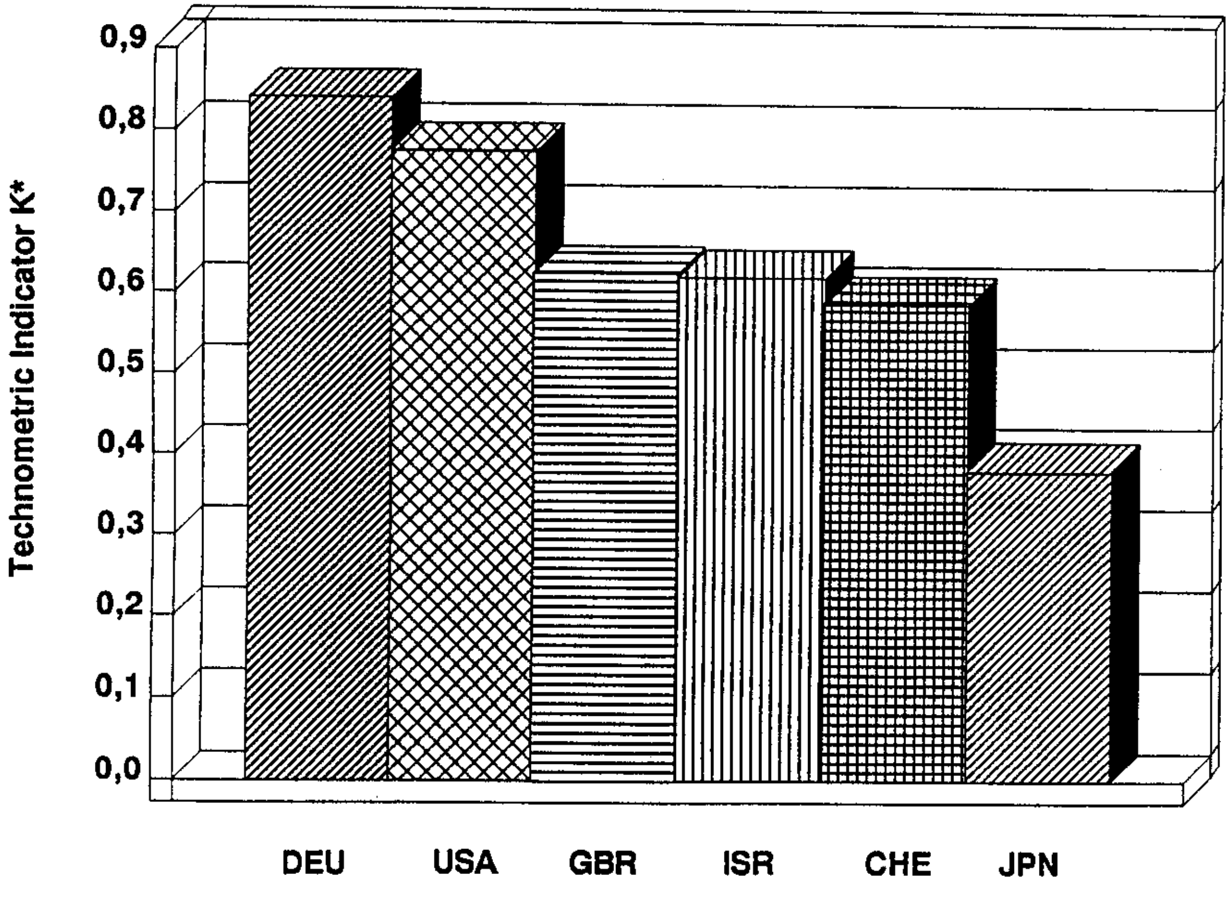
הפרופיל הטכנומטרי מצביע על יתרונה הבולט של גרמניה במיוחד בקבוצת הסנסורים הפועלים על בסיס של רצועות מדידה. רמת הטכנולוגייה של ארה"ב בקבוצת סנסורי הלחץ אף היא גבוהה, ונקודות התורפה שלה הן בקבוצת הסנסורים הפועלים על בסיס רצועות מדידה (בערכי המכסימום של טווח המדידה וערכי המכסימום של טמפרטורה ההפעלה). ישראל מצטיינת במיוחד בטכנולוגיה של סנסורי לחץ הפועלים על בסיס השראתי בהשוואה למתחרותיה, ובמידה מסויימת, אם כי פחותה, גם בסנסורים הפיאזו התנגדותיים. מיפוי הפרופיל הטכנומטרי מאפשר לנו אם כן לזהות את היתרונות היחסיים ואת נקודות התורפה של כל אחת מהמדינות הנבדקות על פי הרמה הטכנולוגית של המוצר הנבדק.

איור מס' 10: פרופיל טכנומטרי של סנסורים למדידת לחץ, לפי תכונות המוצר בחלוקה לקבוצות של עיקרון הפעולה הפיסיקלי בישראל, גרמניה ארה"ב ושוייץ



המודל הטכנומטרי מאפשר גם לקבץ את כל התכונות הפיסיקאליות לאינדכס מיצרפי אחד זאת באמצעות האינדכס המטרי [0,1] עליו הוא מבוסס. באיור מס' 11 מוצגות תוצאות המדד המיצרפי שהושג בכל אחת מהמדינות המושוות במחקר לגבי סנסורי הלחץ. התוצאות מראות כי גרמניה מובילה בראש (עם ציון כולל טכנומטרי של 0.84), לאחריה ארה"ב (0.78) ובריטניה במקום השלישי (עם ציון מצרפי של 0.63). ישראל ניצבת במקום הרביעי (0.62) לפני שוויץ ויפן (0.59 ו-0.38 בהתאמה).

איור מס' 11: פרופיל טכנומטרי מיצרפי השוואתי של סנסוריים למדידת לחץ בהשוואה בין ישראל, גרמניה ארה"ב. שוייץ, בריטניה, ויפן



המסקנה החשובה העולה מניתוח הנתונים הכולל של תעשיית הסנסורים במחקר שחלק קטן ממנו הוצג בפניכם, היא שמבחינה טכנולוגית במרחק לא גדול משלושת המעצמות התעשייתיות הגדולות: ארה"ב, גרמניה ויפן, מצויות לא רק מדינות מתועשות בינוניות כמו בריטניה, צרפת, איטליה ושוייץ, אלא גם מדינות קטנות כגון ישראל, אשר הוכיחה את יכולתה ליסד תעשיית סנסורים מתחרה לפחות בחלק מפלחי שוק הסנסורים. במקרים מסויימים אף השיגה יתרון טכנולוגי בולט על פני שאר המדינות.