



The S. Neaman Institute for  
Advanced Studies in Science & Technology  
Technion-Israel Institute of  
Technology, Haifa Israel



Fraunhofer Institute for  
Systems & Innovation Research  
of Karlsruhe, Germany

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

Vol. I

Final Report 1990 - 1993  
under Support of the German-Israel Foundation  
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## 1. Abstract

This research project applied a new approach to the quantitative measurement of technological sophistication and quality known as technometrics. The basis of this method is construction of a technometric index -- a (0,1) metric -- that reflects the level of a firm's, industry's or country's "best-practice" technology, relative to the prevailing highest standard. Use of the (0,1) metric permits aggregation across product groups, specifications, etc., and generates quantitative estimates of comparative advantage.

This project used technometrics to compare two knowledge-based products made in Israel -- biodiagnostic kits and industrial sensors -- with those of other countries, and to derive resulting policy implications. It was found Israel is highly advanced in diagnostic kits and has products that equal or even surpass those of other nations; but problems in marketing and distribution in distant foreign markets hamper efforts to translate comparative technological advantage into substantial market shares and export dollars. Similarly, our study of industrial sensors revealed that behind the "Big Three" -- Germany, U.S., Japan - - are not only such well-known "players" as Great Britain, France and Italy, but also smaller countries like Israel, who were able not only to produce competitive sensors but in some cases achieved the most advanced technology available on world markets. See [1] [3] [8] [10].

As we collected and analyzed data on product quality, we realized that often, market perceptions of products may differ from objective criteria for product quality. This led to a study of the "voice of the market" -- a comparison of how buyers perceive the relative importance of various product specifications, compared to perceptions of producers and the statistical results obtained by regressing prices on specifications, for industrial sensors. [7].

Our work on technometrics led to a series of broader studies on the entire innovation process, from the basic research stage through the export of

knowledge-based products. Using a system of integrated indicators, we show empirically that compared to 11 European Community nations, Israel is highly efficient in using resources (mainly, R&D expenditures) to generate scientific and technological "outputs" (such as papers, citations, and patents), but is relatively inefficient in using such outputs to generate knowledge-based exports in global markets. See [2] [5] and [6]. We also used a unique database to test empirically two evolutionary theories of innovation. [4].

A final result of this project was construction of an optimization model for second-generation R&D investment, which uses technometric data to guide decisions about which product specifications to improve, subject to constraints on time, manpower and time. [9]

## 2. Objectives of the Original Research Proposal

The primary goal of this joint research project between the S. Neaman Institute and the Fraunhofer Institute in Karlsruhe, Germany, was the application of "technometrics", a technology-assessment methodology originally developed by a team of German researchers, to the evaluation of selected knowledge-based industrial products in Israel, in comparison to similar products abroad.

Our original research proposal stated three major objectives:

- a) Application of the technometric model to the quantitative assessment of comparative advantage, for selected Israeli industries;
- b) Extension and expansion of the technometric methodology;
- c) Extension of the technometric model to products and processes not heretofore studied.

In the course of our research, we extended our objectives to include the following:

- d) The application of the integrated system of indicators for the technological innovation process -- of which the technometric indexes form a part -- to the quantitative measurement of "efficiency" or "success" in resource utilization. This objective was added, because the extensive database on science and technology indicators constructed by Fraunhofer-ISI made it possible to conduct intensive empirical studies of a conjecture widely discussed in Israel, but heretofore not fully explored empirically: Israel's scientific and technological achievements do not find full expression in knowledge-based exports, in comparison with European countries.

### 3. A Summary of Research Results

#### 1. *Technometric Analysis of Israel's Biodiagnostic Industry, vs. Europe, U.S. and Japan*

For biodiagnostic products, Israel is in some cases at the frontier of technological excellence, according to our technometric indexes, and in other cases is close to it. This has occurred despite the fact that far fewer 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.

We believe that 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.

There is growing 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.

*Papers and Publications:*

- [1] A. Frenkel, S. Maital. *The Diagnostic Industry in Israel: Evaluation of Technological Quality Through Technometric Indexes*. The S. Neaman Institute: 1990. Pages iv + 92 . (Hebrew)

(This report comprises a detailed description of technometric results for Israel's diagnostic industry, in Hebrew. The Hebrew edition was requested by the Ministry of Industry and Commerce in order to disseminate the report's results among a wider audience in Israel, in particular among biotechnology firms themselves. )

- [3] Amnon Frenkel, Tomas Reiss, Shlomo Maital, Knut Koschatzky, and Hariolf Grupp. "Technometric Evaluation and Technology Policy: The Case of Biodiagnostic Kits". In press: *Research Policy*.

2. *Technometric Analysis of Israel's Industrial Sensor Industry, vs. Europe, U.S. and Japan*

In the area of industrial sensors, Germany leads in six out of nine analysed physical principles upon which sensors are based -- strain gauge, resistive, piezoresistive, capacitive, mechanic and infrared. Israel's product quality is astonishingly high in thermoelectric and inductive sensors where Israeli products attain the highest scores in quality. The USA rank first in piezoelectric sensors, mainly because her good performance in acceleration sensors.

Behind the "Big Three" -- Germany, U.S., Japan -- such "small" players as Israel prove they are able not only to produce competitive sensors but in some cases achieved the most advanced technology available on world markets.



*Papers and Publications:*

- [8] Knut Koschatzky, Amnon Frenkel, Hariolf Grupp, Shlomo Maital. "A Technometric Assessment of Sensor Technology in Israel vs. Europe, the United States and Japan". *International Journal of Management of Technology*, special issue on Technology Assessment, forthcoming 1994 .

3. *Empirical Study of Relative Efficiency in the Innovative Process: Converting Resources into Scientific Knowledge, and Converting Scientific and Technological Excellence into Knowledge-based Exports*

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 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 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 the earliest stages of innovation, into export performance in the later stages.

*Papers and Publications:*

- [2] H. Grupp, S. Maital, A. Frenkel, K. Koschatzky. "The Relation Between Scientific and Technological Excellence and Export Sales: A Data Envelopment Model and Comparison of Israel to European Countries". Submitted to *Research Evaluation*.
- [5] Shlomo Maital, Amnon Frenkel, Hariolf Grupp, Knut Koschatzky. "Exporting Goods -- or Knowhow? An Empirical Comparison of the Relation Between Scientific Excellence and Export Performance for Israel and European Community Countries". Working Paper.
- [6] Hariolf Grupp, Knut Koschatzky, Amnon Frenkel, Shlomo Maital. "The Relation Between Scientific and Technological Excellence and Export Performance: Theoretical Model and Empirical Test for European Community Countries." Submitted to *Science and Public Policy*. (This paper was accepted for presentation at the 20th Conference of E.A.R.I.E., European Association for Research in Innovation and Entrepreneurship, Tel Aviv, Sept. 3-5, 1993).

4. *Extensions of Technometric Methodology:*

Perhaps among the most critical and difficult decisions faced by senior managers, venture capitalists, and others engaged in R&D funding, are these:

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, or model, able to supply answers to the above questions, based on appropriate data and information. The basic idea is to formulate second-generation R&D investment as a linear-programming problem, with a) an objective function based on technometric indices, and b) constraints reflecting limitations on time, manpower and financial resources. 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]. Work is proceeding on constructing a practical example, in the realm of industrial sensors.

*Papers and Publications:*

- [9] S. Maital, A. Frenkel, H. Grupp, K. Koschatzky. "Toward a Dynamic Technometric Benchmarking Model for Strategic Innovation and Second-Generation R&D Investment." Working Paper, The S. Neaman Institute, Jan. 1993.

There is growing awareness among managers that benchmarking -- the continual examination of product quality and performance, relative to that of industry leaders -- is essential if firms are to maintain their level of competitiveness and market share. The technometric approach to quality measurement is a useful benchmarking methodology. An expository paper was written, and presented on various occasions to scholars and managers, to explain the technometric benchmarking approach, with applications to a wide range of products and processes. Among the examples of technometric benchmarking included are: an evaluation of competing electro-magnetic compatibility (EMC) testing laboratories, and a new hydrogen-based air conditioner for buses.

*Papers and Publications:*

- [10] H. Grupp, K. Koschatzky, A. Frenkel, S. Maital. "How Good are Our Products? Technometric Evaluation of Product Quality". The S. Neaman Institute, Working Paper, March 1991.

Technometric indices of product quality reflect objective product specifications, but fail to take into account the perceptions of buyers -- the "voice of the market". Surveys were undertaken among both the producers of industrial sensors and their customers, to compare perceptions of the relative importance of product specifications; the results were compared, using statistical regression techniques, to "value creation" as expressed in market prices.

*Papers and Publications:*

- [7] A. Frenkel, E. Harel, S.Maital, H. Grupp, K.Koschatzky. "Identifying the Sources of Market Value for Science-Based Products -- The Case of Industrial Sensors". Working Paper: The S. Neaman Institute, May 1993.

5. *Use of Technometric Database for Empirical Study of Evolutionary Models of Innovation:*

A unique technometric database for 12 high-technology product groups, built in Japan in 1982, was utilized to conduct an empirical test of two competing evolutionary models of the innovation process. It was found that newer, more advanced technologies are less diverse (in terms of differences across firms in the same industry or branch). This is consistent with an evolutionary model in which economies of scale and scope inherent in high-level technologies require firms who adopt them to dispose of old technologies, while older, lower-level technologies still permit wide diversities among competing firms.

*Papers and Publications:*

- [4] Shlomo Maital, Hariolf Grupp, Amnon Frenkel, Knut Koschatzky, "The Relation between the Average Complexity of High-Tech Products and Their Diversity: An Empirical Test of Evolutionary Models." Accepted subject to revision, *Journal of Evolutionary Economics*.

(This paper was presented to the 10th World Congress of the International Economics Association, Moscow, Aug. 23-28, at the session in honor of the 50th Anniversary of Joseph Schumpeter's Capitalism, Socialism and Democracy.)

6. *Disseminating Technometric Methodology to Israeli Decision-Makers:*

A final Workshop was held, at which research results were presented to interested scholars and researchers. The three presentations made at that Workshop, by Dr. Hariolf Grupp, Prof. Shlomo Maital, and Amnon Frenkel, form the basis of a Hebrew monograph now in preparation, designed to explain in simple terms the technometric approach to quality measurement, and in general to outline the system of science and technology indicators that help track the innovation process from its start (basic research) to its end (knowledge-based exports).

*Papers and Publications:*

- [11] Workshop on *The Technological Innovation Process: Does Israel Have a Comparative Advantage in Knowledge-Based Products?* (part of it in Hebrew). The S. Neaman Institute for Advanced Studies in Science and Technology, Haifa: 1993.

#### 4. Cooperation between Research Teams in Germany and Israel

Cooperation among the Israeli and German researchers was close and effective. It found expression in the following ways:

- *publications*: We anticipate that as many as 10 publications will result from our collaboration. Responsibility for authorship, revision and submission to journals were all shared. Articles have been submitted to, and in some cases already accepted by, the leading journals in the area of innovation and research, including; Research Policy, Research Evaluation, Science & Public Policy, International Journal of Management of Technology, and Journal of Evolutionary Economics.

- *data sources*: Fraunhofer-I.S.I. has an extensive and remarkable collection of data on scientific and technological indicators, going well beyond technometric data. These data have proved extremely valuable in constructing operational examples of the theoretical models developed during the first two years of our research. The investigators from Fraunhofer-I.S.I. have made available these data, in many cases processing them and converting them into suitable form, and have actively taken part in the choice of suitable parts of the data, in collaboration with the Israeli investigators.

- *data collection*: Frenkel and Koschatzky have collaborated closely in the collection of data on sensors. Frenkel visited the key Nuremberg exhibition for sensors and systems technology in May 1991, and together with Koschatzky, exhaustively canvassed the exhibitors for information on their new products. Following that visit, Koschatzky and Frenkel worked closely on the construction of technometric indicators of sensor quality, particularly during the visit of the Israeli investigators to Fraunhofer - I.S.I. in September 1991. Frenkel and Reiss worked closely on the collection, analysis and processing of data on biodiagnostic kits.

*Formal meetings:* List of mutual visits:

\* Karlsruhe, 1989 -

Prof. S. Maital - Oct. 15 to Oct. 19, 1989

Mr. A. Frenkel - Oct. 15 to Oct. 26, 1989

\* Technion, 1990 -

Dr. Hariolf Grupp - Jan. 27 to Jan. 30, 1990

Dr. Knut Koschatzky - Jan 24. to Jan. 31, 1990

\* Karlsruhe, Oct. 1990 -

Prof. S. Maital - Sept. 23 to Sept. 27, 1990

Mr. A. Frenkel - Sept. 23 to Oct. 12, 1990

\* Nuremberg, 1991 -

May 13, 1991 - May 16, 1991 - Amnon Frenkel: working meeting with Knut Koschatzky during the exhibition SENSOR 1991.

\* Karlsruhe, 1991:

Sept. 23, 1991 - Sept. 27, 1991 - Amnon Frenkel and Prof. Shlomo Maital, working meeting with Dr. Hariolf Grupp and Dr. Knut Koschatzky at Fraunhofer Institute.

\* Cambridge, MA., 1992

(Massachusetts Institute of Technology- Sloan School of Management).

February 1992. Dr. Grupp and Prof. Maital presented a paper on

Technometric Benchmarking to the International Center for Research on Management of Technology.

\* Karlsruhe, 1992 -

October 12-18, 1992. Amnon Frenkel and Prof. Shlomo Maital,

working meeting with Dr. Hariolf Grupp and Dr. Knut Koschatzky at Fraunhofer-ISI.

\* Technion, 1993 -

April 13-16. Dr. Hariolf Grupp, visit to S. Neeman Institute for a working meeting with S. Maital and A. Frenkel, including presentation to a Workshop on Technological Innovation, at the Technion.

\* Karlsruhe, 1993 -

August 8-10, 1993. Amnon Frenkel, working meeting with Dr. Hariolf Grupp and Dr. Knut Koschätzky at Fraunhofer-ISI.



## 5. Evaluation of Research Achievements, In relation to the Aims of the Original Research Proposal

On completion of our research, it is our view that the original research objectives: a) application of the technometric model to the quantitative assessment of comparative advantage, for selected Israeli industries; b) extension and expansion of the technometric methodology; c) extension of the technometric model to products and processes not heretofore studied, were all attained, along with an additional one: d) the application of the integrated system of indicators for the technological innovation process to the quantitative measurement of "efficiency" in R&D resource utilization.

- a) *Quantitative assessment*: The technometric model was applied to an in-depth study of two sub-industries: biodiagnostic kits and sensors. The study of eight biodiagnostic firms, through the technometric approach, revealed a high degree of technological excellence that suggests potential for large exports in future, well beyond the relatively small initial values of exports attained at present (stemming, in part, from the youth of the industry). For industrial sensors, Israel attains an unexpectedly high overall indicator of 0.558, and for some types of sensors holds the lead over all countries in the sample (including Japan and Germany), showing that Israel has an advanced sensor industry, whose smaller variety makes it possible to concentrate technological knowhow to specific fields.

We hope and expect that our technometric studies of biodiagnostic kits and sensors will serve as models for similar quantitative studies of competitive advantage, undertaken for purposes of public policy-making in the areas of science, technology, R&D and trade.

- b) and c) *Extension of the technometric model*: We developed an optimizing model for guiding R&D expenditure in improving second-generation products, built on technometric indicators. We also explored the "micro"

use of technometric indicators, as a benchmarking tool for management decisions, rather than as a "macro" tool for guiding policy-makers at the industry and economy-wide level. We also used a technometric database to conduct an empirical study of two competing evolutionary models of innovation.

d) *Efficiency of R&D resource utilization*: We used a variant of linear programming known as Data Envelopment Analysis (DEA), as well as conventional linear statistical regression techniques, to examine the link between scientific and technological excellence and export sales. Our objective was to address the questions of: a) how to determine whether countries are efficiently translating their investment in the base of science and technology into success in export markets, and b) how well is Israel utilizing R&D resources, to generate scientific knowledge and knowledge-based exports.

Compared to 11 European Community nations, Israel is highly efficient in using resources (mainly, R&D expenditures) to generate scientific and technological "output" (such as papers, citations, and patents), but is relatively inefficient in using such outputs to generate knowledge-based exports in global markets.

One of the objectives originally stated in the proposal submitted to G.I.F. was to disseminate information about "technometric benchmarking" to Israeli policymakers and managers in knowledge-based industries. To that end, a Workshop was held on April 15, 1993 at the S. Neaman Institute, on "The Process of Technological Innovation: Does Israel Have a Comparative Advantage in Knowledge-Based Products?". A Hebrew monograph [11] based on the lectures given at the Workshop, is in preparation and will hopefully make the large and scattered literature on technometrics, much of it in English and German and written in somewhat technical language, more accessible to Israeli decision-makers.

## 6. List of Papers and Publications

- [1] A. Frenkel, S. Maital. *The Diagnostic Industry in Israel: Evaluation of Technological Quality Through Technometric Indexes*. The S. Neaman Institute : 1990. Pages iv + 92 . (Hebrew)
- [2] H. Grupp, S. Maital, A. Frenkel, K. Koschatzky. "The Relation Between Scientific and Technological Excellence and Export Sales: A Data Envelopment Model and Comparison of Israel to European Community Countries". Submitted to *Research Evaluation*.
- [3] Amnon Frenkel, Tomas Reiss, Shlomo Maital, Knut Koschatzky, and Hariolf Grupp. "Technometric Evaluation and Technology Policy: The Case of Biodiagnostic Kits in Israel". In press: *Research Policy*.
- [4] Shlomo Maital, Hariolf Grupp, Amnon Frenkel, Knut Koschatzky, "The Relation between the Average Complexity of High-Tech Products and Their Diversity: An Empirical Test of Evolutionary Models." Accepted subject to revision, *Journal of Evolutionary Economics*.
- [5] Shlomo Maital, Amnon Frenkel, Hariolf Grupp, Knut Koschatzky. "Exporting Goods -- or Knowhow? An Empirical Comparison of the Relation Between Scientific and Technological Excellence and Export Performance for Israel and European Community Countries". Working Paper.
- [6] Hariolf Grupp, Knut Koschatzky, Amnon Frenkel, Shlomo Maital. "The Relation Between Scientific and Technological Excellence and Export Performance: Theoretical Model and Empirical Test for European Community Countries." Submitted to *Science and Public Policy*.

- [7] A. Frenkel, E. Harel, S.Maital, H. Grupp, K.Koschatzky. "Identifying the Sources of Market Value for Science-Based Products -- The Case of Industrial Sensors". Working Paper: The S. Neaman Institute, May 1993.
- [8] Knut Koschatzky, Amnon Frenkel, Hariolf Grupp, Shlomo Maital. "A Technometric Assessment of Sensor Technology in Israel vs. Europe, the United States and Japan". *International Journal of Management of Technology*, special issue on Technology Assessment, forthcoming 1994 .
- [9] S. Maital, A. Frenkel, H. Grupp, K. Koschatzky. "Toward a Dynamic Technometric Benchmarking Model for Strategic Innovation and Second-Generation R&D Investment." Working Paper, The S. Neaman Institute, Jan. 1993.
- [10] H. Grupp, K. Koschatzky, A. Frenkel, S. Maital. "How Good are Our Products? Technometric Evaluation of Product Quality". The S. Neaman Institute, Working Paper, March 1991.
- [11] Workshop on The Technological Innovation Process: Does Israel Have a Comparative Advantage in Knowledge-Based Products? The S. Neaman Institute for Advanced Studies in Science and Technology, Haifa: 1993.