The S. Neaman Institute
for Advanced Studies in Science
and Technology

MIT Enterprise Forum of Israel

G.I.F. - German-Israel Foundation

Technion - Israel Institute of Technology
Faculty of Industrial Engineering and Management

Symposium on

INNOVATION:
Technology Assessment, Forecasting, Strategy and Regional Policy

Iskar Ltd., Tefen, Galilee, ISRAEL

Thursday, May 29, 1997

Conference Volume

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A recent study by W. Chan Kim and Renee Mauborgne (INSEAD) studied the business launches of 100 companies. [Harvard Business Review, Jan-Feb. 1997]. Some 86 per cent of the companies launched products that were similar to existing ones. Only 14 per cent were truly innovative. The innovative companies -- one out of seven -- generated three-eighths of the total sales for all 100 companies, and a whopping 62 per cent of total profits. In other words: the 14 innovative companies generated nearly twice as much total profit as the 86 conservative companies.

Today's symposium on Innovation: Technology Assessment, Forecasting, Strategy and Regional Policy focuses on applied research on technology-based innovation that we hope managers will find helpful in decision-making. The basis of the conference is two research projects, funded by the German-Israel Foundation and conducted by researchers at the S. Neaman Institute for Applied Studies in Science & Technology, Technion, in partnership with scholars from Fraunhofer-ISI, Karlsruhe, Germany.

To stress the applied nature of this gathering, we chose to hold it at Iscar Ltd., a leading global cutting-tool company whose competitive advantage stems from its high level of innovation in both product and process.

Innovation is no longer a luxury -- it is a vital necessity for survival and for profitability for most companies. We hope and trust our discussions today will help create ideas and tools useful for building innovative products and innovative companies.

Sincere thanks to: the German-Israel Foundation for generous research funds. The Neaman Institute for support and facilities, MIT-Enterprise Forum of Israel for supporting this conference, and Iscar Ltd., for their hospitality and support.

With best wishes,

Prof. Daniel Shefer
Daniel Shefer
Dean, Faculty of Architecture
and Town Planning

Prof. Shlomo Maital

Head, MBA Program
Faculty of Industrial Engineering
and Management

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at Iskar Ltd., Tefen, Galilee

Program

08.00	Meet at the S. Neaman Institute, Technion, Haifa Transportation by bus to Iskar Ltd., Tefen
09.15	Registration, Coffee, Welcome
09.30-10.15	**Technology Assessment** "Managing Incremental and Radical Innovation - A Decision-Support Model for Optimizing R&D Investment, with applications to Science Based Products". Asaf Ben-Arieh, Hariolf Grupp, Shlomo Maital
10.15-10.45	**Technology Forecasting** "Technology Assessment through Foresight: Synergies between Two Strands of Research". Hariolf Grupp.
10.45-11.15	Tour of Iskar Ltd. Factory
11.15-12.00	**Technology Strategy** "Technology Assessment in less-developed countries: The strategy of building on regional "unique products" ". Joseph Ben-Dak, Founder and Chief, UN Global Technology Group.
12.00-12.45	Lunch
	Guided Tour of the Tefen Area and Kfar Vradim, including slide presentation by Harry Brand, Tefen Architect

14.00-14.30 **Technology Strategy**
"Dilemmas & Applications of Technology Strategy
in a Changing World: The Case of RAPHAEL"
Naftali Amit, V-P (R&D), RAPHAEL

14.30-15.15 **Regional Policy #1**
"Regional Innovation Profiles of firms in Fast-Growing Industries:
A German-Israel Comparison".
Amnon Frenkel, Daniel Shefer

15.15-15.45 **Regional Policy #2**
"Emergence and Development of Regional Technology Policy in
Germany: The Technological Region of Karlsruhe as an Example".
Guenter H. Walter

15.45-16.00 Wrapup

16.00-17.00 Return by bus to the S. Neaman Institute

Invited Speakers (listed alphabetically)
Dr. Naftali Amit, V-P (R&D), RAPHAEL
Dr. Asaf Ben Arieh, M.D. Senior Manager, Disonics Ltd., Haifa.
Mr. Joseph Ben-Dak, Founder and Chief, UN Global Technology Group.
Dr. Amnon Frenkel, The S. Neaman Institute and Faculty of Architecture and Town Planning, Technion
Dr. Hariolf Grupp, Deputy Director, Fraunhofer-ISI, Karlsruhe, Germany
Prof. Shlomo Maital, Head, MBA Program, Faculty of Industrial Engineeering and Management, Technion
Prof. Daniel Shefer, Dean, Faculty of Architecture and Town Planning, Technion
Dr. Guenter Walter, Senior Researcher, Fraunhofer-ISI, Karlsruhe, Germany

All papers will be presented in English

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PART A: Conference Papers30

Optimal Incremental Innovation
A Mathematical Programming Approach for Integrating R&D & Marketing

Asaf Ben Arieh
Disonics Ltd.
Haifa Israel

Hariolf Grupp
Fraunhofer-ISI
Karlsruhe Germany

Shlomo Maital
Faculty of Industrial
Eng. & Management,
Technion, Haifa ISRAEL

Acknowledgements: This paper is part of a research project on "Technometric Benchmarking" funded by the German-Israel Fund, to whom we express our gratitude. Additional support was provided by the Technion VPR Fund for the Promotion of Research, and the Y. Apter Research Fund. We thank Dr. Alexander Vaninsky for his programming assistance.

Abstract

We construct new operational definitions of incremental innovation, standard innovation, and radical innovation, using our "technometric benchmarking" model. Based on this definition, optimal incremental innovation is formulated as a linear programming problem. The model is illustrated by an actual case: reconfiguration of a gamma camera. We show how our model can contribute to improved allocation of R&D resources, by integrating marketing and R&D in a single decision-support model.

1. Introduction

Whether, when and how to reconfigure existing products, processes or services are standing issues facing senior managers. While much research has been conducted on managing R&D to achieve dramatic, revolutionary innovations, everyday business success probably depends more on the quality of more humdrum, incremental improvements to existing products and services. Perhaps 90 per cent or more of so-called "new" products are in fact reworked versions of existing ones.

Yin (1994), for instance, argues that "...the mentality that seeks large breakthroughs instead of step-by-step cumulative efforts for incremental advances dominates technology strategy ...[as a result] cutting-edge companies have largely overlooked the significance of related economic returns (from incremental advances) in their planning process..." (p. 266). Utterback (1994, p. 189, citing Gomory and Schmitt, 1988) observes, "most products sold today were here in slightly inferior form last year, and most competition is between variants." "Since standard, or dominant designs, exist in most industries, one can argue that incremental innovation is a far more prevalent and common management problem -- though perhaps a more tractable one -- than radical innovation", Christensen, Suarez & Utterback (1996) note.

Decision-makers facing reconfiguration dilemmas must tackle such complex questions as: When should a reconfigured "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 product? Which characteristics of the product deserve priority in terms of their cost-value ratios? How can R&D resources -- funds, manpower and even time -- best be invested, in the most cost-effective manner, to improve the product's value-creating power?

With growing importance attached to strategic innovation, along with rising R&D costs, there is need for a operational, quantitative decision-support models to guide strategic decision-making. Over a decade ago, Lee, Fisher and Yau (1983) asked rhetorically: "How are managers, many of whom are not themselves technically trained, to evaluate in real time the progress --and approriateness -- of {R&D} investments?" Managers who do have the requisite technical understanding face another challenge -- allocating time. Gluck and Foster (1975) observed two decades ago that top managers spend most of their time -- up to 95 per cent of it -- putting out fires in marketing and production even though their ability to influence their firm's outcomes is far greater in the study, design and development stages -- where ceo's invest perhaps five per cent of their time.

How can researchers help managers best carry out R&D for product redesign? Hauser (1996) argues persuasively for the use of mathematical models in product development, and surveys a variety of them. Following his lead, the model proposed here is an attempt to provide a quantitative tool for optimal second-generation R&D. It builds on Hauser (1996) and Meyer, Tertzakian and Utterback (1995), who have proposed a variety of "metrics" , or quantitative measures, for managing R&D.

A number of attempts have already been made to construct quantitative operational models for guiding R&D resource allocation. Scholefield (1994) notes that "the allocation of R&D resource in a multibusiness organisation is often based more on current operating performance than on the relative potential for technological development of the businesses." His model seeks to link R&D allocation to business strategy. Gittins (1994) proposes a planning model he calls "RESPRO" for new-product chemical research; Yin (1994) studies incremental improvements in petroleum refining.

Our model is based on standard economic cost-benefit logic that seeks to quantify and maximize the benefits of reconfiguration, relative to resource constraints on person-hours, capital funds and time alloted to the task. 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 -- and on "benchmarking" -- the continuous process of measuring products, services, and practices against the toughest competitors or industry leaders.

The structure of this paper is as follows. The next section outlines a typology of innovation, and proposes new definitions of the three types of innovation: incremental, standard, radical. Section 3 outlines our model, using cost-benefit logic and building on our typology. The next section provides an empirical illustration based on reconfiguration of a gamma camera used in magnetic imaging for medical diagnostics. We conclude with some general observations on how mathematical modelling can help integrate R&D and marketing.

2. An Operational Typology of Innovation: Some basic theory

a) technometric benchmarking: Lancaster (1991) observed that "the good, per se, does not give utility to the consumer; it possesses characteristics, and these characteristics give rise to utility" (p. 13). A product characteristic is an important feature of the product that satisfies needs or in other ways creates value for its buyers. Marketing researchers have long believed that no-one buys a "car", but rather, buys style, glamor, comfort, convenience, economy, status, and reliability.

It follows that the development, production and marketing of goods and services can best be understood and modelled, by focusing on key product characteristics or attributes. This is the foundation of a novel approach to product benchmarking known as "technometrics" (Grupp, 1990, 1992; Grupp & Hohmeyer, 1986, 1988; Frenkel, Reiss, Maital, Grupp, 1994; Koschatzky, Frenkel, Grupp and Maital, 1996). It is also the basis of a huge literature in marketing on what are called "multi-attribute models" (Fishbein, 1963; Fishbein and Ajzen, 1975; Bass and Talarzyk, 1972; Wilkie and Pessemier, 1973; Curry and Menasco, 1983).

Technometric benchmarking builds comparative metrics of product quality and competitiveness by implementing the following four stages for a given product, process or service:

- Choose the fundamental characteristics or attributes, that capture how the product, process or service creates value for customers. These attributes must be capable of being measured (though ordinal scales are acceptable), and usually number between five and 12.
- Measure those attributes, and do the same for competing products.
- Normalize each of the product's attributes on a [0,1] metric, where 0 represents the attribute's lowest value among all competing products, and 1 represents that attribute's highest value.
- Graph, aggregate, and otherwise analyze, the product's strengths and weaknesses, across all attributes.

Here are two examples of the use of technometric benchmarking, for medical-imaging printers and "laser strippers" (used in removing photoresistance material from silicon wafers).

Table 1 shows attribute values, and technometric scores for seven attributes, for a new laser-stripper and four competitors. (Laser strippers are instruments that remove photoresistive materials, in the semi-conductor industry).

Table 1. Laser Strippers: L-Stripper vs. four competitors
Values of key attributes: Original values ("act") and
technometric [0,1] scale ("tech")

	L-STRIPPER		Competitors: #1		#2		#3		#4	
	act.	tech.	act	tech	act	tech	act	tech	act	tech
Process performance	40	.6	50	1.0	25	0	30	.2	35	.40
Yield	*	1.	77	.97	55	.60	19	0	79	1.0
Reliability	-	0	-	.89	-	1.0	-	.39	-	.36
MTBF	-	-	130	1.0	130	1.0	65	0	80	.25
MTTR	-	-	8.5	.75	7	1.0	13	0	8	.83
UPTIME	-	-	92	.93	95	1.0	85	.78	50	0
Throughput	50	1.0	45	.75	35	.25	50	1.0	30	0
Particles	0.1	1.0	.02	1.0	.02	1.0	.12	0	.04	1.0
CV	100	1.0	100	1.0	100	1.0	0	0	0	0

Notes:

Process performance - test for quality of removal of photoresistors, scale of 1 to 100 points

Yield - percent of total components usable, out of total number of components on the wafer.

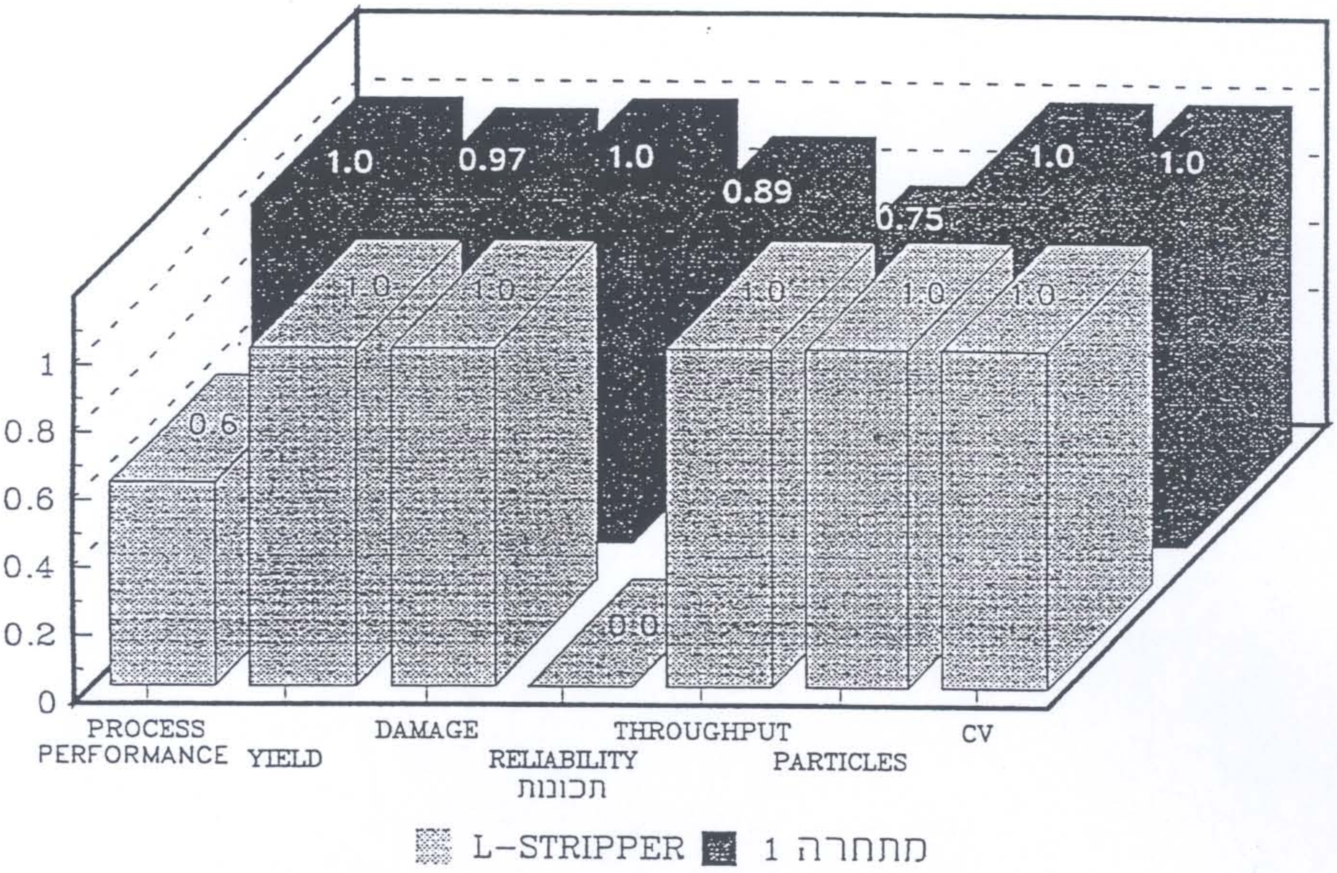
Reliability - three characteristics: MTBF (mean time between failure), MTTR (mean time to repair), UPTIME (% of time the device is operating).

Throughput - speed of operation, measured in wafers per hour

Particles - test for presence of undesirable particles after completion of stripping process.

CV - test for presence of conductive ions (generated in the stripping process).

Fig. 1. L-Stripper vs. Leading Competitor (#1)

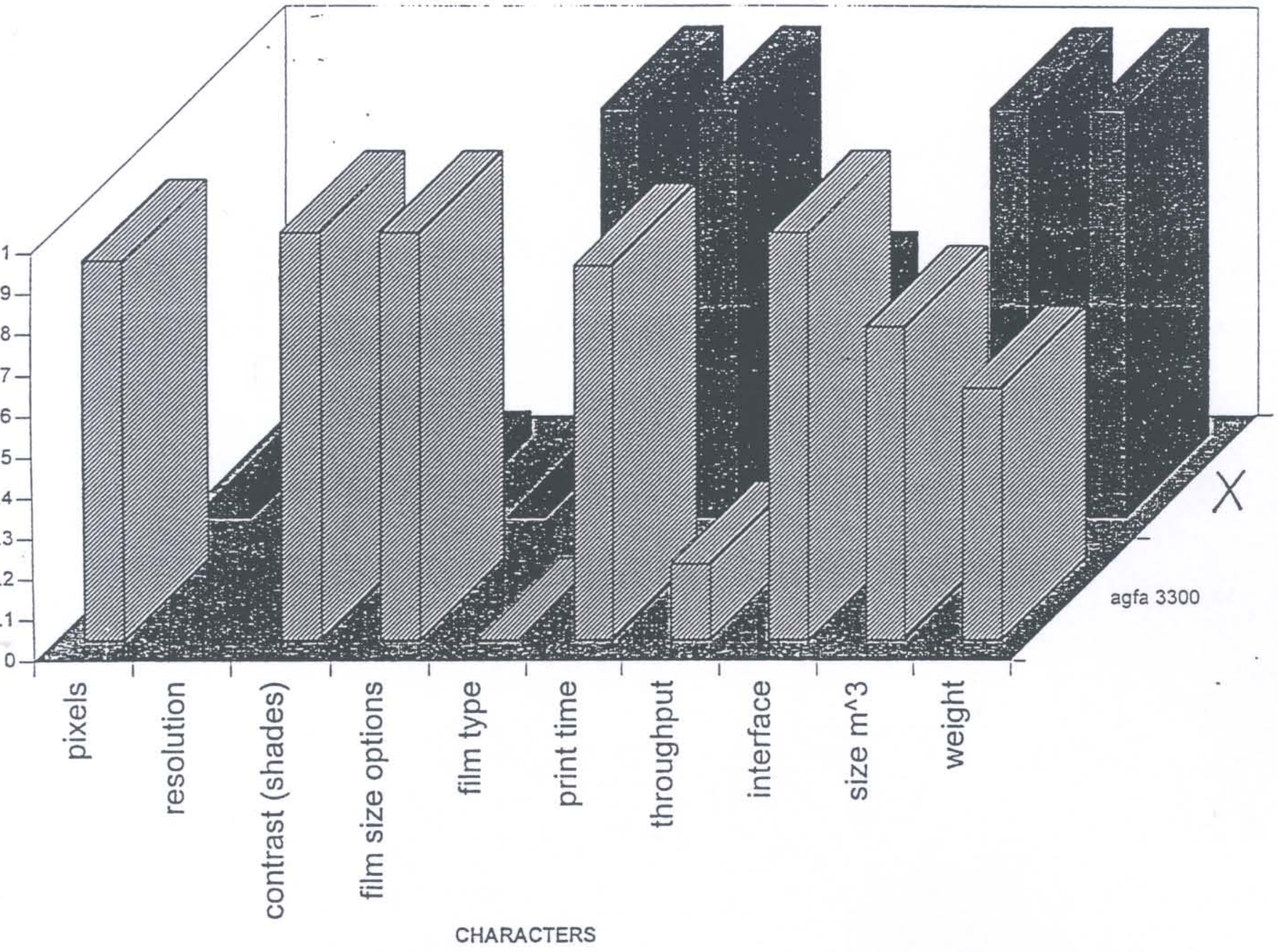


The new product excels in all but two characteristics: "process performance" (rated as highly important by customers) and "reliability", where it scores lowest. Its dismal reliability score make the product unmarketable in its current form. Further development efforts will focus on these two weak points. (See Figure 1).

Fig. 2 compares a leading medical-imaging printer (Agfa) with a new challenger ("X"). The challenger excels against all models, including Agfa, in film type, print time, size and weight -- but falls short in other key attributes. The new product in its existing form failed. The technometric "silhouette" shown in Fig. 2 helps us understand why. What appears utterly obvious, after carrying out the technometric benchmarking, is in our experience often far from obvious beforehand. Carrying out a characteristic-by-characteristic quantitative analysis forces the careful numerical benchmarking that decision-making demands.

b) a typology of innovation: The technometric benchmarking approach can be used to construct a typology of innovation. In our view, no satisfactory operational definition currently exists of the various types of innovation: incremental, standard and radical. Rosegger (1996) defines radical innovations as "clear discontinuities in economic activity" (p. 237) , e.g. steam engine, computers; implying that incremental innovations are innovations that are neither basic nor major, arising principally when standard or dominant designs exist as platforms on which minor improvements are made. Yin's (1994) definition for radical innovation: "a revolutionary change that contains a high degree of new knowledge [while] incremental improvement is a renovation and adjustment of current technology with a low degree of new knowledge." [pp. 265-66].

Figure 2. A graphic technometric comparison of two medical imaging printers: Agfa versus "X"



These definitions rest on rather vague notions of "major", and "new knowledge". We now proceed to build a new operational typology of innovation, based on the Lancaster attribute model.

We define a product, service or process as a finite collection of characteristics or attributes, all of them measurable in either physical or ordinal units (e.g. consumer satisfaction scales). For a given product, let those "n" attributes be x_i , where i = 1...n . A product, then, is simply a vector of attributes:

$[x_1 \quad x_2 \quad \ldots\ldots\ldots\ldots \quad x_n]$

Definitions:

1. An incremental innovation is one in which a new version of an existing product has some or all of its existing attributes improved. The new vector is:

$[x^*1 \quad x^*_2 \quad \ldots\ldots\ldots\ldots \quad x^*_n]$, $x^*_i > x_i$

where x^*_i is the new post-development value of attribute i.

{We are aware that managers may consciously choose to "worsen" some xi attributes, perhaps to improve others or save costs. An example that comes to mind: Purchase by RJR Nabisco of a bakery-products company, Engelman's, and resulting reduction in the quality of ingredients. Our model, however, presumes this particular design stage to have been optimized already - perhaps using conjoint analysis. We deal only with innovation involving attributes that are "better, or at least no worse".}

2. A standard innovation is one in which the vector of product attributes is:

$[x'_1 \quad x'_2 \quad \ldots\ldots\ldots\ldots \quad x'_n \quad x'_{n+1}]$, $x' > x$

where x'_{n+1} represents a new product attribute that did not previously exist.

The difference between a standard innovation and an incremental innovation, is that one additional attribute is added to the product, that did not exist before (while existing attributes may or may not be improved somewhat). An example could be the addition of CD-ROM

read-only drives to PC's.

A radical innovation is an innovation such that "k" significant new attributes are created, $k > 2$, which did not before exist -- creating, essentially, a wholly new product:

$$[(x'_1 \quad x'_2 \quad \ldots\ldots\ldots\ldots \; x'_n) \quad (x'_{n+1} \; x'_{n+2} \; x'_{n+3} \ldots x'_{n+k})] ,$$

An example is a new pen-based computer, that stores handwritten material in its memory, then recognizes each character and transfers the material to standard computer files. Some of its attributes: pen size, memory size, accuracy of letter recognition, etc., are new and are thus not comparable to existing attributes of conventional computers.

A hypothetical example of an incremental innovation is shown below in Table 2, for a large business jet, the Gulfstream IV. A reconfigured improved Gulfstream V may have better range, speed, payload, climb and cabin room. The new vector of attributes quantifies the degree to which the product was improved, in a way that permits easy benchmarking against competing products.

Table 2

Gulfstream IV vs. "Improved" Gulfstream

	range	payload	speed	climb	takeoff
OLD	4141	3.66	459	4014	5280
NEW	5000	3.66	480	4500	5280

	cabin room	noise	cost per mile
OLD	2008	76.8	18.28
NEW	2500	76.8	18.28

Corporate decisions to launch R&D programs for radical innovation are often crucial, and often compete with less risky, less costly -- and potentially less profitable -- incremental-innovation R&D. An example is Intel's decision to continue developing SISC technology for its 486-successor chip, rather than develop a RISC chip, like the Power-PC of Motorola-IBM-Apple. In retrospect, the decision was a good one, aided by clever technological improvements leading to the Pentium and Pentium Pro.

We propose here a decision tool to aid managers in optimizing their incremental innovations, based on technometric benchmarking. With slight adaptation, our model could serve decision-making for standard innovations as well, and with considerable alteration, for radical innovation.

3. A Mathematical Programming Model of Incremental Innovation

Consider a managing with limited labor, capital and financial resources, and especially limited time, managing an R&D project to create incremental innovation for an existing product. What attributes should be improved? How can the R&D investment best be utilized? Is the project worthwhile at all? How can one know? Our model supplies some answers.

Managers seek the most valuable feasible combination of improvements in product (or process) specifications, that meets a) cost; b) skill; and c) time constraints. "Valuable", in our model, means: The highest possible weighted average of product attribute improvements, where the weights reflect the value consumers attach to the improvement of each attribute.

We believe that senior management's ultimate objective is to supply the market with the most valuable, attractive package of attributes possible. Products that best create value, will best create sales,
market share and profit.

)

Formally,

a) Terminology:

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

x_i - technometric specification for characteristic "i", based on {0,1} metric {0 is lowest performance, 1 is highest performance, among competing products}

Δx_i - change in xi through R&D investment

c_i - cost of making incremental change in x_i

t_i - time needed to make incremental change in x_i

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

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

C - total R&D budget ($ million)

L - total number of skilled labor-hours

T - time available for completing R&D

b) Model:

Objective function:

Choose Δx_i to: Max $\Sigma\ w_i\ \Delta x_i$

subject to Capital, Labor and Time Constraints:

Capital: a) $\Sigma\ ci\ \Delta x_i < C$

Labor: b) $\Sigma\ li\ \Delta x_i < L$

Time: c) $\Sigma\ t_i\ \Delta x_i < T$

That is: allocate labor, capital and time to R&D efforts, in order to improve the product's attributes, in a way that generates that highest-value "basket" of product attributes, where "basket" is a weighted average of the product attributes, with weights reflecting how the market (i.e. customers) values the improvements.

This is a linear-programming model. Incremental improvements are consistent with the assumption of linearity. But in many cases, the constraints may well be non-linear in nature. This can easily be handled by implementing quadratic or other non-linear programming techniques.

Standard linear programming algorithms provide solutions that include: the optimal improvement ΔDxi for each attribute, and the way to achieve the improvement through investment of labor, capital and time.

c) Voice of the Market:

A vital aspect of the model is the "w_i " weights, which can play a crucial role in deciding which attributes of the product should be improved How can they be determined? One approach is through conducing "voice of the market" surveys among customers, who indicate on a questionnaire the relative importance of each of the product attributes. There are other 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). {See, for example, H. Grupp and S. Maital, "Interpreting the sources of market value in a capital goods market: R&D Management in industrial sensors", 1996}.

Finally, conjoint analysis can be used to evaluate "tradeoffs" of consumers among competing attribute improvements. Chan Choi and DeSarbo (1994) define conjoint analysis: "In a typical conjoint-based product designing or concept testing procedure, estimated individual level part-worth utilities are used to simulate the potential market shares of proposed product concepts against existing competitors' brands. .... "we compute equilibrium market shares and prices for each scenario of a concept profile versus existing brands". (pp. 451-454).

4. An example: The Gamma Camera - "Acu-Scan"

Background:

The gamma camera is an imaging system intended to assist in diagnosis of illness by doctors. It produces images of the radiation generated by radioisotopes within a patient's body, with the objective of examining organ function and anatomy and to detect abnormalities. It serves as a diagnostic tool, in the hands of the physician, for evaluation and followup of disease and physiological problems. Initially a radioisotope attached to a chemical mediator is injected into the human body and targeted to a specific organ. When the radiopharmaceutical accumulates in the target organ, it emits radiation, which is detected and counted by the gamma camera detectors. The data collected is then processed by a computer, and can be rendered as a graphic picture, on a computer monitor. The nuclear radiologist can then provide his interpretation and diagnosis, and report his findings.

The customers whose preferences are decisive are those of the doctors, who use the camera's output, and the technicians who operate it. The market for gamma cameras is increasingly influenced by the trend to managed health care, which focuses attention on the camera's price efficiency: cost relative to its performance.

Seven basic parameters charcterize the camera's appeal to customers: a) price, b) its ability to carry out optimally a wide variety of medical applications, c) ease of operation; extent to which operation is automatic; d) connectivity to other systems and work stations; e) ability to carry out examinations using high-energy isoteps (511 kev); f) resolution; g) downtime.

The Product:

Acu-Scan is a pseudonym for an actual multipurpose gamma camera, produced by a mid-size firm that specializes in medical instruments. Acu-Scan has two detection heads positioned opposite one another, at a fixed 180". The heads are attached to a gantry and are placed on a large ring that rotates the heads around the patient. Patients are usually examined in a prone position, lying on a bed. The bed moves up and down, backward and forward. Acu-Scan is regarded as a highly sophisticated system, incorporating cutting-edge mechanical, electronical , and computer technologies. Its resolution is high, its automated operation provides ease of operation and reduces the need for skilled operators. Its conectivity with other systems is good, making it usable in modular form with other equipment in the clinic. However, Acu-Scan's price is regarded as above average in its market, and it lacks some attributes other cameras possess -- like heads with variable, adjustable angles. Acu-Scan is unable to perform transmission of rays simultaneously with emission (of radiation), a method used to improve reliability and reduce artifacts, an attribute that now represents state of the art in nuclear medicine, specifically in nuclear cardiology.

The Management Problem:

As Acu-Scan completed its introduction and penetration of the market, a marketing need was discerned, to develop a more advanced dual-head camera, with only a 12-month development time and a limited budget. The Acu-Scan marketing department defined a number of improvements in the camera's performance attributes, that were perceived as vital to maintain market share and market leadership in the nuclear medicine marketplace.

The questions that faced management were:

- In which attributes should R&D resources be invested,
- what are the priorities,
- how much money, manpower and time should be invested, and
- what will be the value of the reconfigured Acu-Scan camera compared with its predecessor, relative to the resources invested in developing it.?

In other words: what is the optimal R&D program for incremental innovation? The vital issue is, of course: How do buyers perceive the value of improvements to the six key attributes? Which feasible combination of such improvements would create the most attractive, marketable second-generation camera?

The Model:

The following mathematical programming model was employed.

Six key product attributes were identified (together with the relative importance of each attribute, or weights. The weights were computed by consulting senior doctors and a leading professional journal, ... (See Table 3).

The sum of up to $X million was budgeted for the development; development time was not to exceed 12 months; and up to 20 man-years of skilled labor was made available.

The model itself is shown in Table 4. The linear programming solution is shown in Table 5.

Table 3

Nuclear Camera Attributes and their Importance

	Technometric Value #	Weight**
1. price	6.2	9.75
2. down time	6.3	9.5
3. connectivity	7.6	9.6
4. all-purpose	8.5	9
5. resolution	6.6	10
6. simultaneous transmission/emission.	6	8

for Acu-Scan camera, relative to competitors.

* (ability to perform all the nuclear medicine functions)

** on a scale of 1 to 10.

Table 4. Programming Model:
Optimal Incremental Innovation for Acu-Scan Camera #

Attribute	1	2	3	4	5	6
1. Vector of weights: (wi)	9.75	9.5	9.6	9	10	8
2. Cost coefficients (ci)	0.9	0.1	0.1	1	0.6	0.3
3. Labor coefficients (li)	4	2	2	10	1	1
4. Time coefficients (ti)	2	2	2.5	5.5	3	2

MAXIMIZE $9.75\,\Delta x1 + 9.5\,\Delta x2 + 9.6\,\Delta x3 + 9\,\Delta x4 + 10\,\Delta x5 + 8\,\Delta x6$

subject to:

a) financial constraint:

$0.9\,\Delta x1 + 0.1\,\Delta x2 + 0.1\,\Delta x3 + 1\,\Delta x4 + 0.3\,vx5 + 0.3\,\Delta x6 < \$X$ m.

b) labor constraint:

$4\,\Delta x1 + 2\,\Delta x2 + 2\,\Delta x3 + 10\,\Delta x4 + 1\,\Delta x5 + 1\,\Delta x6 < 21$ man years

c) time constraint:

$2\,\Delta x1 + 2\,\Delta x2 + 2.5\,\Delta x3 + 5.5\,\Delta x4 + 3\,\Delta x5 + 2\,\Delta x6 < 12$ months

improvements are defined in terms of "one technometric unit", which is 0.1 on the {0,1} technometric scale; for instance, an improvement of 0.1 in the price means development that enables a price reduction of $20,000; the cost of such a price reduction, in terms of R&D investment, is $900,000, or a coefficient of 0.9.

** The company with which we worked asked that we not disclose the R&D budget, which is noted above as $X m.

Table 5. Optimal Resource Allocation for Incremental Innovation: by Attribute

	CAPITAL ($ million)	LABOR (person yrs.)	TIME (months)	optimal value	Initial value
Price	0.9 $X	12	6	9.2	6.2
Downtime	0.1 $X	2	6	9.3	6.3
Connectivity	0	2	0	7.6	7.6
All Purpose	0	0	0	8.5	8.5
Resolution	0	0	0	6.6	6.6
Trans/Emiss.	0	0	0	6	6
total:	$X m.	16	12 m.		

Overall Improvement in the Objective Function: 15 %

The linearity of the model moves the solution toward improving only two of the attributes -- resources are directed toward where they contribute most to the objective function, and the system does not encounter the diminishing returns present if non-linearities were taken into account. Labor is a slack variable: 4 person-years are unused. The identification of slack resources is an important advantage of the model -- skilled workers generally work long hours, are fully occupied, and the manager's naked eye has trouble discerning that their labor may in part be superfluous.

Capital and time are "scarce" variables, with non-zero shadow prices. From the high shadow price of time, we can see that this is the most severely-binding constraint -- a common situation when a two-month reduction in time-to-market may mean the difference between market success and failure.

We found that if the time constraint were relaxed, adding three months to the 12-month period, along with $100,000 in additional capital, some of the resources would then be directed to improving "connectivity". The sensitivity of linear-programming models to small changes in parameters and coefficients make it vital to undertake sensitivity analyses - alteration of parameters to determine how the model's outcome reacts.

The model directs managers to improve the Acu-Scan incrementally, by performing R&D that will permit a significant reduction in price (perhaps, by improving the process technology used in production), and result in a significant reduction in down time. Overall, the price decline achievable is 3 technometric units, or 3 x $20,000 = $60,000, and raise the downtime score from mediocre (6.3) to excellent (9.3).

The optimal allocation of R&D resources leads to a 15 per cent improvement in the Acu-Scan's technometric objective-function score. About two-thirds of that improvement stems from price reduction, and one-third, from improvement in down time.

Discussion:

Management's R&D decision was not guided by the model, because it was not available to them at the time. Senior managers decided to invest R&D resources in improving the "All Purpose" attribute, and in "transmission/emission". This was a logical decision. The "all purpose" attribute has a reasonably high customer-preference weight, and it is the feature in which the Acu-Scan camera scores highest. It makes good sense to further strengthen the attribute that already provides strong competitive advantage, in anticipation that competitors will work hard to close the gap in this area.

The marketplace's demand for high "all-purpose" scores is interesting. This characteristic is kind of an "entrance exam" or "quality test" -- cameras that lack it, flunk. Yet, doctors generally do not make use of it. "All purpose" is a buzzword that cameras must convey, or fail. Such knowledge is brought to the R&D lab from the marketplace. Knowing it can make the difference between success and failure in reconfiguration. Excess reliance on mechanical models is, for this reason, dangerous.

Resolution is a key characteristic; however, enormous investments are needed to improve it significantly enough to make a difference in the marketplace. The cost-value ratio is prohibitive.

Connectivity is driven in part by cost containment; buyers seek to purchase from suppliers their best instrument, then link them all up together, rather than buy the complete system from one supplier.

Transmission/emission was the Acu-Scan camera's weakest feature, and it made sense to work to improve it. However, the linear programming model showed that the cost-benefit ratio or return to investment in improving this attribute was dismal.

The model, therefore, focuses R&D investment on three attributes: price, connectivity, down time. The marketplace speaks loud and clear, that cost-effectiveness is a crucial attribute in the age of managed health care and cost-cutting. It also says, for similar reasons, that in order to be competitive gamma cameras must have minimal downtime - in nuclear medicine, time is literally money - and that the camera must link up seamlessly with a wide variety of peripheral equipment. These were the variables our model found gave the highest value/cost ratio for R&D investment.

In practice, considerable resources were invested in providing the camera with variable-angle capability, to make it All Purpose. Managers simply believed they had no choice in this matter. All-purpose capability was perceived as a kind of "entry fee" gamma cameras needed, to prove credibility in the market.

5. Implications & Conclusion:

How does this model contribute toward integrating marketing and R&D? Managing incremental innovation is a matter of balancing cost and value. The value of incremental improvements to product attributes is a crucial input to the model, that can be obtained best from marketing managers in the field. The cost of those improvements is an input that the expertise of R&D managers can provide. Optimal R&D investment in incremental innovation results from obtaining the biggest bang for the buck -- maximizing the value of incremental improvements, relative to their cost in terms of time, money and labor.

There is value in quantifying such decisions, even at considerable cost. It is sometimes surprising that managers who thoroughly explore investment options when engaging in financial investment, risk huge sums in R&D with very little effort to gather data or quantify and model the decision.

There will surely be occasions on which the results of a programming model deserve to be ignored -- especially when high uncertainty attaches to its cost parameters. But the combination of mathematical programming, and intuition, is in almost all cases more powerful than pure intuition alone.

Incremental innovation is subject to the dangers of the "sunk cost" fallacy -- the notion that because a product exists, with considerable investment of resources and time, it is necessary to continue to improve, market and produce it.

As Phillips, Phillips and Phillips (1994) note:

> "Dassault's decision to bring out the Falcon 900 as a follow-on to the Falcon 50 illustrates a second feature of the sunk-cost risks in a market characterized by continuing technological opportunities. The need to devote resources to the development of new products does not stop after successful innovation. The learning that occurs in the first element of the process leads to ideas about improving the product. This is augmented by developments in science and technology that occur outside of the firm in question. Great pressure exists to use that knowledge in creating yet another airplane, partly because of the urges characteristic of the Schumpeterian entrepreneur." (p. 133) .

We simulated the Falcon 900 investment, for instance, using our model and found only an 18% incremental improvement in the objective function in return for a large investment, even when the incremental innovation is managed optimally. It is generally believed that the Falcon 900 will not be successful in challenging the market domination of the Gulfstream Series V and VI.

Two decades ago, Gluck and Foster (1975) proposed that top managers participate earlier in the R&D process, emphasizing: 1. strategic performance parameters of products in each product/market segment, how they have shifted, how they may shift in future, and the product's position in each parameter compared with that of the principal competitors; 2. the improvements that customers would value most in each parameter; 3. changes in each parameter that could lead to competitive advantage; and 4. potential moves of competitors, government, consumer groups, or work markets, that could undermine the company's advantages in each parameter (pp. 147-148).

We believe that our typology of innovation, and the mathematical programming model based on it, can provide at least partial answers to the first three issues, by bringing the key input of the marketplace to the lab bench of the R&D engineer, perhaps via the desk of the chief technology officer.

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Technology Assessment through Foresight: Synergies between two strands of research

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by Hariolf Grupp
Deputy Director
Fraunhofer Institute for Systems and Innovation Research
(Fraunhofer-ISI), Karlsruhe, Germany

Why is policy and business in need of assessment and foresight?

Today, the architecture for understanding the impacts of a modern science and technology (S&T) policy portfolio is more complicated than it ever was. The interwoven nature of various types of policies and the trade-offs any policy portfolio requires touches on different aspects of the entire quality of life issue. The challenges for a particular policy in the area of science and technology originate from increasing environmental, economic and social problems. The aim of those policies is to make the (national) innovation system adaptive enough to meet those challenges. Further, in the area of technology and science an increase in interdisciplinary and transdisciplinary subfields is observed. Basic or even fundamental research is in closer contact with industrial research and development and science-based technology is pervasive in many industries.

In politics, there is an increasing number of actors and interventions. National policies in some countries are pressured by supranational as well as local and regional bodies. In industry, but not in government, globalisation is taking place. However, public and private finance is getting short. R&D budgets are limited in particular as any negative effect of reduced spending is not short-term. Efficient and effective input-output relations are required. The significance of policies other than monetary ones increases and sufficiently explains the renewed emphasise on foresight and assessment.

The variety of arguments cannot be dealt with in its entirety in this brief introduction into the interlinks between technology foresight and assessment. The rather limited approach tries to focus the 'new complexity' between policy, business innovation strategy, assessment and foresight. This is a rather limited view in the framework of other societal bottlenecks, but certainly an important focal point: In years of recession and at times of multinational direct investments, global sourcing, net-working and the 'mobile' location of R&D establishments it is meaningful to reconsider the framework of the national innovation system.

On the history of foresight

The main initial work was performed at the RAND corporation, Santa Monica, in the years following 1948, the pioneers being A. Kaplan, O. Helmer, N. Dalkey et al. 'Forecasting', as it was known then, was motivated by V. Bush's book 'Science the endless frontier', advocating the transformation of the US marshal economy research during World War II (e.g. the Manhattan project) into long-term civilian research and commercial exploitation. The early attempts were also spurred by the amazing scientific successes of the Soviet 'planned economy' (e.g., the hydrogen bomb or the launch of the Sputnik). In the context of forecasting work at RAND, also a new innovation economics developed (including work by Arrow, Winter, Nelson et al.).

Methodological starting points were systems analysis, operations research and comparable procedures. After early successes, many serious misconceptions of what 'forecasting' ought to be, arose. In the sixties and early seventies, the mechanical 'prognosis' or 'trend prediction' type of word based on 'linear', i. e. sequential, models ceased to look interesting and the related forecasting activities fell into oblivion. This coincided with the end of the long growth euphoria since the War marked by the first oil price adjustment, for example, or the 'Limits to Growth' report of the Club of Rome (1972). Although the 'linear' models of thought were discarded (e.g. by the project 'Hindsight'), some science policy communities further supported them for their legitimating power on R&D spending with no priorities (e.g. the project TRACES by the NSF 1968).

With the new evolutionary economics coming up with selection procedures and the notion of variety generation by new products, and the sociology of science working on the functions of social systems in science as opposed to technology or the economy emphasising the 'bounds of rationality' and 'negotiating systems', it became clear that there may be a new, different use of forecasting methods. Martin and Irvine (1984) coined the term 'foresight' and pointed to the communication or procedural power of it. The modern perception is that the actions of social systems, in particular science communities, cannot be predicted in terms of 'natural' laws, and that future events in science and technology cannot be determined by extrapolation, but are shaped by these communities and a negotiating system.

However, this present understanding of foresight was available in the literature from the very beginning and may be - less-well pronounced than nowadays - found already in one of the earliest papers in the field: 'Policy making rests in part on anticipation of the future (...) and of the consequences of and responses to alternative lines of action. Many policy decisions require *foreknowledge* of events which cannot be forecast either by strict causal chains (...) or by stable statistical regularities (...).' A. Kaplan et al., 1950, p. 93 (emphasis added by H.G.). Even the forerunner of the term 'foresight' was coined in 1950! 'Verification' or 'falsification' of foresight results are, thus, meaningless ends.

Germany is a latecomer in the foresight but not in the assessment arena and was not active on federal and state level in the eighties. After several assessment institutions were installed towards the end of the eighties including a Parliament Office, recently, the unification of the country and the corresponding tasks to restructure a formal socialist economy as well as the budget constraints associated with the unification and the world-wide economic recession urged a policy change towards foresight as well. A further argument to look at the relation of technology foresight and technology assessment originates from the renewed emphasis in non-European countries, in particular the United States and Japan. Before reviewing some interlinked foresight-assessment activities in Germany, let us discuss some important temporal aspects of technology development.

Significance of temporal aspects of technological assessment and foresight

There is a constant temptation for technology assessment (TA) to restrict itself to describing the potential supply of scientific and technical solutions and the study of their impact. However, it must do far more than depict the supply factors. The potentials and the risks of technology in the future depend just as much on the pressure of the social, ecological and economic problems expected to arise and make important demands on science and technology. For this reason, any discussion of problems must focus increasingly on factors relating to demand. How one might determine which basic values for innovation activities might be adopted world-wide in the medium and long-term perspectives, and forecast the resulting problems, of course, has no satisfactory empirical answer. The current fundamental legal (the state founded on the rule of law), social (the social market economy) and political (parliamentary democracy) conditions for innovation activities are taken as a basis.

The long-term scientific and technological developments on which the planning and technology policy might be based arise from the interplay between what is technically feasible and what is required from a political and economic point of view. It is precisely on this crucial point that several studies show poor forecasting ability and make ill-founded assertions. For factors relating to demand, the documented state of knowledge is poor. At the international level, it is only now that initial attempts are being made to achieve a more comprehensive assessment of technologies. It is obvious that opinions in Europe are more likely to concur with regard to demand, when compared with overseas countries and markets which may differ more in demand than in technology.

Because of many supply-demand mismatches, initially euphoric expectations of a new technology (mostly on the part of the scientific community) tend to be followed by increasingly cautious developmental phases before the market is finally penetrated. The use or rejection of innovative products often leads to new demands on research and technology, which is why it generally makes sense to speak of 'feedback processes' (see Figure 1).

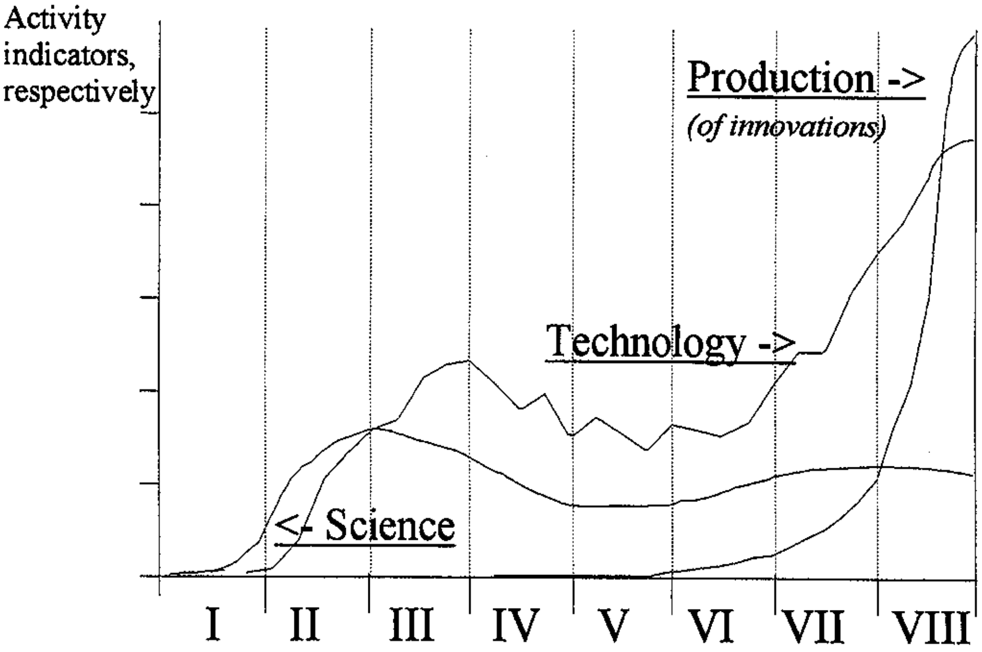

Figure 1: Sketch of standard phases in research, technological development and innovation: I, first exploratory research; II, increasing research with further perspectives; III, technical realisations and prototypes; IV, onset of industrial R&D; V, temporary stagnations and difficulties; VI, orienting R&D towards specific applications; VII, first commercial products; VIII, market penetration, R&D levels off.

The time-scale of technology (and market!) development ranges from the early stages of exploratory research in scientific institutions (stage I) to full market penetration (stage VIII). If some of the new technologies have penetrated the markets, exploratory research continues to be carried out in the scientific sphere, and such research will naturally concentrate on problems other than those in the early days. The long time-scale is the result of the cyclical development of science-intensive technologies and provides a warning for the technology assessment analyst: She or he must incorporate both important fundamental areas and major application systems into anyone study of detrimental aspects of technology.

Since many technological subject areas in assessment studies are important from both a purely scientific and an applications-oriented point of view, the question is to what extent an assessment of technology has to incorporate aspects of industrial research and pure research, and consideration must also be given to institutional support. It is true that those impacts of new technology which are currently still the subject of scientific exploration cannot achieve their full potential in a mere - say - 10 years. It is only where prototypes or initial technical realisations have already been produced that it will be possible to assess the full (positive or negative) potential of technology within such a time frame. These deliberations also call into question the possible expectation that a technology needs no more than a single action to regulate its impacts. Any hopes of being able to drop the accompanying pure research once the applied objectives have been achieved, will meet with disappointment; tomorrow's science-based technology is shaped continuously through targeted basic research.

By noting those areas of technology which are expected to witness particularly strong leap-frogging in the next 10 years, it is clear that there is more need for assessment in years to come. The more erratic the developments are, the greater is the need for more precise technical monitoring. In view of the differing stages of development of technologies the information base for an assessment has to be checked. For all subject areas which are in their early development stages objective knowledge is low. Where the first technical realisations have occurred, the facts available both world-wide and to an assessment team should be at least satisfactory. The more progress that has been made in the field of applications, the more accurately can impacts be anticipated. In setting priorities for future technology assessment ventures, the respective agencies and government could allow themselves to be guided by the diagnosed inaccuracies of assessment.

Dual-use methods

Let us approach the methods used in the foresight and assessment strands of activity. One of the German foresight studies is medium term and uses a relevance tree approach - it is called 'Technology at the Threshold of the 21st Century'. The main motive behind the study is to complement economic growth criteria by the idea that growth should not harm the environment and social welfare, if not provide remedies to existing problems. The relevance tree method is known as a 'normative' method. These kinds of methods have their foundations in system analysis. They start with future problems and needs and then identify the technological performance required to meet those needs. Relevance trees are used to analyse situations in which distinct levels of complexity or hierarchy can be identified. Each successively lower level involves finer distinctions or subdivisions.

The time horizon of this particular study is approximately the year 2000. The project team considered two separate sets of relevance criteria as important. One relates to basic conditions like infrastructure and financial requirements in Germany. This set of criteria is specified for the national context. With the notion of specialisation and division of labour, the aim is to find out what makes the development of the given technology important for Germany in distinction to other countries. The second set of relevance criteria is more interesting for our present task: It tries to cope with the technology assessment requirement and seeks to provide information on the problem solving capacity or potential of the given technology. This means that the traditional economic criteria of growth and competitiveness are brought together with criteria typical for assessments being related to health, environmental problems and so on.

It is difficult to summarise the findings of this study. By means of multi-dimensional scaling it was shown that the border lines between individual technologies become less distinct in the next decade. New disciplines are being shaped outside of classical research areas. This certainly has dramatic effects on the necessity of technology monitoring, on technology policy implementation of R&D projects and the appropriability of technological opportunities by firms. But at the same time new queries as to the justification and relevance of single technology assessment are on the agenda. We have to conclude that some methods originally developed for technology assessment are now being used for foresight activities and that these 'dual-use' methods are equally meaningful in both areas of investigation.

In foresight studies, the Delphi method is considered especially useful for long-range aspects (20 - 30 years) as expert opinions are the only source of information available.

The Delphi method is one of those methods developed during the fifties at the RAND Corporation to make better use of the knowledge potential by group interaction. A questionnaire sent to experts more than one time is the medium for group interaction. The panel members will usually have widely varying estimates on each question in the beginning of the process and do not always shift their opinion under the influence of the assessments given to them by the other panellists. The main advantage of Delphi is that panel members can shift position without losing face if they see convincing reasons for doing so, the main problem remains, that the issues asked must be generated elsewhere; they do not originate from the panellists. It is surprising that a widespread use of the Delphi technique for foresight, but not for assessment, is being made. Especially for debatable and biased assessment items, this method could be helpful as the issue is determined by the TA problem and has not to be anticipated as in foresight studies.

Most recent foresight surveys were undertaken by government agencies. Yet, enterprises may also make effective these approaches. One pharmaceutical company in Germany has just concluded its own Delphi investigation on the future of physicians in residential areas and their ability to follow modern trends both in medical technology and in pharmaceuticals assuming an increasing use of information technology in the health care system. The results were published by the company and are reported here as a case study.

The medium-sized German pharmaceutical company started its internal project „meeting point future“ in 1994, which included several activities like workshop discussions, quality circles, conferences and, as a central part, a Delphi survey about the future of the health care system. Two groups of experts were included in this study: about 10,000 physicians and in addition about 1,000 other experts on the health care system, who came mainly from hospitals, public services, associations, health care insurance companies and other bodies. All in all more than 700 questionnaires were used for the final evaluation. Future aspects of the health care system have been covered with 50 statements. They concentrate on the following issues: developments in society and legislation, topics related to the physicians; hospitals; the pharmaceutical industry; distribution systems; health care insurance companies; and developments in medical sciences. The experts were asked to evaluate each topic with respect to the time of realisation and the significance for the health care system. In addition they were asked for their personal view on each topic.

In general, a high degree of agreement could be observed between the judgements of the two expert groups of the survey. This may be considered a rather surprising result, because from many public discussions a rather pronounced dissent between physicians on the one hand and representatives of associations, insurance companies and representatives from political institutions on the other hand could be presumed.

The results of the study highlight many different options for the future development of the German health care system. As a result it turned out that a great majority of the experts is convinced that the health care system in Germany will remain a self-governed system in the future. However, certain modifications of the system will be necessary. These modifications can be grouped into two categories: firstly, more free market elements; secondly, more governmental influence to some extent.

Opportunities of technology assessment through foresight - Scoping future applications for policy, business and society

Contemporary technology policy has moved away from the inappropriate idea that the state can direct technological developments right down to individual national innovations. Equally outmoded is the idea that the state should be satisfied with the role of a subsidiary supporter of research leaving the future control of technology to anonymous market processes. Technology policy for the start of the 21st century requires a middle course, i. e. one in which the state plays an active role as an intermediary between social systems negotiating (companies, associations, interest groups, science, consumers, media, employers' and employees' representatives, etc.). This intermediary role also must take account of the fact that national technology policy is increasingly restricted in its scope, both from above and below. This is because of the activities of the European Union and the efforts of regional bodies such as the Federal Länder in Germany to promote research on a regional basis.

State support for projects, in so far as these are concerned with future technology, cannot be replaced by indirect instruments of technology policy. In the field of preventive research in particular, selective project support continues to be of the greatest importance. Technology policy should not only examine technological options but also indicate creative perspectives. This concerns research-related assessment of the consequences of technology.

The state's new role as active moderator necessitates a policy process which is coordinated with industry, science and society. However, cooperation does not occur by itself, since too many divergent interests predominate. If there is to be agreement over the possibly selective eligibility for support of technology, dialogues with other social players must be initiated and pursued on a permanent basis. Otherwise, it cannot be expected that lasting cooperation can be achieved or that the platforms to be created for a subject-specific understanding will become more than simply forums for the exchange of information. Don't we need integrated technology assessment through foresight to provide the knowledge base for these platforms?

Care has to be taken in these social negotiations on technological wants not to stray too far from what is reliably known, and wander into the realms of speculation. In view of the typical recursive phases of science-related technological innovations, it can be generally assumed that everything that will dominate technology impacts in 10 years' time is already recognisable today. However, strategic planning in enterprises is necessary, aiming towards horizons even further in the future, because new technologies - especially those which will contribute to long sought solutions to problems - must be identified at an early stage.

As far as enterprises are concerned, a considerable improvement of the intramural knowledge base through participation in foresight surveys is reported. There is sporadic evidence that in some companies, during participation in the Delphi, it was felt that too little effort is dedicated towards strategic innovation management and some remedies have been taken. Some companies started their own investigations in the direction of an intramural breakdown of the overall national studies towards the special interest of their business areas or establishments, both in the manufacturing and the service sectors. One large chemical company in Germany, especially, started with topics of the Delphi survey, made their own evaluation of the topics and built up a strategy until 2010. In working groups, the information was discussed and distributed. Some smaller-scale comparisons of the business portfolios to the future-oriented areas are also being done in other companies, sometimes assisted by external consultants. These activities are largely confidential.

Several lessons can be learned from the industrial application of foresight methods. Firstly, it is important to note that a foresight activity should not be a single event but should rather become part of a broader company strategy which deals with the company's strategic orientation. Secondly, the individual results of a survey should trigger various follow-up activities within the company, for example, workshops on selected items. Thirdly, going through the process of a foresight survey itself is a very valuable aspect since great numbers of experts are being motivated to think critically about future scenarios which are favoured or rejected by their peer colleagues.

Fourthly, for the company, the benefits of a foresight survey should not only be seen as gains in information and reputation among its clients, but also extended to the internal situation: the strategies for dealing with challenges of the future must become broad company issues which are to be discussed and supported by many employees, thereby contributing to an increase of in-house motivation and identification.

From the social point of view, the direction to be taken in the future may be seen from the increasing demands made on technological development in terms of minimal use of resources, elimination of emissions, circular economy and sustainable development. These demands require the creation of the necessary framework conditions, especially those of a non-technical nature, such as legal regulations. Similarly important than such ecological problems is the sociopolitical dimension in particular the unemployment problem. From the point of view of technology policy, we need a form of technological development which encourages wide-ranging participation by players from various sectors, and of varying size, and which leads to an open market with no specific centralised structure.

In brief, this long-term view of technological development offers various starting points for technology assessment through foresight, which overlap the individual subject areas, such as the following:

- how to demarcate and encourage such new physical, chemical and biological basic effects which can influence 'wanted' innovation in various technical areas;
- how and when to provide manufacturing technologies which promote the rapid conversion of the above basic effects into sustainable innovative products;
- how to determine technologies which may be linked with the available know-how and manufacturing structures, so that new solutions may be produced on the basis of the available experience and social structures, with restricted volumes of investment;
- how to promote such technologies which are expected to lead to short-term beneficial and socially desirable multiplier effects while under development (i. e. during or immediately after the period in which they are promoted);
- how to set up framework conditions, especially legal regulations, which point technological development in the direction of sustainable development, full employment and the protection of scarce resources;
- in which manner to take account, at an early stage, of non-technical factors such as service areas, user guidance, questions of standardisation, working organisation and skill levels;

- by which means to promote opportunities for communication and cooperation which bring together social groups from various fields of activity and, in particular, ensure that innovative companies (in particular small and medium-sized companies) are not excluded from an adequate knowledge base (oriented basic research) both at home and abroad;
- in which way to set up cross-disciplinary facilities at educational and research institutions, which can develop new non-subject-related perspectives;
- how to encourage wide-ranging participation by those involved in R&D and beyond and to produce and maintain an open negotiating system for innovations, without special idiosyncratic structures.

It is in the nature of long-term foresight that it is burdened with a high degree of uncertainty how the decision-making groups will behave; it is not unusual for wishful thinking, arising from the most diverse motives, to be presented as a probable future event. Taking the long term view, the motivating power of guiding visions is helpful in that it releases social energies and the willingness to undertake concerted action. Long-term lead projects in technology can produce lasting motivation and unite powers which can work towards problem-solving requirements recognisable in the long term, and also produce successes along the way (desirable multiplier effects).

Lead projects in technology which represent outline solutions to large, global, economic, social and ecological problems, and especially the visionary view of technological development and the challenges now facing us, throw up other, more radical questions of technology policy than those set out here for the time being. It was not the aim of this brief essay to give the questions more concrete form. However, it has been possible to indicate that technology assessment through foresight can itself provide the key to far-reaching changes in future policy. The technology policy of tomorrow must be in place to shape technology policy in the long run.

In Germany, generally, there is a public tendency to be critical about new technology, often without going into any detail. After some foresight studies were published and as they are rich in presenting visions of detailed trends in science and technology, several 'second thought' articles concerning the public understanding of technology by science journalists were published. The message in these articles is basically that dogmatic scepticism against new technology as such should be replaced by public reservations against *certain* technologies. A need of a *technology-specific* public debate on the future of the so-called 'science and technology nation' was triggered off. From these observations one is tempted to conclude that the assessment foresight processes have a lasting and direct impact on society as it affects our notions of future technology. By reflecting future opportunities and impacts of technology, we reflect our procedures to get there.

Regional Innovation Profiles of firms in Fast-Growing Industries: A German-Israel Comparison

Amnon Frenkel*, Daniel Shefer*,Knut Koschatzky , Gunter, H. Walter****

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

** The Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany.

ABSTRACT

The contribution of innovation to regional growth has been widely recognized in the development literature. Regional development as a location where technological innovation takes place is usually accompanied by new economic activities; market expansion; and technological adaptation. Regions with a high level of innovation have become magnets for highly-skilled labor and provide impetus for improved educational infrastructure.

The present paper compares the characteristics of industrial plants belonging to three fast-growing industries, electronic, plastic and metal, in Israel and Germany. Innovation potential is at the heart of the present study. Therefore, analysis was carried out with respect to the rate of innovation of firms belonging to the three fast growing industries located in three distinct locations, i.e. center, intermediate zone and periphery. A significant different rate of innovation potential was found between the Israeli and the German firms in our two respective samples.

1. Introduction

This paper is the result of a research project jointly conducted by a team of researchers from the Neaman Institute for Advanced Studies in Science and Technology, Technion, Israel, and the Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany, and sponsored by the German-Israel Foundation (GIF).

The principal objective of this study is to investigate the spatial diffusion of innovation in selected industries and its effect on regional growth. It is assumed that the engine of growth is technological change and innovation. Thus investment in rapidly growing industries could be a vehicle to foster regional growth.

Uneven distribution of resources over space, imperfect mobility as well as indivisibility of production factors, and the necessity to economize on scarce resources all induce the concentration of economic activity at discrete and selected points. Consequently, there exist variations among regions. These variations manifest themselves in the levels of economic and social well-being of the population in various regions. In order to reduce the disparities among regions, government agencies devise policies and initiate programs whose main objectives are to increase the employment level, to increase *per capita* income, and in general to increase the rate of economic growth in the underdeveloped regions. Different regions offer different opportunities for specialization. When these opportunities are exploited, they add to the aggregate income and well-being of the region. It is necessary first to identify these opportunities, and thereupon to devise those policies that will advance the declared objectives.

If employers attempt to maximize profits, they are motivated to invest in regions where the greatest profits can be secured, given some prespectified level of the risk involved due to uncertainties. Profit will be maximized in regions where there is comparatively higher productivity of inputs like labor and capital, and efficiency in the infrastructure networks of transport and other communication systems.

In recent years researchers have become increasingly aware of the role of technological innovation and the impact of its diffusion on regional development and growth. This growing interest resulted from the relationship that exists among innovation, competitiveness, and economic growth (Pavitt and Walker 1976; Freeman 1982, 1990; Freeman et al. 1982; Dosi 1984, 1989).

The contribution of innovation to regional growth has been widely recognized in the development literature (see, among others, Freeman et al. 1982, Jorgenson et al. 1988, Schmookler 1966, Rosenberg 1972). Regional development, as a location where technological innovation is taking place, is usually accompanied by new economic activities, market expansion, and technological adaptation. Regions with a high level of innovation have become a magnets for highly-skilled labor, and provide impetus for improved educational infrastructures (Suarez-Villa 1993).

From a technological point of view, advanced economic activities tend to possess a high market value, resulting in a competitive advantage at least during the first stage of the diffusion process. Thus they enjoy opportunities for their development, expansion of their market share, profitability, and employment growth.

Compared to other regions, regions characterized by a high level of technological innovation will show a greater acceleration of economic growth. The level of innovation is demonstrated in the existence in the region of many plants engaged in technological innovation.

2. Classification of Industries

Classification of industries is aimed at identifying the fast growing industries, in Israel and in Germany. We postulate that the potential innovation and innovativeness in fast growing industries is greater than in the slow growing industries. Thus we embarked on the task of identifying the group of fast growing industries in the two countries - Germany and Israel. This was done in order to choose a sample of high growth industrial firms for the empirical study.

We classified the industrial branches according to their rates of growth with respect to outputs and employment. The growth rates indicate the vitality of the industry and its competitive edge. The assumption is that among plants that belong to the fast growing industries, we can find a significantly higher rate of innovations. Therefore, their influence on the regional economy could be greater than that of plants belonging to the slow growing industries.

The choice of the period for which we examine the growth rates is of great importance. There exist large fluctuations in growth rates over long periods of time. These fluctuations derive from changes that take place in local, national and international economic conditions. The conclusion is that it would be better to examine the growth rate in the most recent period for which data is available. Thus the period determined to be relevant in our analysis consists of the five-year interval 1987-1992. Examination of the industries growth rates during that period was based on the following five indices:

1. Change in industrial production.
2. Change in the number of employees.
3. Share of export in total turnover (revenue).
4. Change in export share.

The first two indices are concerned with the relative position of each industry independently from its export performance. These indices point out to the growth trend in each industry, as indicated by the rate of growth in both the number of employees and production.

Both of these indices are used in order to identify industries that reduce the number of their employees, but at the same time increase their output. Concomitantly, it allows us to identify industries that show noticeable increase in the number of employees, and no increase in production output.

The other two indices emphasize the relative importance of export industries to the economy of a small country like Israel, in which the size of the local market is limited. We postulate that industries having a great export potential stand a better chance to grow, in comparison to industries that rely mainly on local markets. This potential is expressed by export share in total revenue and the growth of that share during the time period selected.

In addition to the above mentioned indices, the relative size of each industry selected and its share of total industrial employees are also taken into consideration.

Data Base and Procedures

The data sources for Israel were based on the reports published by the Central Bureau of Statistics and by the Center for Economic Planning, a unit within the Ministry of Industry and Commerce.

The data sources for Germany were based on reports of the Statistics Bundesamt (Federal Statistics Office), Stiftverband der deutschen Wissenschaft (Germany Science Foundation) and the Deutsches Patentamt (German Patent Office).

In order to make the data for Israel and Germany compatible, the German industrial branch code (SYPRO classification) has been matched, as much as possible, with the Standard Industrial Classification used in Israel.

Classification According to Growth Indicies

The analysis is based on comparing growth rate for each of the industrial branches in the 5 indices mentioned above. The rates of growth are examined with regard to 17 major industrial branches, according to the matching classification division at a level of two digits of the Standard Industrial Classification.

Table 1 depicts the classification of industrial branches based on the above five criteria. The results show that there are a number of fast growing industrial branches. Among these we can find several industries that were affected by the unique circumstances which prevailed during the selected period in both Israel and Germany at the time the data was collected. Therefore we exclude those industrial branches in Israel and in Germany from the analyses, and they are excluded form the table (a detailed explanation is giving in appendix A).

Table 1: Classification of Industrial Branches According to the Five Growth Criteria

code	Major industrial branch	Increase in industrial production 1987-1992	Increase in number of employees 1987-1992	Export share 1992	Change in export share 1987-1992	Share of industrial employment	Increase in industrial production 1987-1992	Increase in number of employees 1987-1992	Export share 1992	Change in export share 1987-1992	Share of industrial employment
		ISRAEL					GERMANY				
11,12	Food beverages and tobacco	⬩	⬩	⬩	⬩	◆	exp.	exp.	exp.	exp.	exp.
13	Textile	❖	⬩	❖	❖	❖	⬩	⬩	❖	❖	⬩
14	Clothing and made-up textile	⬩	❖	◆	◆	◆	⬩	⬩	❖	◆	⬩
15	Leather and its products	❖	◆	⬩	◆	⬩	⬩	⬩	❖	◆	⬩
16	Wood and its products	exp.	exp.	exp.	exp.	exp.	exp.	exp.	exp.	exp.	exp.
17	Paper and its products	❖	⬩	⬩	◆	⬩	exp.	exp.	exp.	exp.	exp.
18	Printing and publishing	⬩	◆	⬩	⬩	❖	exp	exp	exp	exp	exp
28	Miscellaneous	◆	◆	◆	❖	❖	⬩	❖	❖	❖	⬩
10	Mining and quarrying	❖	⬩	◆	⬩	⬩	⬩	⬩	⬩	⬩	❖
21	Non-metallic mineral products	exp.	exp.	exp.	exp.	exp.	❖	❖	❖	❖	⬩
19	Rubber and plastic products	◆	◆	❖	◆	❖	◆	◆	❖	❖	❖
20	Chemical and oil products	◆	❖	◆	⬩	❖	❖	❖	❖	❖	❖
22	Basic metal	◆	⬩	⬩	⬩	⬩	❖	⬩	❖	❖	❖
23	Metal products	❖	◆	❖	⬩	◆	◆	◆	❖	❖	❖
24	Machinery	⬩	❖	◆	❖	⬩	❖	❖	◆	❖	❖
25	Electrical and electronic equipment	◆	❖	◆	◆	◆	◆	❖	❖	❖	❖
26	Transport equipment	⬩	❖	◆	❖	❖	❖	❖	◆	❖	❖

Rate of growth: ⬩ = low ❖ = medium ◆ = high exp. = exception.

Six fast-growing industrial branches were identified, of which three appear in both Israel and Germany. These industries are: rubber and plastic products (19), metal products (23), electrical and electronic equipment (25). The three other industries are fast growing in only one of the two countries: the miscellaneous (28) in Israel, and the machinery and transport equipment in Germany.

Most of the Israeli's fast-growing industries exhibit high performance with high score in at least three out of the five indicators, and medium scores in the other two indicators (except the metal products industry (23), (with low score in the change in export share indicator). Two of the industries: electric and electronic equipment (25) and metal products (23) are large industries that together employ about 28% of all industrial employees in Israel. The miscellaneous, and rubber and plastic industries are smaller, but they displayed a high rate of growth in the course of the past five years, in both industrial production and employment. The miscellaneous industry is one of the leading export industries, while the rubber and plastic industries showed an accelerate increase in export share during the years 1987-1992.

In Germany most of the fast-growing industries had a high scores on at least two out of the five criteria and medium scores on the other two, except the metal products industry with high scores in three out of the five criteria. Four out of the five industries (except rubber and plastic) are large industries, employing altogether 53.3% of all industrial employees in Germany.

With respect to their export growth the leather, clothing and textiles industries can be included in the group of fast growing industries in Germany, however at the same time they are the only industrial branches with a decrease in production as well as employment. Therefore they were not classified in our analysis as fast growing industries.

Altogether four industrial branches were classified as fast-growing industries in the two countries:

- rubber and plastic products (19)
- metal products (23)
- electric and electronic equipment (25)
- miscellaneous (28)

The first three industrial branches are fast growing industries in both countries. The forth "miscellaneous", is found to be a fast-growing industry only in Israel. However it was decided to include this industry in the empirical analysis despite its low percentage of employees in Germany.

3. The Sample of Firms

In both Israel and Germany a field survey was caried out through which a sample of industrial firms was selected, a sample large enough to support statistical tests needed for the research.

The Israeli interviewed companies were randomly selected from the FGI (fast growing industries), such as: electronics, precision equipments, plastic and metal. The Israeli field survey took place during May to December 1995. Owners, managers or high level officers of 211 industrial plants were personally interviewed. Overall the companies interviewed represent about 72 percent of the total industrial firms belonging to the FGI in the regions selected for analysis - northern Israel.

In Germany the data collection was finished at the end of February 1996. From 2,801 questionnaires sent out by mail to industrial firms in the region under investigation, 482 were filled-out and sent back, out of which 220 belong to the fast growing branches of electronics, precision equipments, plastics, and metal.

The investigated region contain in both countries an area where all three types of zones are represented as suitable for the study: a) The core zones; b) The intermediate zones; 3) The peripheral zones.

In Israel the Northern part of the country was selected for the analysis. The Northern region is one of the most fascinating regions in Israel in terms of the composition of its residents (Jews and non-Jews, veteran settlers as well as new immigrants), its settlements (type and pattern), and its landscape. In 1994, some 1.4M people, constituting about 26% of the population of Israel, resided in the region, which extends 5,000 sq. km., or 23% of the total land area of the state. The population of the region is divided between Jews (63%) and non-Jews (37%), the latter being primarily Muslim. In the past 5 years, the population growth rate was very rapid (almost 12%). This growth was mainly due to the large waves of immigrants who migrated to Israel since 1990 from the former Soviet Union.

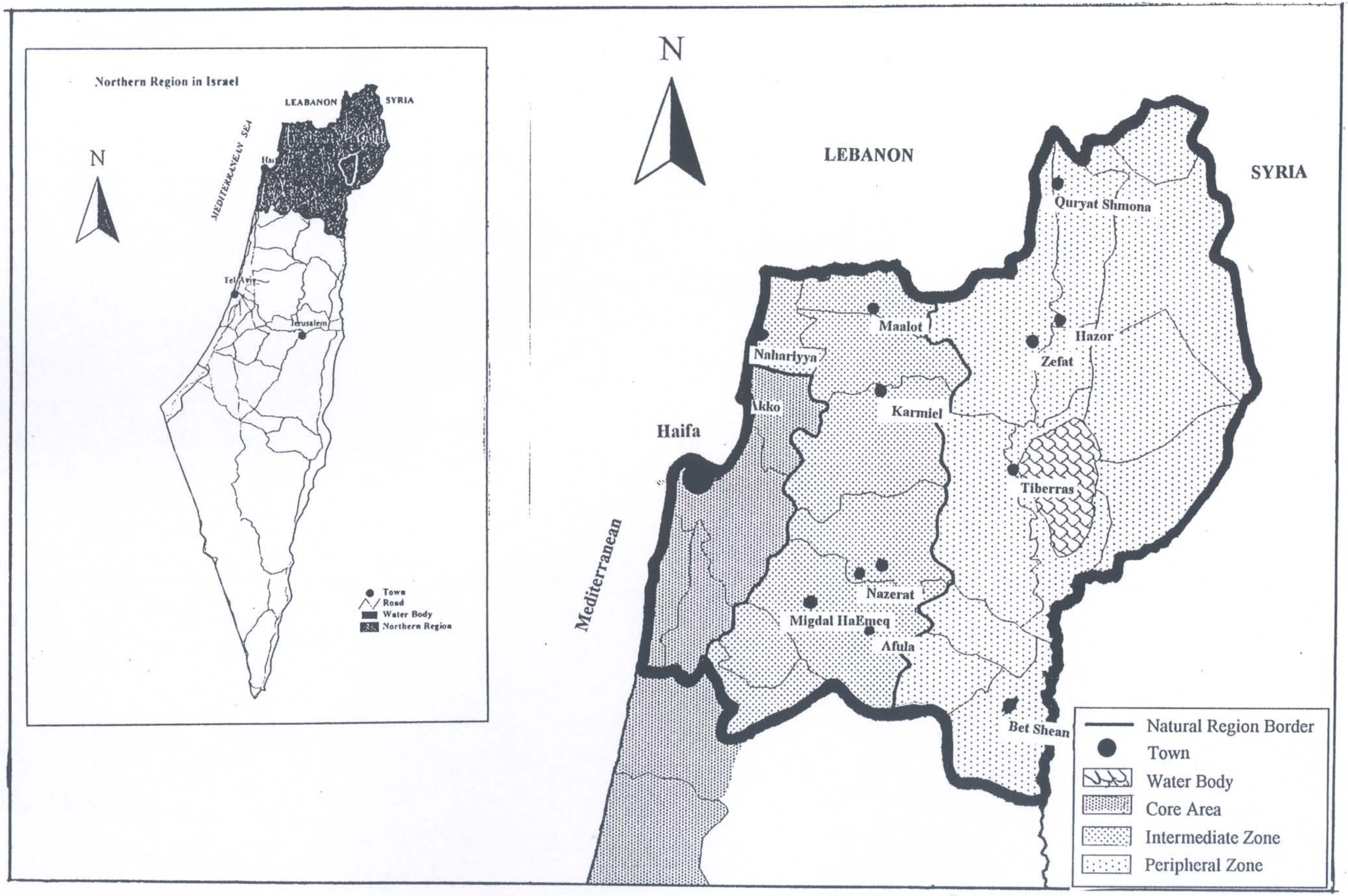
The northern region of Israel was divided into three subregions: 1) Haifa Metropolitan Area (central zone). 2) central Galilee (intermediate zone) the areas that surround the Core zones, on the fringe of the metropolitan area, and are within acceptable commuting distance. Although this zone was considered until not too long ago, peripheral, the recent tide of population expansion in the Core zone 'spilled over' into the surrounding areas, bringing about a change in their rate of growth and regional functionality. The northern intermediate region contain the central and west Galilee. 3) Eastern Galilee (peripheral zone) an area that removed from the metropolitan influence, and are not within acceptable commuting distance. It exhibits most of the classical characteristics of a Peripheral zone, including fewer employment opportunities, as well as social and commercial services. This area consists the Golan Heights, Eastern Galilee and all along the Jordan Valley, from Metula and Kiryat Shamona in the north to B'iet Sh'ean in the south-east (see map 1).

In Germany the investigated areas are part of the federal state of Baden-Württemberg. Baden-Württemberg is one of the industrial regions in Germany. It is characterized by a broad, medium-sized industrial structure and by large, internationally operating companies like Daimler-Benz, Porsche and Bosch. Major branches are machinery, electrical and electronic equipment, transport equipment, and metal products. The "Mittelstand" of Baden-Württemberg is seen as the important economical success-factor of this federal state, also named as "model region" (Cooke et al. 1993). Baden-Württemberg consists of 12 planning regions whereas three of them were selected for the analysis (see map 2). In 1994 the three planning regions investigated contain 2.4M people, constituting about 23% of the population of Baden-Württemberg. These planning regions represent the 3 types of regions analyzed in the study: 1) Karlsruhe region - "Mittlerer Oberrhein" (central zone), 2) Südlicher Oberrhein - Freiburg region (intermediate zone) and 3) Schwarzwald-Baar-Heuberg (peripheral zone).

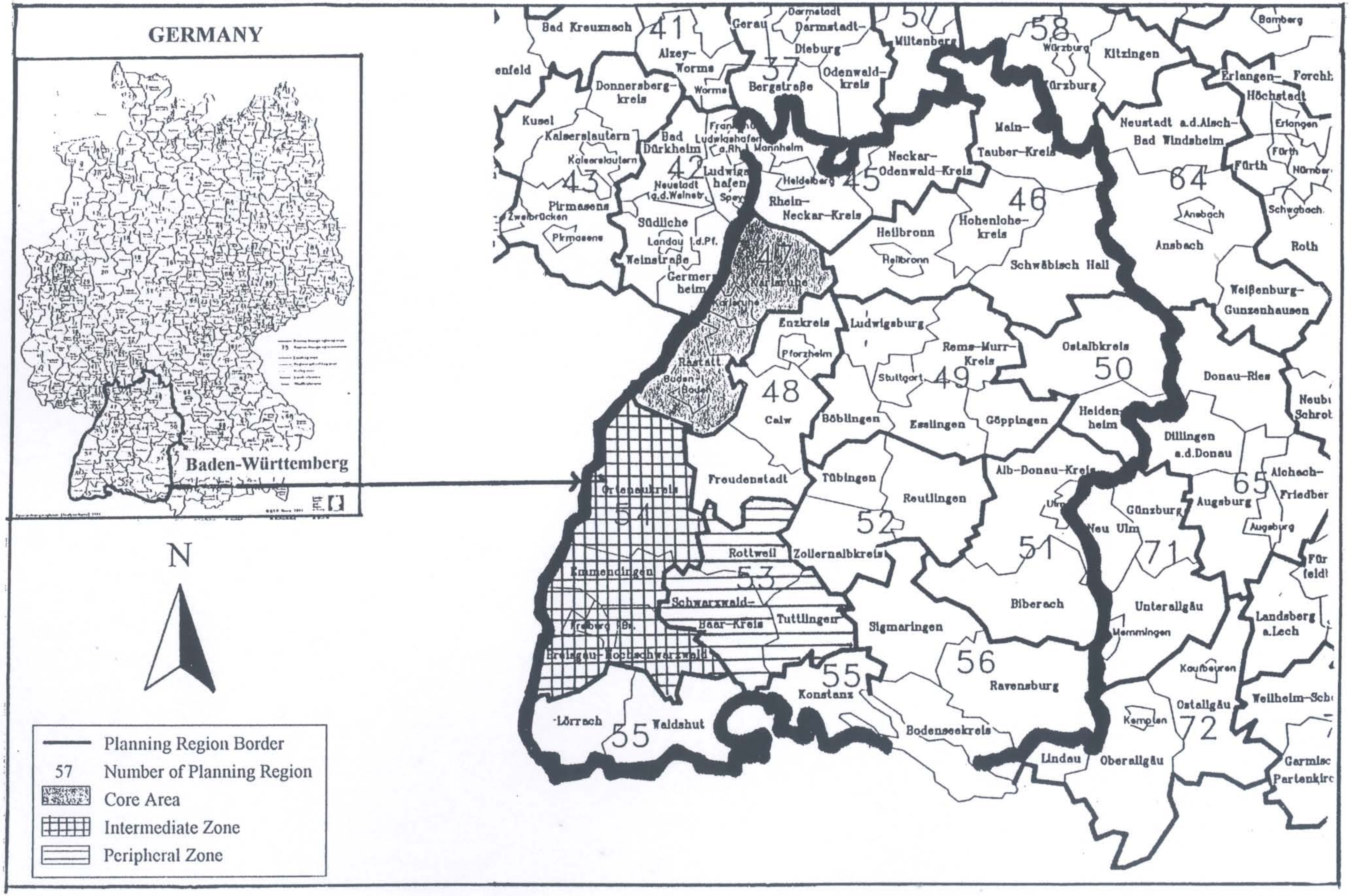
4. Caracters of the Firms - Cross Nation analysis

The field survey data were analysed by using descriptive statistics, e.g. frequency distributions, and inferential statistic tests (like chi-square and T-Test) to obtain information about the significance level for confirming or rejecting the null-hypothesis of equal distribution.

Map 1: Major Aerial Devision of the Northern Region In Israel



Map 2: Major Aerial Devision of the Planning Region in Baden-Württemberg Under Study



In Israel, after having classified the industrial plants according to their characteristics, analyses were carried out according to innovative and non-innovative firms and by using descriptive statistics. Thus the effect of each variable various according to the location and the industry type. Variances between location, within a given industry and between industries, and within a given location, were often found to be statistically significant.

Analyses for the German data indicate that most differences in the innovative performance of firms can be attributed to branch influences. Aspects peculiar to their regional economic environment, do not play a major role in explaining firm differences. Due to the interregional homogeneity in infrastructural supply and in the access to customers, suppliers, services and R&D institutions there seems to be only a small variance between the different types of regions, at least in those regions under investigation. Nevertheless, branch differences also reflect a locational pattern which at least indirectly might shed some light on variations between locational factors in the regions.

The main results of the T-test analysis is depicted in the following table:

Table 2: Distribution of plants characteristics, T-Test between Israel and Germany (in brackets number of observations)

Variable	ISRAEL mean	GERMANY mean	t value
Average Number of Employees	97 (211)	107 (220)	-0.567
% Highly Skilled Labor (Academicians)	17.5 (208)	8.4 (217)	5.574*
Average number of R&D employees	10.6 (209)	8.6 (198)	0.588
Average annualTurnover ($ million)	12.51 (198)	34.26 (212)	-3.305*
Annual Turnover per employee ($ '000)	94.4 (198)	280.3 (212)	-18.010*
R&D employees (% of total employees)	12.3 (202)	6.8 (198)	3.480*

* Significant at $p<0.05$

The average percent of academicians in the Israeli industrial plants is significantly higher than in the German industrial plants (17.5% compared to 8.4% respectively). Also the average percent of employees engaged in R&D is higher in the Israeli industrial plants compared with the German industrial plants (12.3% and 6.8% respectively).

On the other hand the average annual turnover per plant in Germany is significantly greater than that of Israel ($ 34.26 million compared to $ 12.51 million, respectively). Likewise, the average annual turnover per employee is also greater in Germany compared to that found in Israel ($ 280.3 thousand and $ 94.4 thousand, respectively).

Location and Sectorial factors

The geographical distribution of the firms from the data file is presented in Table 3. There is a significant statistical diffrentiation between the Israeli and the German samples in their locational distribution. In Israel geographical distribution of firms, from the selected industrial branches, displays a clear dominance of the intermediate zone, almost 39% of the firms identified are located in this area compared with only 24.5% in the German intermediate zone of Freiburg. On the other hand, the most industrialized area in German regions is the periphery, where 48.2 % of the firms in the sample have their location in the peripherial region of Schwarzwald-Baar-Heuberg, compare to only 30% in the Israeli northern periphery selected zone. The share of the central areas in both countries are almost the same - 27.3 % in Germany and 31.3% in Israel.

Table 3: Distribution of Plants by Location and by Country (%)

Location	Israel	Germany	Total
Metropolitan Area	31.3	27.3	29.2
Intermediate	38.9	24.5	31.6
Periphery	29.9	48.2	39.2
Total	100.0	100.0	100.0
N	211	220	431

$\chi^2=16.81$, $p=0.000$; d.f.=2

The distribution of plants by industry type, depicted in Table 4, shows that in both countries the electronics industry is the major branch (44.5% in Germany and 40.8% in Israel), while the other two branches show a significant statistical differentiation. In Germany the share of the metal industry is almost the same as the electronics industry (42.7%) while plastics stand far away behind with only 12.7% of the total. In Israel we have the oposite situation where the plastics industry comprises up to 37.9% of the plants in the Northern region and the metal industries, only 21.3% of the total. The dominance of the electronics industriy in Germany becomes clear especially in the intermediate zone 56.7%, while in Israel, in the Metropolitan area, with 54.5%. In Germany the metal industries contributes up to 50% of all firms in the periphery but in Israel it is the plastic industry that contributes 57.1% of all firms in the periphery.

Table 4: Distribution of Plants by Industry Type and by Country (%)

Industry type	Israel	Germany	Total
Electronics	40.8	44.5	42.7
Plastic	37.9	12.7	25.1
Metal	21.3	42.7	32.3
Total	100.0	100.0	100.0
N	211	220	431

χ^2=42.92, p=0.000; d.f.=2

Age of Firms

Distribution of firms by year of establisment is dipicted in Table 5. It shows that the percent of young plants, established since 1980, is greater in Israel compared to that in Germany (49.3% and 31.3%, respectively). In Israel 72% of the plants, located in the intermediate zone, were established there since 1980 while in Germany, in comparison, only 46.3% of the plants located in the intermediate zone were established there since 1980. i.e. the average and median age of plants in Israel is significantly younger than that found in Germany. In Israel the electronic plants are significantly younger than the plants belonging to the plastic and the metal industries (see Table 6). It is also younger by comparison to plants in Germany. For example: 61.6% of the electronic plants in Israel were established after 1980 compared with only 30.6% of the electronic plants in Germany.

Table 5: Distribution of Plants by Year of Establishment, by Country and Location (%)

Year of establishment	Countries		Regions					
	Israel	Germany	Metropolitan		Intermediate		Periphery	
			Israel	Germany	Israel	Germany	Israel	Germany
Before 1969	21.3	50.9	28.8	60.0	13.4	42.6	23.8	50.0
1970-1979	29.4	17.7	34.8	21.7	14.6	11.1	42.9	18.9
1980-1989	32.7	22.7	22.7	13.3	42.7	35.2	30.2	21.7
After 1990	16.6	8.6	13.6	5.0	29.3	11.1	3.2	9.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	211	220	76	60	82	54	63	106
χ^2	41.43		12.91		16.72		18.23	
p	0.000		0.005		0.001		0.001	

Table 6: Distribution of Plants by Year of Establishment, by Country and Industry Type (%)

Year of establishment	Countries		Industry Type					
	Israel	Germany	Electronics		Plastic		Metal	
			Israel	Germany	Israel	Germany	Israel	Germany
Before 1969	21.3	50.9	12.8	46.9	23.8	50.0	33.3	55.3
1970-1979	29.4	17.7	25.6	22.4	35.0	14.3	26.7	13.8
1980-1989	32.7	22.7	37.2	24.5	31.3	17.9	26.7	22.3
After 1990	16.6	8.6	24.4	6.1	10.0	17.9	13.3	8.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	211	220	86	98	80	28	45	94
$\chi 2$	41.43		30.31		10.08		6.783	
p	0.000		0.000		0.018		0.078	

Size of Firms

Measuring the size of the firms was done by the number of employees. In general, the Israeli firms are bigger than the German firms (see Tables 7). More firms in the Israeli sample (54.5%) belong to the medium size group (20-99 workers) or to the largest size group (28.0%) (above 100 workers), compared with the German sample (48.6% and 21.4% respectively).

When looking in the different selected regions, it becomes clear that in Germany, the average plant size in the intermediate zone and in the periphery is relatively smaller than the average plant size in Israel.

In the electronic plants there is no significant differences in the distribution of average number of employees by size catagories between Israel and Germany (see Table 8). In the plastic industry, on the other hand, the percentage of plants employing over 20 workers is 91.3% in Israel compared to 67.9% in Germany. In the metal industry the percentage of plants employing less than 20 workers is larger in Germany than it is in Israel, 31.9% and 20.0% respectively.

Table 7: Distribution of Plants by Number of Employees, by Country and Region (%)

Number of Employees	Countries		Region					
	Israel	Germany	Metropolitan		Intermediate		Periphery	
			Israel	Germany	Israel	Germany	Israel	Germany
less than 20	17.5	30.0	25.8	25.0	18.3	29.6	7.9	33.0
20-99	54.5	48.6	48.5	48.3	48.8	57.4	68.3	44.3
+100	28.0	21.4	25.8	26.7	32.9	13.0	23.8	22.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	211	220	66	60	82	54	63	106
χ^2	9.628		0.017		7.491		14.77	
p	0.008		0.980		0.023		0.001	

Table 8: Distribution of Plants by Number of Employees, by Country and Industry Type (%)

Number of Employees	Country		Industry Type					
	Israel	Germany	Electronics		Plastic		Metal	
			Israel	Germany	Israel	Germany	Israel	Germany
less than 20	17.5	30.0	24.4	27.6	8.8	32.1	20.0	31.9
20-99	54.5	48.6	45.3	39.8	67..5	50.0	48.9	57.4
+100	28.0	21.4	30.2	32.7	23.8	17.9	31.1	10.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	211	220	86	98	80	28	45	94
χ^2	9.628		0.590		8.994		9.335	
p	0.008		0.748		0.011		0.010	

Turnover

The differences between the Israeli and the German firms according to size categories, measured by turnover, are statistically significant. In Israel, the average annual turnover in more than half of the plants is below $5 million, while in Germany just 37.3% belong to these category (see Table 9). On the other hand, in Germany 26.4% of the plants has more than $20.4 million in annual turnover, while in Israel just 14.8% of the plants, belong to the same category.

In the metropolitan area, to differetiate from other locations, a statistically significant difference were found between Israel and Germany. The percentage of plants whose annual revenue is lower than $5 million is 65.2% in Israel compared to 28.3% in Germany. Similar results were obtained in the electronic industry where the percentage of plants whose annual turnover was lower than $ 5 million reaches 60.5% in Israel compared to 33.7% in Germany (see Table 10).

Table 9: Distribution of Plants by Turnover, by Country and Region (%)

Annual Tuenover Categories	Country		Region					
	Israel	Germany	Metorpolitan		Intermediate		Periphery	
			Israel	Germany	Israel	Germany	Israel	Germany
less than $5M	54.8	37.3	65.2	28.3	54.3	42.6	44.4	39.6
5M-20M	30.5	36.4	15.2	35.0	32.1	35.2	44.4	37.7
more than 20M	14.8	26.4	19.7	36.7	13.6	22.2	11.1	22.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	210	220	66	60	81	54	63	106
χ^2	15.27		17.24		2.411		3.528	
p	0.001		0.000		0.300		0.170	

Table 10: Distribution of Plants by Turnover, by Country and Industry Type (%)

Annual Tuenover Categories	Country		Industry Type					
	Israel	Germany	Electronics		Plastic		Metal	
			Israel	Germany	Israel	Germany	Israel	Germany
less than $5M	54.8	37.3	60.5	33.7	45.6	35.7	60.0	41.5
5M-20M	30.5	36.4	25.6	27.6	39.2	46.4	24.4	42.6
more than 20M	14.8	26.4	14.0	38.8	15.2	17.9	15.6	16.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	210	220	86	98	79	28	45	94
χ^2	15.27		17.57		0.819		4.919	
p	0.001		0.000		0.670		0.084	

R&D Employees

R&d activity is found to be the most important variable influencing on the capability of the firms to innovate. The differences in the distribution of average number of R&D employees by size categories, between Israel and Germany, were found to be statistically significant (see Table 11 and 12). In Israel 25.3% of the plants has more than 9 workers per plant engage in R&D activities, while in Germany only 19.8%. In Germany more than half of the firms have fewer than 2 workers engaged in R&D while in Israel, just 20.7% of the plants have fewer than two workers.

It is clear that Israeli plants are more involved in R&D activities than the German plants, as measured by the number of R&D workers. This is true not just in the whole sample, but also in the distributions by location and industry types.

In the metropolitan area, the percentage of plants employing over 9 workers in R&D is 39.6% in Israel, compared to 25% in Germany (see Table 11). In the intermediate zone and in the periphery the percentage of plants employing 2 or less workers in R&D is greater in Germany 57.8% and 58.5%, than it is in Israel 23.0% and 24.4% respectively.

In the electronics industry the percentage of plants employing more than 9 workers in R&D is larger in Israel compared to that in Germany, 43.5% and 37.6% respectively (see Table 12).

In the plastic industry the percentage of plants employing 2 or less workers in R&D is larger in Germany compared to that in Israel, 70.0% and 36.8% respectively. The same trend is found in the metal industry, where the percentage of plants employing 2 or less workers in R&D is larger in Germany compared to that in Israel, 73.2% and 25.0% respectively (see Table 12).

Table 11: Distribution of Plants by R&D Employees, by Country and Region (%)

Number of R&D employees	Country		Region					
	Israel	Germany	Metorpolitan		Intermediate		Periphery	
			Israel	Germany	Israel	Germany	Israel	Germany
less than 2	20.7	52.4	14.6	35.4	23.0	57.8	24.4	58.5
2-9	54.0	27.8	45.8	39.6	49.2	26.7	70.7	22.3
more than 9	25.3	19.8	39.6	25.0	27.9	15.5	4.9	19.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	150	187	48	48	61	45	41	94
χ^2	37.53		6.967		13.37		28.88	
p	0.000		0.050		0.001		0.000	

Table12: Distribution of Plants by R&D Employees, by Country and Industry Type (%)

Number of R&D employees	Country		Industry Type					
	Israel	Germany	Electronics		Plastic		Metal	
			Israel	Germany	Israel	Germany	Israel	Germany
less than 2	20.7	52.4	5.8	28.2	36.8	70.0	25.0	73.2
2-9	54.0	27.8	50.7	34.1	56.1	25.0	58.3	22.0
more than 9	25.3	19.8	43.5	37.6	7.0	5.0	16.7	4.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	150	187	69	85	57	20	24	82
χ^2	37.53		13.39		6.662		18.48	
p	0.000		0.001		0.035		0.000	

5. Innovation Behaviour

Innovation in the Spatial Dimention

Innovation potential is at the heart of the present study. Therefore, the second step was, to analyze the data according to innovative and non-innovative plants. Innovative firm is defined in the analysis as a firm that carried out product innovation in the last 3 years (before the field survey took place), with or without process innovation.

A regional descent, although not as highly significant (according to chi-square), can be identified in the distribution of innovating and non-innovating firms, by location (see Table 13). The rate of innovative firms in Israel is higher than in Germany. 82.0% of the plant located in the Northern region of Israel carried out product innovation, and 67.0% of the plants in Baden-Württemberg, Germany. We found a different regional pattern of innovation in the two countries. In Israel the highest share of innovating firms can be found in the Haifa metropolitan area (87.9%) followed by the peripheral zone of the Eastern Galilee (85.7%). The intermediate zone of Central Galilee, stand behind (74.4%). The regional pattern in Germany is quite different, where the highest share of innovating firms are found in the intermediate region of Freiburg (78.2%), followed by the metropolitan area of Karlsruhe (68.0%) while the peripheral region of Schwarzwald-Baar-Heuberg trails (60.4%).

Table 13: Distribution of Plants by Location and by Innovationin in Isreal and Germany (%)

Country	Location	Innovative	Non Innovative	Total	N	χ^2 (P)
Israel	Metropolitan	87.9	12.1	100.0	66	5.3 (0.068)
	Intermediate	74.4	25.6	100.0	82	
	Periphery	85.7	14.3	100.0	63	
	Total	82.0	18.0	100.0	211	
Germany	Metropolitan	68.0	32.0	100.0	50	5.1 (0.077)
	Intermediate	78.2	21.8	100.0	55	
	Periphery	60.4	39.6	100.0	101	
	Total	67.0	33.0	100.0	206	

In Germany, the regional pattern of innovation descibe above can be partially attributed to the average plant size in the regions. Plants are largest in the intermediate zone, where the average number of enployee per plant is 169 workers, compare to 100 workers in the periphery and 51 workers in the metropolitan area. Table 14 depicts the positive and significant relation betweem the firms size (measuring by number of employees categories) and the ability to innovate. The larger the firm, the higher the share of innovating firms (and vice versa). This explains the high share of innovating firms in the intermediate zone.

Table 10: Distribution of Plants by Size Category and by Innovation in Germany (%)

Innovation Numbert of empoyees	Innovative	Non Innovative	Total
1 - 19	23.2	41.2	29.1
20 - 99	47.1	35.0	48.5
100 and more	29.7	7.4	22.3
Total	100.0	100.0	100.0
N	138	68	206

$\chi^2 = 15.437$, $p = 0.000$, d.f.=2

In Israel the relation between firm's size and the distribution according to innovation is not statistically significant. A partial explanation of the lower share of product innovative firms in the intermediate zone, is given by the role of the Central Galilee in the spatial dimension of the Northern region in Israel. In the last few years this intermediate zone became attractive to industrial firms. Firms in the mature stage of their life cycle move from the core area to the intermediate zone, where they enjoy cheaper land, and accessibility to un-skilled labor force needed for mass production. In this phase of their life cycle, many of the firms are interested more in improving their competitiveness, by reducing production costs. Therefore, by definition, they emphasize process innovation more than product innovation.

A complementary explanation of the share of innovating firms in the selected regions in both countries is given by the distribution of industry types. Industrial branches play a major role in the different shares of innovating firms. As can be seen from Table 15, in both countries the metal industry shows the lowest innovative share of all the three selected industrial group in the study. In Germany more than 50 %, and in Israel more than 30%, of the plants in the metal industry belong to the non-innovating group of firms. Accordingly, the metal industry concentrates mostly in the intermediate zone in Israel and in the periphery in Germany (see Table 2 above), both regions were found to be less innovative respectively (see Table 13 above). On the other hand the electronic industry is the most innovative group in both countries. Almost 85% of the electronic plants in Germany and 86.0% in Israel belong to the innovative group. The electronic industry is the major branch in the metropolitan area in Israel and in the intermediate zone in Germany, both are regions with the highest share of innovative plants.

Table 15: Distribution of Innovation Plants by Industry Type in Israel and Germany (%)

Country	Industry	Innovative	Non Innovative	Total	N	χ^2 (p)
Israel	Electronics	86.0	14.0	100.0	86	6.7 (0.035)
	Plastic	85.0	15.0	100.0	80	
	Metal	68.9	31.1	100.0	45	
	Total	82.9	17.1	100.0	211	
Germany	Electronics	84.8	15.2	100.0	92	26.1 (0.000)
	Plastic	64.3	35.7	100.0	28	
	Metal	48.8	51.2	100.0	86	
	Total	67.0	33.0	100.0	205	

Innovation Inputs

The relation between various characters of the plants and the tendency to innovate is depicted in Table 16. The table represents the results from t-test analysis, between innovative and non-innovative group of firms in Germany and Israel. In both countries the relation between the age of the firms and their belonging to the innovative group was found to be not a statistically significant. In Germany the size of the plants contributes to the explanation of innovativness of the firms. Innovative plants are larger (as measured by number of employees and annual turnover) than non-innovative plants and the differences are statistically significant. The corresponding results in Israel were not statistically significant.

Table 16: Characteristics of Firms, T-Test between Innovative and Non-Innovative Plants in Israel and Germany (in brackets number of observations)

Characters	Israel			Germany		
	Innovative plants	Non Innovaitve plants	t value	Innovative plants	Non Innovaitve plants	t value
Average age of plant (years)	18.7 (173)	15.8 (38)	1.398	31.3 (135)	36.1 (67)	-1.08
Average number of employees	101.4 (173)	74.5 (38)	1.123	147.7 (138)	40.2 (68)	4.20*
Average annual turnover (mln. $)	14.05 (164)	5.08 (34)	1.637	18.11 (123)	4.10 (66)	3.67*
% employees in R&D	14.7 (164)	2.0 (38)	3.545*	9.3 (133)	1.6 (66)	7.65*
% academic employees	19.8 (170)	7.3 (38)	3.382*	10.9 (137)	11.5 (5)	6.15*

* Significant at $p<0.05$

As mentioned above, R&D inputs is the most important factor for the plants in their effort to be innovative. In both Germany and Israel the relation between the R&D-intensity of firms and their innovativeness was found strong and highly statistically significant. The percent of R&D employees and the percentage of highly skilled labor (academics including: scientists, engineers, and economists), in the innovative plants is much higher than in the non-innovative plants. The comparison between the two countries shows the advantage of the Israeli innovative plants. R&D intensity in Israeli firms is larger than in German firms. In Israel almost 15% of total employees in the innovative plants are engaged in R&D and almost 20% of the total employees are academics. In the German innovative plants it is much less: 9.3% and 10.9% respectively. That might explain the lower rate of innovative plants in the German sample as compared with the Israeli sample (see Table 13 above).

Within the regions we can see from Table 17, that R&D-related variations between innovating and non-innovating firms can be found as well. In both countries, the percent of R&D employees and highly-skilled labor is much higher in the innovative plants located in the Metropolitan areas than in plants located in the intermediate and in the peripheral zones. In Germany there are almost no differences in the R&D and highly-skilled labor parameters between the intermediate zone and the periphery, and they are rather small in comparison to the metropolitan area, as opposed to the Israeli case. In Israel it is interesting to note that those parameters are higher in the periphery than in the intermediate zone, still less than the Metropolitan area. The advantage of the Israeli innovative plants is expressed mostly in the Metropolitan area, where the average percentage of R&D workers is almost 25%, and the highly-skilled labor rate is 27.8% of all employees, against 12.9% and 18.2% respectively in the innovative plants in the German metropolitan area.

Table 17: **Characteristics of Firms, T-Test between Innovative and Non-Innovative Plants, by Location in Israel and Germany (in brackets number of observations)**

Area	Characters	Israel			Germany		
		Innovative plants	Non Innovative plants	t value	Innovative plants	Non Innovative plants	t value
Metro-politan	Average age of plant (years)	20.9 (58)	20.3 (8)	0.15	25.0 (34)	27.9 (16)	-0.44
	Average number of employees	126.3 (58)	60.5 (8)	0.90	56.9 (34)	39.0 (16)	1.13
	Average Tunover (mln $)	21.68 (55)	3.81 (8)	0.99	6.59 (29)	4.21 (15)	1.09
	% employees in R&D	24.6 (55)	0.0 (8)	-	12.9 (31)	1.6 (15)	4.33*
	% academic of employees	27.8 (58)	5.2 (8)	2.29*	18.2 (34)	1.9 (16)	4.55*
Inter-mediate	Average age of plant (years)	14.03 (61)	13.1 (21)	0.32	34.3 (43)	47.3 (12)	-1.00
	Average number of employees	95.0 (61)	89.7 (21)	0.18	218.1 (43)	54.4 (12)	2.66*
	Average Tunover (mln $)	12.24 (56)	5.94 (17)	1.48	23.58 (40)	6.81 (12)	1.93
	% employees in R&D	14.0 (58)	3.4 (21)	2.45*	8.4 (42)	1.0 (12)	5.41*
	% academic of employees	19.8 (59)	7.5 (21)	2.51*	9.4 (43)	5.1 (12)	1.95
Peri-phery	Average age of plant (years)	21.7 (54)	18.1 (9)	0.95	32.7 (58)	36.0 (39)	-0.52
	Average number of employees	81.9 (54)	51.4 (9)	1.19	148.7 (61)	36.4 (40)	2.93*
	Average Tunover (mln $)	7.41 (53)	4.59 (9)	1.08	20.26 (54)	3.23 (39)	2.77*
	% employees in R&D	4.8 (51)	0.5 (9)	1.70	8.1 (60)	1.8 (39)	4.60*
	% academic of employees	11.0 (53)	8.8 (9)	0.60	7.8 (60)	3.1 (39)	3.60*

* significant at $p<0.05$

Analysis of the differences between industrial sectors reveals the dominance of the electronic industry as the most highly innovative industry (see also Table 15 above). The results from the analysis are shown in Table 18. In Israel most of the characteristics tested in the analysis belonging to the plastics and metals industries found to be not statistically significant, as opposed to the electronics industry. In Germany it is the plastics industry that shows no significant differences in those indicators between innovative and non-innovative firms. The difference in R&D intensity parameters between the innovative plants and the non-innovative plants in the German metals industry is quite small, while in the electronics plants is much greater.

Table 18: Characteristics of Firms, T-Test between Innovative and Non-Innovative Plants, by Industry Type in Israel and Germany (in brackets number of observations)

Industry Type	Characters	Israel			Germany		
		Innovative plants	Non Innovative plants	t value	Innovative plants	Non Innovative plants	t value
Elecronics	Average age of plant (years)	15.4 (74)	14.6 (12)	3.50*	31.3 (76)	45.5 (13)	-1.17
	Average number of employees	108.5 (74)	0 (12)	3.55*	197.6 (78)	46.8 (14)	3.38*
	Average Tunover (mln $)	14.56 (71)	8.29 (11)	0.54	25.5 (72)	3.46 (14)	3.55*
	% employees in R&D	28.3 (74)	0.7 (12)	-0.54	13.0 (76)	1.3 (13)	8.11*
	% academic of employees	34.6 (74)	7.3 (12)	0.24	15.2 (77)	6.5 (14)	3.26*
Plastic	Average age of plant (years)	19.9 (68)	16.0 (12)	1.15	24.0 (18)	23.7 (10)	0.05
	Average number of employees	91.3 (68)	40.5 (12)	1.65	93.6 (18)	32.9 (10)	1.31
	Average Tunover (mln $)	13.97 (66)	4.1 (11)	1.14	3.85 (14)	4.26 (8)	-0.28
	% employees in R&D	3.9 (61)	0.9 (12)	2.43*	4.0 (15)	2.1 (10)	1.17
	% academic of employees	8.3 (65)	8.8 (12)	-0.20	5.2 (18)	1.2 (9)	3.15*
Metal	Average age of plant (years)	20.9 (58)	20.3 (8)	0.15	34.3 (41)	36.1 (44)	-0.29
	Average number of employees	126.3 (58)	60.5 (8)	0.90	78.2 (42)	39.7 (44)	1.87
	Average Tunover (mln $)	21.68 (55)	3.81 (8)	0.99	9.15 (37)	4.28 (44)	1.66
	% employees in R&D	24.6 (55)	0.0 (8)	-	4.6 (42)	1.6 (43)	3.08*
	% academic of employees	27.8 (58)	5.2 (8)	2.29*	5.3 (42)	2.5 (44)	2.46*

* significant at $p<0.05$

Once more, the results indicates that among the innovative electronic plants in Israel, R&D intensity is greater, almost double, than among the German plants. Average percentage of R&D workers and highly-skilled labor in the innovative electronic firms in Israel is 28.3% and 34.6% respectively, compared with 13.0% and 15.2% among the electronic plants in Germany.

6. Conclusions

Innovation potential of firms located at different locations, i.e. center, intermediate zone and periphery, is at the heart of the present study. Therefore a thorough analysis of the firm's characteristics in the three designated fast-growing industries was carried out.

A comparison between Israeli and German firms revealed that in the Israeli firms a significantly higher percentage of highly skilled labor and R & D employees are employed. On the other hand, in the German firms, the annual turnover per employee is significantly greater than in the Israeli firms.

The Israeli firms tend to be, on average, much younger firms, in all three locations. The electronic industry was found to be particularly and significantly younger than counterpart firms in Germany.

As far as the rates of R&D employees are concerned, the statistical analyses revealed a larger percentage of firms with more than 9 R&D workers per plant in the Israeli firms. This is particularly true of the electronic and metal firms, but also to some extent, in the plastics industry. The same higher concentration of R&D employees was observed in the Israeli firms located in the Metropolitan and Intermediate zones.

Turning now to innovation, a far greater percentage of larger German firms (with 100 employees and more) are innovative. In general, the Israeli firms in all of the three selected fast growing industries are significantly more innovative than their German counterparts.

In both countries, in the electronics industry, the average size of the innovative firms and the average annual turnover are significantly larger.

In Germany, innovative firms, in practically all three of the fast-growing industries, possess a higher percentage of R&D employees and academic employees. This is hardly the case in Israel, except for the percent of R&D employees in the plastics industry and the percent of highly-skilled labor in the metal industry.

To sum up: the innovative Israeli firms in our sample appear to be younger, larger in size and with a larger percent of employees in R&D or academicians. On the other hand, innovative German firms, located in each of the three zones, appear to have a larger percentage of R&D employees and highly-skilled labor. This observation generally holds true also for innovative firms in the three selected fast growing industries.

These results point out to the rapid growth in industrial plants which took place in Israel, particularly in the electronic industry, in the past 20 years. But the most rapid growth took place in the past 5 years.

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APPENDIX A: Eliminating Industrial Branches

The advent of the unexpected events which took place in the late 1989 and early 1990 made a significant mark on the entire world, but most pronouncely they affected Germany and Israel. The sudden shock ensued by the reunification of Germany and the absorption of a flux of hundreds of thousands of new immigrants, who migrated to Israel from the former Soviet Union, vibrated throughout the entire social and economic fabric of both countries. The rapid expansion in the local demand for consumer goods and services, particularly food and beverages, construction material, as well as other durable and non-durable goods, resulted in a significant growth in the output of several related industries. Thus it was our intention to differentiate between export-based fast growing industries and local demand-led industries.

The former, we maintain, indicates competitive advantage and thus could be long lasting while the later is a mere response to "once and for all" sudden change in the local demand.

In Israel the waves of new immigrants, from the former USSR brought about, in a short period of time, a rapid growth in the population (close to 10%) and in Germany the reunification had also a far reaching effect on some selected consumer oriented product industries.

In Israel the effect was profound especially on the non-metallic mineral products and the wood and its products. In these two industrial branches the growth rate was very high (five to seven times of the average increase in employment and twice to four times the average growth in production).

These tremendous growth rate in both of these industrial branches are due to the rapid increase in the local demand for consumer products. The most profound effect is on the construction industry. The fast increase in the local demand, that occurred during that period, is the result of the high waves of immigration coming from the former USSR during the period 1989-1993 when half a million are new immigrants poured into Israel in a very short period of time. The immigration created new demand for housing and thus putting great pressure on the construction industry.

Consequently, these two industrial branches bias the average growth rate of the entire manufacturing industry in a way that skewed the "natural increase rate" of the manufacturing industries as a whole. Table 2 depicts the data on growth rates, excluding the above mentioned two industrial branches. The table shows that by excluding these two industrial branches, the average rate of growth in industrial production in Israel was only 14%, and the increase in the number of employed was only 5.5%.

In Germany the effect of the reunification, particularly during the years 1989-1991, were:

- the need to close the gap between the west and the east with respect to the consumption of durable and consumer goods;
- increase in the demand for housing, thus affecting the construction industry;
- a production boom in wood and its products
- the urge to compensate for decades of repressed information needs (print media)

In the following two periods 1987-1989 and 1989-1991, the rate of production of food, beverages and tobacco increased by 5.8% and 23.2% respectively, and for wood and its products, by 12.2% and 17.3% respectively. These growth rates would thus appear to be caused by the first shock of the reunification. These reasons and the large amount of subsidies transferred to the east from the west seem to provide a good explanation for the sudden rapid growth in production in the above mentioned industrial branches. Therefore the following industries: food, beverages and tobacco, wood, paper and their products and printing and publishing, were excluded from our data analysis. After excluding these industries, it can be seen from Table 2 that the total growth in production is 15.4% and the total increase in employment is only 2.2%.

Emergence and Development of Regional Technology Policy in Germany - The TechnologieRegion Karlsruhe

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by Günter H. Walter
Fraunhofer Institute for Systems and Innovation Research
(Fraunhofer-ISI), Karlsruhe, Germany

What is Technology Policy?

Technology policy is a policy which concentrates primarily on techno-scientific issues (Meyer-Krahmer, Kuntze 1992). By supporting basic research, applied research and industrial research, it assists the **initiation and expansion of an innovation system**. It helps to create societal frame conditions conducive to the performance of industrial research and development (R&D) - in particular by making the necessary financial means available. It consciously attempts to influence the general development of technology towards an orientation that will secure industry's innovative capability, in order to ensure its competitiveness.

Under the point of view of economic theories (Ewers 1990) justification for the existence of technology policy is grounded, among other things, in the duty of the state to remove supply deficits in the production factor of information and communication, and to make public and publicly financed commodities, such as (basic) research, available to all enterprises. Other reasons are the purpose of supporting small firms in competition with large enterprises, and the duty to intervene to correct the business climate (anti-cyclical activity). Technology policy can also provide a channel for making use of specific public possibilities and potentials (as in information leads for joint projects) or can be applied in co-ordination with other public measures (e.g. norms, standards), leading to synergy effects. Practically every developed state has implemented such policies.

In Germany, a sophisticated, self-complementary **bundle of measures** (figure 1) exists for the institutional promotion of R&D and for the support of industry in the generation of new ('high tech') technologies (Meyer-Krahmer, Kuntze 1992). The broad, rapid application of new ways of production and production processes is also promoted, as are product innovations. The most important instruments of this kind of policies are financial incentives granted by the state to institutes and industry (financial transfers).

Other technology policy instruments (real transfers) relate to the infrastructure (Reger, Kuhlmann 1995). These include innovation services (technology transfer, information, consulting, co-operation). This type of promotion is not primarily directed towards the generating of new technologies, but rather towards increasing the diffusion and utilisation of already available technologies, while exploiting local and regional advantages.

In Germany, measures of the Federal Government are in competition with the regional programmes of individual states (Laender) and with the local activities of public, semi-public and private institutions on the one hand, and on the other with international measures, particularly those of the European Union.

2 The Origins of Technology Policy in Germany today

Technology policy in Germany has become very lacking in transparency. It is characterised by a multitude of different measures and a "fragmentation" of the technology policy actors involved. In technology policy, tendencies can be observed towards decentralisation, as well as towards internationalisation and globalisation.

How has a situation of this kind arisen, and what factors determine the behaviour of those involved? To elucidate this, a brief historical account of the development of technology policy, will be given (Bräunling, Maas 1988).

2.1 Macrotechnology Policy

The position with regard to **national - i.e. federal - measures** (macrotechnology policy) was as follows: in the 1950s a process of re-structuring took place. In particular, the research institutions had to be reconstructed. Support centred on the institutional financing of basic research at universities and in other public research institutions. The support of industrial R&D was not a top priority.

Technology policy in the **1960s** attempted to close the 'technology gaps' that arose in relation to the USA and other industrialised nations, by carrying out **large-scale technological programmes** (e.g. coal processing, nuclear technology, aviation and space technology), partly in national research laboratories. Particularly (large) industrial enterprises were involved in cooperations with national science laboratories.

Technology policy in the **1970s and 1980s** was characterised by efforts towards the modernisation of industry, by promoting the development and use of **trans-sectoral technologies** as basic technologies, e.g. semiconductor technology and new materials. Besides technological goals, measures in the 1970s also addressed socio-political viewpoints concerning the aspects of environment, health and working conditions. The technology policy after the 1980s once more concentrated on the acceleration of technical change and industrial competitiveness, thus providing support oriented towards particular interests in industry. Enhancing the technical competitiveness of industry was always its explicit goal. The tendency was to support modern firms. As well as the generation and application of high tech, there was also support for the introduction and diffusion of new and improved products and processes, particularly in small and medium sized firms (SMEs). **Promotion funding flowed mainly into densely-populated regions** with a diversified industrial structure.

Today, national state technology policy sees itself confronted with new challenges, and not only in Germany. The problems that have to be solved are complex and have often become transnational problems. It is necessary to work on new topics, such as linking industrial growth with minimal use of resources, reducing the dependency of industry on oil, new environmental concepts, renewal of urban districts, and the issue of transport.

The more intensive science base of many high tech areas is leading to new concepts of the innovation process, with the linear model being replaced by a model with feed-back loops at all stages, from generation to diffusion (Kline, Rosenberg 1986). This requires a global approach to research topics and new forms of interdisciplinary and multidisciplinary co-operation. In view of limited financial means, new methods of optimisation have become necessary. When supporting R&D, promotion has to perform a comprehensive ecological analysis of projects, including upstream processes and disposal. It also has to find a way towards alternative, resource-conserving solutions.

2.2 Microtechnology Policy

As well as the principal actor - the federal government - other actors are active in German technology policy (Kirchhoff, Müller-Godeffrey 1991). Considered from a **regional viewpoint,** i.e. from the microtechnology level, policy in Germany in the **1950s and 1960s** shows efforts to create jobs in structurally weak regions. Promotion of regional development gave incentives to allocation and investment, industrial and commercial sites were made available. The idea was simple: to channel superfluous capital away from already-prosperous regions. In the **1970s** it became apparent that the potential for re-distribution was dwindling, and that simply transferring capital from agglomerations to structurally weak regions did not necessarily lead to a balanced distribution of independent, innovative enterprises.

Investigations on the innovative behaviour of firms carried out at the beginning of the **1980s,** showed substantial differences between regions. Compared to enterprises in agglomerations, firms in structurally weak regions realised fewer product innovations and generally conducted less R&D (Meyer-Krahmer et. al. 1984). Their R&D activities were concentrated on further development and adaptation. Although firms there bought substantial amounts of innovative plants and machines in structurally weak regions, the diffusion of new production technologies was still comparatively slow. Qualified R&D personnel were mostly recruited internally by the firms. However, there were still frequent personnel problems. The supply of information on markets and technologies in structurally weak regions - and sometimes also the supply of capital - were also assessed as inadequate.

Regionally-oriented technology policy adopt an approach of **real transfer** to combat these particular deficits (Steiner et al. 1996). New institutions, re-orientation of existing institutions and changes in individual patterns of behaviour are a "regional way" to accomplish this. They can be used to mobilise endogenous potentials, as well as mobility oriented approaches in order to form a regional innovation network by strengthening scientific and industrial potentials (e.g. fast growing industries) and integrating the regions more strongly into international industry and research .

Successful regional technology policies should give support for:

- **Motivating** firms located in the region, which so far have not been innovative, to engage in appropriate activities, by attempting to positively influence the interactions of objective and informal mechanisms in industrial innovation activities. For instance, providing enterprises with information and knowledge would create a sufficient awareness of innovations among the firm's decision-makers, thus clarifying the risks for the firm associated with innovations, and making them easier to deal with.

- **Attracting** innovative, mobile firms from other areas into the region. The strategies that can be used here are the "classic" industrial promotion measures and the establishing of technology and incubator centres.
- **Stimulating the foundation of new technology-based firms (NTBFs)** within the region. This does not necessarily mean expensive financial programmes, but rather concern the creation of regulatory conditions for industrial and scientific establishments in the region which will help to support founding activities both formally and informally, e.g. for employees of R&D institutions wishing to found their own firm. This may consist in paid or unpaid leave, an agreed guarantee of re-employment in case of failure of the enterprise, and the right to make use of certain results of the R&D institute either free of charge, or at low cost.

Regionally-oriented measures aim to **increase the innovation and adaptation capability** of already present industry and of enterprises to be attracted into the region. They mainly take the form of innovation management assistance, qualification and the support of possibilities for contacts and cooperations with R&D establishments.

As well as these aspects, which are general features of regional technology policy, the differing situations encountered in individual regions are also important policy determinants (Meyer-Krahmer, Walter 1993):

- In **structurally weak regions,** regional technology policy can attempt to sensitise industry in the region to the necessity for carrying out industrial innovations and to motivate its engagement in innovations, subsequently to encourage it to make use of innovative services. Mobilisation of endogenous potentials was the strategy primarily pursued here.
- In **regions of obsolete, monostructural industry**, the technology policy activities can have the aim of an innovation-oriented "new direction" for existing industry, and attracting new industries into the area e.g. by installing technology and incubator centres.
- Regions with existing technological **competitiveness of a well-developed, diversified industry**, by technology policy usually try to maintain their capabilities by enlarging and extending the existing networks.

Requirements from regionally-oriented technology policy, as a microtechnology policy, arise on the one hand from the possibilities of achieving comparable success in industrial innovation activities using different procedures for different regions (under the rubrics: exploitation of regional innovation styles, best practice, cohesion) to exploit existing resources. On the other hand regional technology policies has to ensure the linkages of the region to international industry and research, e.g. by co-ordinating these activities with the existing macrotechnology.

3 Complementarity between Macrotechnology Policy and Microtechnolgy Policy

The most important instruments of **macrotechnology policy** are financial incentives for the establishment of research institutes, for covering the operating costs of these institutions and for the realisation of large research projects. This type of policy is closely associated with high costs and stipulates as prerequisites the existence of specific conditions and organisational structures on the governmental and research side. Furthermore, such a policy is based on a political decision to become engaged in technology, that will possibly have future global impact. Such investments are almost impossible to make for the whole technology spectrum, which means that specific areas have to be selected and the required goals precisely defined. This is true for the public assistance to institutions and also for the granting of financial incentives for expensive complexes, research and development projects e.g. in association with several institutions and/or firms and the establishment of high technology enterprises. The target-group is therefore limited - namely research institutions and technology based firms. That fact again implies for the state a concentration of the available means in specific areas. Macrotechnology policy represents therefore a top-down technology push policy for areas that are regarded from an economic standpoint as direction indicators. The extent of the state capital involved by such measures requires a systematic evaluation and objective supervision (if necessary intervention) by the government or state designated institutions. Macrotechnology policy is result and goal oriented.

Microtechnology policy is practised by regional/local institutions and groups. Such institutions have generally very limited financial means. Due to the exclusion of financial support for the generation of new global technology the measures are concentrated not on a selected target group but on a larger number or even the majority of industrial actors within a specified region. The starting points for such measures do not lie in financial support but in the direction of advice, information and co-ordination, and support through suitable infrastructural services. Possibly such services must be expanded or the scope of activities of already existing institutions must be suitably broadened and modified.

Microtechnology policy is rather a bottom-up approach and demand oriented. Because less financial means are directly used, the control possibilities of public bodies are correspondingly reduced. Public institutions are less actors as moderators between different interest groups. In such a role personal contacts and advantages resulting from close spatial and social proximity are important. Therefore microtechnology policy is more an instrument for regions or local institutions. Through close personal contact its result is usually an improvement of already existing potentials or activities, i.e. a reinforcement of the innovative activities in already existing structures. Through the social and spatial proximity is this type of policy more action based with integrated feedback mechanisms. Actor-based feedback technology policy, as here described, also integrates successfully cultural and social factors and is, in comparison to the clearly prescribed results of a "massive" macrotechnology policy, rather more experimental.

This comparison between macrotechnology policy and microtechnology policy shows that every approach has its specific effects, advantages and disadvantages. Thus an effective overall technology policy has to **integrate both elements**.

Comparison of Macrotechnology Policy and Microtechnology Policy

Macrotechnology policy	Microtechnology policy
financial support of R&D	real transfer
support at high tech	support of intelligent use of technology
funding flows into agglomerations	comprehensive regional coverage
reinforces regional differences	reduces regional differences
support of basic innovations; carrying out large-scale R&D projects	further development and adaptation
promotion of basic and applied research; concentrating on the early phases of the innovation process	incremental innovations, small R&D projects, support of development tasks; concerned with final phases of the innovation process
building up new industries	implementing new routines in existing firms and re-structuring existing enterprises
installing new institutions	involving existing institutions (with existing relationships of trust), possibly giving them new fields of activity.
supply of new techniques	demand-oriented measures
the state as actor	public institutions tend to act as moderators
rigid steering (via the distribution of financial means)	"soft" handling by face-to-face contacts, informal mechanisms, sounding out areas for manoeuvre, sensitisation, co-ordination of existing resources and of various measures
autonomous	links and feedbacks with global R&D
small industrial target groups, technology-based firms	broad target groups; enterprises that adapt, innovate, 'catch up'
aim: building up new innovative capacities	aim: allocation and modification of existing enterprises
concentration on technical content, often difficult to co-ordinate with other policy areas	inclusion of social dimensions
policy with predetermined, fixed targets (goal focused policy)	experimental policy

4 Impacts of Technology Policy for Innovative Regional Development

Industrial innovations ensure industrialised countries and regions continuous adaptation to changing societal conditions, as well as prosperity economic power. The purpose of technology policy especially on a regional basis therefore is to strengthen industrial potentials and integration the region into international industry and research (e.g. by participating in marcotechnology). In order to achieve this, regional technology policy has to support:

- **Establishing a regional vision:** The nature of individual thought and action, the lifestyle and working style, the existing status of training and education of the (working) population, "entrepreneurial spirit", institutional modes of behaviour - in other words, the cultural frame conditions - are factors which exert an influence on industrial innovations. Thus access to technology, readiness, ability and familiarity in handling technology as well as marketing skills are important for the innovative capability of a region. A regional 'vision‘ ensures a positive public opinion of innovation.

- **Economic performance:** The enhancement of economic performance by support of industry could be necessary (e.g. co-ordinated planning of the use of industrial and commercial estates). Initiatives of permanent industrial structural change should be encouraged by creation of an innovative milieu, i.e. NTBF in future-oriented industrial branches, innovation projects in enterprises that have not previously been innovative, additional and extended innovation projects to strengthen innovative activity in already innovative firms. Further possibilities are the establishing of new services supportive of innovation and expansion of the working spectrum of existing information, financing and advisory service institutions.

- **Intraregional networking:** The support of the creation of a broad regional innovation base will intensify regional networking in production and service. According to their capabilities, techno-scientific capacities of research and development must co-operate closely with industry (e.g. through mixed public-private financing). R&D establishments should create specific focuses in technology fields of regional industry. Also the capability of regional industry for an adequate division of labour between large enterprises and SMEs can be supported (small firms produce for the regional market and as qualified suppliers of large regional enterprises).

- **Supraregional and international networking:** This particularly concerns the international exchange of information and communication (setting up new service institutions, extending the fields of activity of existing ones). Supraregional/international co-operation projects possibly with financial support from macrotechnology policy are to be carried out. Science and industry in the region will make knowledge and experience available, also internationally, possibly via newly-created service enterprises. This aspect is important, since an innovative region also has to make substantial contributions of its own in international techno-scientific co-operation, if it is to be recognised as an equal partner in the global exchange of information.

- **Administration** in the region has to support substantially innovative efforts by appropriate measures (creation of regulatory structures). This requires continuity, awareness of industrial issues on the part of administration, binding, yet flexible actions with a clear assignment of responsibilities. Administrative institutions should be involved at an early stage in industrial promotion measures to support innovation.

An example of an approach to achieve at least some parts of these goals of regional technology policy are the consensus-based activities in the Technology Region of Karlsruhe ("TechnologieRegion Karlsruhe").

5 The TechnologieRegion Karlsruhe

This region is one of the technologically most developed regions of Germany with a competitive and diversified industry. The TechnologieRegion Karlsruhe can be regarded as a model of regional technology policy especially to build up and maintain innovative potentials. The TechnologieRegion Karlsruhe (Leder, Seeck o.J.) was inaugurated in 1987 and comprises the eight municipalities of Baden-Baden, Bretten, Bruchsal, Bühl, Ettlingen, Gaggenau, Karlsruhe and Rastatt and the county districts of Karlsruhe and Rastatt. The organisational form is based on the principles of voluntary co-operation and inter-disciplinary approach. The representatives of industry, science, culture and administration work in concert. The TechnologieRegion Karlsruhe is tackling the mayor issues of an innovative regional development and of regional technology policy in a spirit of partnership.

The total workforce of the TechnologieRegion Karlsruhe is more than 370.000, with about 45% employed in manufacturing industry (the majority in the processing sector) and more than 50% in services, such as knowledge intensive business services. The rest are employed in the primary sector. SMEs are the backbone of the regional economy. Of about 10.000 firms entered in the commercial register more than 90% have fewer than 100 employees and only about 30 companies are large enterprises with more than 1.000 employees. There is also a large variety in the industrial structure of the TechnologieRegion Karlsruhe. The strongest sectors are electrical engineering, vehicle manufacturing and mechanical engineering (more than half of the industrial jobs and about one third of sales).
The Technology Region has an outstanding manpower employed in R&D, more than any comparable region in Europe:

- The Fridericiana University, focusing on the natural sciences and technology, with the largest computer sciences faculty in Germany: 120 institutes, 21.000 students (8 % of these from abroad), 2000 professors and academic staff.

- The Computer Science Research Center at the University of Karlsruhe (FZI) focusing on the fields of Computer Science for planning, design, development and construction and for production, assembly, transport and conveyance systems in close co-operation with industry: 80 academic staff, 9 areas of research.
- The Karlsruhe National Research Center specialising in the areas of: energy research, environmental, climatological and safety research, microstructural and operative engineering, solids and materials research, follow-up technology assessment: 4,200 employees (including 1,400 academic staff) and chemical energy conductors; combustion and reaction kinetics, environmental and safety engineering, environmental simulation of technical systems, accident and breakdown research; transport stress demands and packaging research; electrochemistry, energy storage and chemical sensory technology.
- Karlsruhe Polytechnical College with fields of study in architecture, construction management, construction engineering, electronic energy engineering, precision mechanics, computer sciences, cartography, mechanical engineering, communications engineering, physics, chemistry, surveying and associated fields, economic sciences, economic engineering and social sciences: 150 professors, 250 assistant lecturers, 4000 students.
- Technology Factory, Karlsruhe, one of the largest founding centres for technology-oriented business start-ups in Germany with 650 employees, 900 million DM turnover.

Each of these institutes existed before the TechnologieRegion Karlsruhe was "created". Just the network, the co-ordination was missing.

To support the co-ordination of the regional resources in order to maintain competitiveness is one of the main tasks of TechnologieRegion Karlsruhe approach. On the one hand this kind of "technology policy" is an continuous elaboration of operative solutions in the short term, on the other hand it sets up of stable signals for sustainable activities in the long term.

The vision of the TechnologieRegion Karlsruhe: Science and technology are based on reasons and logic, but have a sensitive feeling for home. The TechnologieRegion has a long history of being such a "home" as there took place the:

- Invention of the velocipede in 1813 - the precursor of the bicycle
- First German production of locomotives in 1842 - a foresight enterprise
- Discovering of the electromagnetic waves by Heinrich Hertz in 1888 - the preparation of the age of radio and TV

and there is a wide acceptance of regional enterprises and population of the necessity for continuous innovation as e.g. presentations of the regional research institutions attract numerous visitors (Karlsruher Technologietage in average 30.000 visitors). Being also situated in nice landscapes between Rhine and Black Forest and close to

France the vision of the TechnologieRegion refers to "high tec" and "high culture". Here the support of technology based firms in order to give a specific lead to the whole region as always in technology oriented history also means to develop a own special way of linking German desire for depth and meaning with "savoir vivre" as a long term stable regional strategy.

Economic performance and intraregional networking: The eight municipalities and two rural districts of Baden have not only joined forces to form this unique association. They are backing it with a combined approach of very specific ideas and resources.

- Baden-Baden (international spa with health and convalescent therapy establishments and production of cosmetic and pharmacy brands),
- Bretten (centre of rural county administration and a communication centre within the TechnologieRegion Karlsruhe and to abroad)
- Bruchsal (with specific promotion of business and arts alike, availability of attractive new industrial sites with specific transport links to all directions),
- Bühl (combining Black Forest and vineland tourism and living potentials to its industrial assiduity and production plants such as Bosch and UHU),
- Ettlingen (attracting industries exploiting new technologies has resulted in close links with the think tanks of Karlsruhe),
- Gaggenau (Black Forest and automotive industry but also known for its innovations in kitchen design and urban planning),
- Karlsruhe (the urban centre and a service metropolis with the think tanks of the region),
- Rastatt (location of dynamic industrial and commercial activities with a high standard of facilities such as Rastatt's Daimler-Benz factory branch with production methods of the most modern variety).

On a voluntary basis the TechnologieRegion Karlsruhe combines these capabilities in a complementary way according to their strengths and constraints (e.g. integrated planning of industrial sites of the regional partners) and thus in a confidence of the regions own competences to solve problems.

Technology transfer within the TechnologieRegion Karlsruhe is regarded as an important tool for intraregional networking. Mainly the think tanks of Karlsruhe offer services for businessmen.

- At the University of Karlsruhe (TH) some 100 institutes provide technological consultant services;
- The National Research Centre Karlsruhe (FZK) works out complete "technology packages" in close co-operation with industry. The "Technology Transfer Centre" of the FZK organises ongoing collaboration projects between some 100 academic staff and technical personnel from industry;

- The Steinbeis Foundation, located at the Polytechnical College Karlsruhe, offers start-up consultation;
- Three Fraunhofer Institutes provide consultancy services in data processing, chemical and systems engineering, energy saving, environmental technologies and new product technologies, biotechnology and company development;
- The Technology-Fabrik Karlsruhe as an innovation centre is offering young businesses an opportunity to develop advanced technological products and processes;
- Five research institutes have established the Karlsruhe Computer Sciences Co-operative in close co-operation with the Chamber of Commerce, to reinforce technology transfer, especially for SMEs.

Supraregional and international networking: The Karlsruhe Information Centre, an electronic data archive is an inexhaustible international interface of the TechnologieRegion Karlsruhe to abroad and a source for business and institutes to online investigation regarding patents, primary and secondary literature as well as the latest in research results. The network "STN International" with partners in Japan and the USA assures the constant updating of the available data. Numerous joint projects between facilities of R&D and industry in the TechnologieRegion Karlsruhe and from abroad. In the case at the TechnologieRegion Karlsruhe the linkages to international R&D networks mainly were given by the large governmental funded research institutes (e.g. University Karlsruhe, National Research Center). The benefit at these international networks for the regional SMEs was just enabled through the development of an intraregional network integrating the nearby PAMINA (Euroregion Southern Rhineland-Palatinate/Germany, Mittlerer Oberrhein/Germany and Northern Alsace/France).

The region has a dual location advantage. Firstly, service to carry out research that will serve the needs of the market, and to implement this in the free market economy.

Regional Forum: Experts from industry, administration and science of the TechnologieRegion Karlsruhe can easily get together in a regional forum to work out development programmes for the future but also produce useful ideas on municipal, regional, state and federal policies. Ways of eliminating bureaucratic barriers and simplifying administrative procedures additional are important issues.

6 Outlook

The activities of the TechnologieRegion Karlsruhe mainly refer to production enterprises in the region with potentials in employment, turnover, export, innovation (personnel and financial means) and cooperation, as well as new (technology-based) firms. Experience has shown that such firms are in a position of fast growing and to "give a lead" to other enterprises. In this way, quantitatively significant positive economic and social effects were achieved. For these firms product innovation capability was strengthened by the formation of cooperative approaches (innovative milieu, industrial networks) as qualified service institutions could be formed for mediating cooperations, scientific institutions as partners for enterprises. Public bodies integrated in the network became more demand oriented, efficient placed and better qualified to represent their work to the general public and gained a higher degree of acceptance.

The voluntary basis such as the joint initiative of the TechnologieRegion Karlsruhe seems to be an appropriate approach for technology policy on a micro level - on the level of regions. It combines capabilities in a complementary way according to their strengths and constraints, create a confidence of the regions own competence to solve problems. Regional synergies also provide better access to existing macrotechnology. Due to the 'globality' of new technologies, this is necessary for regions to engage in supraregional and global cooperations with other regions, specialising in similar or complementary fields. In any case national and global technology policy (the macrotechnology policies) and regional technology policy (the microtechnology policy) should learn from each other.

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PART B: Background Papers

TECHNOLOGICAL INNOVATION AND DIFFUSION MODELS: A REVIEW

Amnon Frenkel and Daniel Shefer
Center for Urban and Regional Studies,
Technion - Israel institute of Technology, Haifa, Israel*

ABSTRACT

In recent years researchers have become increasingly aware of the role of technological innovation and the impact of its diffusion processes on regional development and growth. This paper reviews some of the main works published in the field of innovation. The review emphasizes the role of innovation and its influence on economic growth, stages of economic development, definition of regional innovative capacity, and more. The structure of several analytical diffusion models and their development are presented and finally, we discuss new developments in research concerning modelling diffusion of technological innovation.

INTRODUCTION

There has been growing interest over the years concerning the role of technological innovation and diffusion processes in regional development and growth. The objective is to identify new approaches leading to regional growth by which it will be possible to foster the growth of peripheral regions in particular, and to reduce regional disparity.

Many countries over the world are interested in developing peripheral regions, especially in developed countries having socio-economic gaps between central areas, peripheral and rural regions. These gaps very often result in national social and political agitation. In order to stimulate economic growth in peripheral areas, there is a need, amongst other things, to create employment opportunities to attract populations to migrate and settle in these regions.

Regional disparity, inherent to the capitalistic system, is based on spatial and regional inequality as a means of survival. The center periphery theory explains the concept of spatial dichotomy which exists between the center and the periphery in many countries. Most industrial development and capital projects are concentrated in central areas. These areas are characterized by intensive economic activity where most of the population is concentrated; they are more developed than other regions of the country and they usually overlap metropolitan regions. On the other hand, peripheral regions, dependent on the central regions, are normally sparsely populated and characterized by lower income levels

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and social welfare, factors which differentiating them from the center areas (Soja 1990, Friedmann 1973).

The difference between central and peripheral regions may be measured in three ways:

a. The level of involvement in decision-making
b. The level of economic activity
c. The level of individual social welfare

Several writers hypothesize that as the economic development level of a country increases, the inter-regional difference gradually decreases (Williamson 1965, Lipshitz 1992). Justification for governmental intervention and implementation of public policies in national spatial organization is related to the desire to hasten the process of closing inter-regional differences (Friedmann 1973).

Many studies have been conducted in order to identify the principal factors affect industrial plant locations. Location considerations of hi-tech industries significantly differ from those of traditional industries, and they are also related to the product and plant life cycles. Growth in production in a large number of industries generally brings about an evolutional development in manufacturing technological changes (Scott et al. 1988). Initial product development and innovation result in the same firm types to locate close to scientific research activities and to places where chances for the product to succeed on the market are greatest (Shefer and Bar-El 1993, Shefer and Bar-El 1989).

The reason for geographical preference - center versus periphery - is related to the type of industry and activities (R&D versus production) of firms belonging to the same type of industry (Shefer and Frenkel 1986, Malecki 1979a, b, 1981). There is also close accordance between plant location and type of ownership (public or private) (Razin 1988). Local plants in peripheral regions normally seek out locations having a large unskilled labor force which could be employed in the production process. However, plants located in metropolitan areas place greater importance on highly-skilled labor.

There is general agreement that during the period of structural adjustment, economic growth is based on existing industries and on existing markets. Despite this, future economic growth will need to be based on the expansion and development of new markets (Freeman et al. 1982, Rothwell and Zegveld 1985). Schumpeter's theory that innovative entrepreneurship turns the wheels of capitalistic economic growth has become more and more relevant (Schumpeter 1934).

The contribution of innovation to regional economic change is often advocated in dealing with economic growth and development (see, among others, Freeman et al. 1982, Jorgenson et al. 1988, Schmookler 1966, Rosenberg 1972). Regional development in a location where discoveries and technological changes and inventions are created is generally accompanied by the sprouting of new economic activities, new markets, and new technological applications. Regions having a sound infrastructure of inventive capability become preferred locations for highly-skilled labor, as well as a target for reinforcing the educational and cultural infrastructures by attracting higher level populations from other regions (Suarez-Villa 1993).

In the first part of this article, the nature of technological innovation and its influence on economic growth will be reviewed. In the second part, the approach of life cycle in industry and technology will be critically presented, as well as the relation between the different stages of economic development. The third part of the article will discuss the definition of regional innovative ability, and the fourth section will present the structure of several analytical diffusion models and their development. In conclusion, the fifth section will provide a thorough review of the development of research in the field of diffusion of technological innovation.

Technological Changes and Economic Growth

Technological Opportunities, Invention and Innovation

One of the definitions of the term "technological change" provided by Fischer (1989) is:

> *"Technical change refers to all the changes in technology and techniques which lead to new products, new processes and new methods in industrial and distributional organization and covers all the activities related to the innovation process, but also those related to the transfer and diffusion of knowledge".* (Fischer 1989, p. 47)

Over the past few years, the concept of "technological opportunities" has become much better understood. Improvement in production over time is related to the extent of technological opportunities presented to the firm. The greater the extent, the greater the chances that the firm will learn to produce more efficiently compared to its competitors. Firms having a higher level of innovativeness ability also increase their chances to better compete (Dosi 1988).

Many researchers have come to the conclusion that technological development processes in many industries are processes having strong internal logic, induced by the extent of existing and forecasted market demand. The choice of production technology depends, amongst other things, on decision-making related to the extent of required investment. In the past, technological opportunities were perceived as an external variable influencing the firm, a source of knowledge fed by scientific development. Today, there is a tendency to view opportunities, in no small way, as internal variables influencing decision-making processes (Sharp 1990).

The term "innovation" refers to the first appearance of a new product on the market, or the first application of a new process (Fischer 1989, Davellar 1991, Rogers 1983). Innovative development is thought to be a process which includes a series of logical operations, not necessarily a continuous linear process.

The process consists of three separate stages: a. the recognition and conceptualization stage; b. the R&D stage; and c. the innovative stage. That is, the innovative solution includes the discovery component as well as the creation component (Dosi 1988). A new and/or improved products will lead in the competition, particularly if there will be great demand for this product in comparison to alternative products or substitutes. Competition based on a new product is therefore effective only to the extent that it increases the firm's sales and profits. In addition, innovative processes focusing on technological changes related to the production process of existing products and services are important factors affecting production efficiency, thereby improving competitiveness.

The firm's opportunity to innovate depends on the flow of new knowledge and its dependency on internal and external information sources, while communication channels linked between functionally separate departments within the firm, on the one hand, and between the firm and external information and technology sources, such as between firms and consumers, on the other hand. The importance lies not only in the existence of opportunity, but in the firm's ability to innovate. This innovativeness depends not only on the flow of information but also on the accessibility to sources of capital required for innovative development as well (Fischer 1989).

The difference between a discovery and innovation is that a discovery emanates from basic research and technological know-how, whereas innovation includes the application and development of the same discovery in such a way that will bring about an economic change (Suarez-Villa 1990, 1993). R&D generally includes both discovery and innovation. The risk component and uncertainty of the innovation are less than those characterizing discovery, and the efforts involved in its development are less pronounced. Skill levels required for the development of innovations are more prevalent in the market in comparison to the unique skill levels required for a discovery, which are difficult in general to define and choose in advance.

The most important long-term goal is to bring about constant growth in the innovativeness of the region. A stock of discoveries combined with a high level of innovativeness will ensure the generation of additional innovations. This stock will also ensure rapid recovery during recession periods. In these cases, rapid technological substitutes can increase efficiency, productivity and open new markets (see, for example, Kamann and Nijkamp 1990, Nijkamp 1986, Berry 1991, Adams 1990, Ayres 1990).

One of the first models which dealt with technological changes and innovation processes is that of Schumpeter (Schumpeter 1950) and its derivation, as reviewed by Nelson and Winter (1982). According to this model, ideas and technological innovations compete for limited resources in the firm's environment. The most suitable technology is the one that survives. The process may be lengthy and often inefficient. Schumpeter's model is not an equilibrium model in a competitive and dynamic market of entrepreneurs (Freeman et al. 1982). Schumpeter related the technological innovation process with scientific research. The incentive of entrepreneurs to invent new technologies is based on the possibility of enjoying temporary monopolistic power. Subsequently, additional potential entrepreneurs, who observed the success of their predecessor, join in. They try to be "free riders" by adopting these technological changes and improving on them. Economic growth occurs when more and more entrepreneurs adopt technological innovations, however, as the number of entrepreneurs increases, profits decrease as well. Schumpeter's model emphasizes that technology acts as an accelerator in the economic growth process.

Innovation and Economic Growth

A significant portion of technological innovation is an incremental innovation resulting, on the one hand, from a combination of expanding demand and the firm's increased costs of production, and, on the other hand, from learning by doing. Along with this, radical innovation appears from time to time, representing a drastic change over the incremental innovation or a continuous improvement of existing technology. This type of innovation is termed "frog-leaps". Nelson and Winter termed this change as "technology regime", which describes the series of new opportunities created by a radical change in technology (Nelson and Winter, 1977, 1982). The introduction of this radical innovation marks a new kind of "technology paradigm" (Dosi 1988).

The increased interest in the innovation process emanates from the existing relationship between innovation, market competition, and economic growth (see, for example, Pavitt and Walker 1976, Freeman 1982, 1990, Freeman et al. 1982, Dosi 1984, 1989). The net effect of innovation may be expressed in the short-term by labor savings and in the long-term, by the expansion of the labor market. As a result, producers begin operating more efficiently, the relative competitiveness of the economic unit is improved, and product sales and marketing ability on local, national and international markets are improved.

Technological innovation has followed a noticeable trend of change in stages as expressed in the technological and economic characteristics of products and processes. Related to this is the new concept of "technological trajectories" (Dosi 1982, 1984). This concept does not perceive the process of technological change as a factor responsible for the appearance of new products or services as a certain or random process, rather as a dynamic process extending over specific transitions stages. The new technological trajectories are presented as transitions of innovation activities including new products and services (Davelaar 1991).

Technological trajectory may be defined as a process during which there are trade-offs between the economic and technological dimensions (Dosi 1988). It is reasonable to foresee that economic growth and division of labor between production activities will increase the range of demand on the macro level. Conversely, a change in technology paradigm generally implies a change in the technological trajectory.

For a single firm, as for the entire sector, the trajectory approach describes non-continuous technological progress, illustrating the processes of incremental innovation. In other words, improvement reveals itself in product design and controlled processes derived from production and marketing experience. Technological trajectories describe the course over which technology develops with time. They do not cover the radical change but rather the incremental innovation resulting from continuous marginal improvements in the product and the technological progress. They result, on the one hand, from internal scientific/technological logic, and on the other hand, from market forces. Nelson summarized it as follows:

> *"Where these easily pursued directions correspond to user needs, and where innovations have some mechanisms for assuring that they receive a non-trivial fraction of the use value of innovation, technological change tend to proceed along these tracks"*, (Nelson 1988, p.220).

The concept embedded in the basic principle of incremental innovation is termed the "natural" trajectory - the natural course of development resulting from the **basic knowledge of the firm**. There are two reasonable explanations for this assumption. The first is related to the search for new ways of development which the firms tend to seek out in familiar areas. These innovation searching procedures are expensive, therefore firms tend to rely on their expertise while at the same time, strengthen this skill. The second reason is related to the search for information which could enhance existing expertise, since the character of innovative processes lends itself to this tendency. Most incremental innovation is, therefore, innovation resulting from learning by doing which is something not easily transferable (Sharp 1990). Most firms limit the search process for new ideas, new products and new processes to familiar areas. Firms tend to search for ways of improving their technology by searching for regions which would enable them to use existing technologies and rely on the markets for their products. In other words, searching for new technologies in every firm is a process having a cumulative effect. In most cases, the firm's future technological development will be directed toward narrow paths utilizing the firm's past implementational ability (Teece 1982, 1986).

The second side of this argument is, of course, the great difficulty of new firms having no experience to break into the market place once this trajectory has been created. Therefore, incremental innovation and the "learning by doing" process are very useful, especially for existing firms working in the market place, but not for new firms trying to break into the market. In this way, the competitive advantage of veteran firms over new firm potential is strengthened. This description helps explain the relative stability of the oligopoly market structure which develops in mature industries (Sharp 1990). New technological trajectories will generally invoke new opportunities to bear profits, therefore, many new firms are attracted to these new opportunities. This stage is characterized by accelerated economic growth expressed by an increase in investments in these new industries, in the number of employees, and in the quantity of sales.

The two models described above, developed by Schumpeter, contain two opposing approaches regarding the performance of technological changes. The first approach perceives these changes as a result of what may be called "technological push". The second approach, on the contrary, perceives them as a result of "market pull" or the influence of demand. The growth in demand may be a stimulus to create technological innovation and knowledge through basic economic activities (Schmookler 1966, Mowery and Rosenberg 1979). These two separate stages may be observed in the two approaches which operate during different stages in the life cycle of new industries and technologies (Davelaar 1991).

The firm's ability to innovate emanates, to a great extent, from the existence of a sound infrastructure of institutions and information in space:

> *"...Innovation is dependent upon a broad technological infrastructure or social structure of innovation to mobilize resources, knowledge, and other innovative inputs which are essential to the innovation process."* (Feldman and Florida 1992, pp. 15-16).

The spatial example of a firm's innovative production is expressed as the firm's innovativeness, an ability influenced by two primary components: a) the firm's structural component, and b) the production milieu.

The structural component includes the firm's characteristics supporting the rapid process of adopting innovations. They are related, amongst other things, to the age of the firm, its affiliation to a large industrial concern or investment company, its area of activity, the character of its management method, the integration of research activities and marketing in the firm, the level of expenditures on R&D, and the internal organization of the firm.

The production milieu component includes the environment of the economic conditions and the essential infrastructures needed to transfer information. The busness milieu provides the psychological, cultural and social background necessary for the educational level, willingness to take risks, high organizational ability, and accessibility to technology (Camagni 1985),

The Life Cycle Model, Competition and Economic Growth

The dependence of technological change on economic efficiency is examined using the dependency relations between product life cycle and technologies. The product life cycle model is the dominant model through which the dependency relations between industries, technologies and economic growth are explained (Vernon 1966). The present point of view regarding product life cycle and the strategy of moving from the initial S-shaped learning curve to the new innovation curve, was originally espoused by Schumpeter:

> *"...innovation breaks of any such "curve" and replace it by another, which ... displays higher increments or product thought"* (Schumpeter 1939, p. 88)

Based on this perception, innovation brings about a move in the curve, expressed in the growth of the number of products. Therefore, for every point in time, some firms will be found on the new and higher "S" curve, and others on the lower curve. As technology becomes progressively newer, it may be expected that the measure of homogeneity between the firms using it increases.

Three main stages characterize the life cycle of a new product or innovation influencing the firm's location considerations: the innovation and development stage, the maturing or growing stage, and the mature product stage (Vernon 1966). This approach was extensively adopted later in other studies (Norton and Rees 1979, Norton 1979, Taylor 1987, Barkley 1988, Karlsson 1988).

The life cycle model refers independently to the products, the production processes, and the technologies. It may represent a valuable tool for understanding the influence of industrial change on the work place and on employment (Ford and Ryan 1981, Shanklin and Ryans 1984). Understanding the combined processes of the technology life cycle may contribute to early prognosis of changes in products and production processes on the verge of taking place.

Just as changes occur in production processes during the product life cycle, changes also occur in the skills and training needs of labor during the technology life cycle. The early stage of technology progress characterized by innovation generally requires highly-skilled labor, such as scientists and engineers. Most positions in the following stages are intended for skilled management and marketing personnel who specialize in production. Location incentives influence the types of diverse production activities in different ways. In the early stages of the product life cycle, competition between firms primarily focuses on aspects of product innovation. Salary subsidization and tax incentives may be very valuable for firms operating in latter stages of the product life cycle; these programs are not as effective for firms engaged in R&D and entrepreneurial activities. Similarly, short-term training programs are suitable for firms dealing in mass production, are not as effective for firms engaged in complex non-standard activities requiring training of highly skilled labor (Flynn 1994).

The conventional relationship between product life cycle model and technological changes ignores space and time dimensions. The contribution of new technological systems, which represent basic technological innovation for the creation of new life cycle of industries and technologies, is not presented in the model (Davelaar 1991).

The product life cycle model is related to activities carried out in the central and peripheral regions during different stages of the product life cycle. On the contrary, technological change appears in the model as an external factor only, and does not influence the spatial transfer of production processes or employment. As a result, the model is unable to explain the empirical findings of studies showing that firms located outside of the metropolitan regions are also engaged in the creation of innovations (Davelaar and Nijkamp 1992).

The Spatial Diffusion Process

Diffusion of innovation is defined as a process which, with time, and through various means, causes the transfer of innovation between groups and individuals belonging to a certain social system (Roger 1983). It may be compared to a specific type of communication specializing in the transfer of information and new ideas. Diffusion is concerned also with a certain type of social change in which the adoption of new ideas may result in socio-economic changes. It requires four main components: innovation; means for innovation transfer; time; and a socio-economic system.

Technology diffusion is a complex process, involving changes in the behavior of economic agents. Many studies emphasize the great importance of the technology diffusion process for market development, but despite this, it is surprising to find that only a few policies are designed to foster this process. The societal expected return on new technology without the diffusion process will be insignificant (Metcalfe 1990).

The diffusion process may be understood by integrating three basic elements: companies, environment and technology (Camagni 1985). The integration between these three elements creates the early necessary conditions to adopt innovation, and each pair play a central role in one of the stages of the decision-making process.

The three stages are:

1. The awareness stage - the integration stage between technology and the environment. The strategic element in this stage is the availability of information representing a necessary condition to adopting innovation.
2. The consideration stage - the integration stage between technology and the firm. This stage is strategically characterized by problems related to the measure of adaptability and the relative advantage of the new technology or innovation over the old. This stage is related to a second essential necessary condition for adopting innovation, and that is the relative profitability of the new technology or innovation.
3. The adoption stage - the integration stage between the firm and the environment. This is the third and final stage in which the firm evaluates the cost of replacing old technology by new (Scherer 1980). It is not enough that new technology is available to replace old technology, it is also necessary to ascertain that the present value of the expected income will be greater than the cost of adapting the firm to it (Camagni and Cappillin 1984). This cost is a function of the firm's internal factors such as expenditures on R&D and sales ability, as well as external factor such as the ability to tap loan opportunities, remove political and union-dependent obstacles, etc.

A common distinction made in diffusion studies of technological innovation is related to the division between product innovation and process innovation in the regional context (Davelaar 1991). Development regions are able to adopt technologies associated with production processes, however, they may face severe difficulties in adopting advanced product innovation. Process innovation ussually can be bought "off the shelf" on the open market. Product innovation, on the other hand, is not as readily available. This is so because innovation is the means by which the firm can maintain a competitive advantage over its rivairies. Therefore, product innovation is less transferable in terms of diffusion (Okey et al. 1982, Alderman 1990).

Innovation transfer involves a component of risk or uncertainty. Thus the importance of information lies, amongst other things, in its ability to reduce uncertainty.

Greater importance must be placed on the uncertainty component as it pertain to innovation activity than presently afforded it by the popular economic models. Uncertainty is concerned not only with lack of information regarding the exact incomes and expenditures associated with the various alternatives, but most often with the limited knowledge concerning the nature of the alternatives (Freeman 1982, Nelson and Winter 1982).

Dosi (1988) believes that a distinguish should be made between uncertainty expressed in terms of partial information concerning the occurrence of known events, and what is termed "strong uncertainty". The latter exists when a set of possible events is unknown and therefore, it is impossible to determine the results of specific activities of each given occurrence. Innovation is characterized in most cases by strong uncertainty.

The diffusion model is described using different distribution functions such as the normal cumulative function, the Gompertz function, or the logistic distribution function. All of these fanctions can be expressed graphically using an "S" curve (Griliches 1957, Davies 1979, Metcalfe 1981, Andersson and Johansson 1984, McArthur 1987). The behavioral logistic model is the most common one used to describe the diffusion process. This model was derived from the model describing the process of disease spreading in a homogeneous population over time (Camagni 1985). Diffusion models were primarily developed in order to describe, explain and forecast the spreading of innovation by a given number of potential adopters. The increase in the number of adopters over time may be illustrated by using simple mathematical functions (Mahajan and Peterson 1985).

The diffusion curve can have a normal cumulative structure or a normal cumulative log structure, depending on the special innovation properties. A log-normal cumulative diffusion curve structure is attained when the diffusion is related to simple technological innovation, is of relatively low cost, and has a rapid spatial transfer process. This type of innovation is normally very rapidly replaced by an even more advanced technology. In contrast to this model, the normal cumulative diffusion curve is attained when the innovation diffusion is concerned with complex technology, is generally expensive, and has a long learning curve, even though it apparently yields higher long-term profits (Alderman and Davies 1990).

Innovation Diffusion Models

The Basic Diffusion Model

The basic diffusion model may be expressed by the following differential equation:

$$(1) \qquad \frac{dN(t)}{dt} = g(t)\ [\overline{N} - N(t)]$$

$$(2) \qquad N(t = t_0) = N_0$$

where:

N(t) = cumulative number of adopters during period t

$\overline{N}$ = total number of potential adopters in the system during period t

$\frac{dN(t)}{dt}$ = rate of diffusion during period t

g(t) = diffusion coefficient

N_o = cumulative number of adopters during period t_o

Equation 1 depcit the rate of diffusion of innovation during time t, which is a function of the difference between the total number of possible adopters existing during this period, and the number of prior adopters $\overline{N} - N(t)]$during this period.

The reciprocal relationships between the rate of diffusion and the number of potential adopters during the period $\overline{N} - N(t)]$ are shown by the diffusion coefficient g(t). This coefficient depends on the diffusion process such as: properties of the innovation, means of information transfer, and properties of the social system in which the process takes place. g(t) can even express the probability of the adoption during period t so that g(t) $\overline{N} - N(t)]$ will express the number of expected adopters during period t. N(t) expresses the number of individuals/firms associated with the socio-economic system, which moved from a stage of potential adopters to actual adopters during period t, where g(t) is the conversion coefficient or the transfer mechanism. In the more accepted and popular approach for using coefficient g(t), it represents a function of the number of previous adopters even if the less popular approach also exists in which it represents the time function.

g(t) is expressed as a linear function of N(t) by g(t) = (a+b)N(t). In this case, the mathematical expression of the basic diffusion model will be as follows:

$$(3) \qquad \frac{dN(t)}{dt} = a + bN(t)[\overline{N} - N(t)]$$

where the coefficient 'a' expresses the system's external influence and the coefficient 'b' expresses the internal influence.

The typical model describing the innovation diffusion process assumes a full and complete flow of information between potential and former adopters. This assumption is based on the free flow of information concerning the innovation between regions. If this basic assumption does not hold true, a significant diversion could occur in the results obtained with this basic model (Coleman 1964). In such circumstances, Lavaraj and Gore (1992) suggested using the model consisting of the following two difgerential equations:

$$(4) \qquad \frac{dN_{1t}}{dt} = bN_{1t}(k_1 - N_{1t})$$

$$(5) \qquad \frac{dN_{2t}}{dt} = (b_1 N_{1t} + b_2 N_{2t} + b_3 N_{1t} N_{2t})(k_2 - N_{2t})\ldots$$

where N_{1t} defines the innovation adopters until time t in the central region, N_{2t} defines the innovation adopters until time t in the peripheral regions, k_1 and k_2 define the potential adopters in the central and peripheral regions, respectively, and b, b_1, b_2, b_3 represent the model's parameters. Equation 4 is equivalent to the basic logistic model. In equation 5, the term $b_1 N_{1t}(k_2 - N_{2t})$ depicts the increase in the number of adopters due to the interaction between the center and the periphery, the term $b_2 N_{2t}(k_2 - N_{2t})$ depicts the influence of the internal regional communication on the periphery, and the term $b_3 N_{1t} N_{2t}(k_2 - N_{2t})$ depicts the attempt to prevent double counting.

Another assumption of the basic model is related to fixing $\overline{N}$ as the number of the system's potential adopters, which may be either a pre-determined number or alternatively an estimated number. Actually, this approach simply states that the size of the socio-economic system is fixed and final, and therefore, the diffusion model is static. The socio-economic system included in the model is not permitted to increase or decrease during the diffusion process (Mahajan and Peterson 1979, Shrif and Ramanathan 1981). A topic to be further studied is the aspect of the basic structure of technology and understanding its properties.

> *"Clearly, in the study of spatial diffusion of new technologies, the changing nature and expanding range of applications of these technologies 'moves the goal posts' in that the population of potential adopters can change if major new developments occur, while saturation levels can also be affected".* (Alderman 1990, pp. 295)

The dynamics of innovation processes is expressed by the variability of diffusion rates over time as it reveals itself by the introduction of new approaches emanated from the accumulation of information by previous adopters. It could also be that this rate is a reaction to the external development of the innovation itself, expressed by its technological and marketing characteristics (Davies 1981, Gold 1979). Thus, technology adoption also depends on the relative profitability which could vary due to a reduction in the cost of its acquisition, resulting in an increase in its potential applications (Metcalfe 1981, 1982). Innovation may therefore not be statistically defined during the beginning of the diffusion process since its characteristics depend on the time variable which changes the number of possible adopters population. In analytical model terms, it is not possible to discuss a single curve but rather an envelope of continuous logistic curves, where each refers to a separate set of environmental and technological characteristics (Metcalfe 1982).

Limitations of the Model

Use of the logistic model entrails several assumptions, as discussed in detail by Davies (1979). He assumed that the potential adopter will expose himself to innovation when the reward occasion will meet his expectations. In his estimation, this time is a function of firm size, amongst other things, and adoption will take place once the critical size is reached. The influence of new technology on every relevant sector, after the superiority of the old technology has already been proven, may take place only in the long-term (Camagni 1985). Technological pluralism may exist for many years if the relative profitability of the new technology significantly varies among regional markets. The appearance of a new technology does not automatically guarantee replacing it with the old one in the short-term.

Another criticism of the basic assumption is that the diffusion process binary, suggesting that potential adopters choose between adopting or not adopting innovation. In other words, the process does not represent continuous events but rather disijointed events. The basic model, therefore, does not take the existence of stages of the adoption process (such as awareness, knowledge, etc.) into account (Rogers 1983). The solution for this situation is a dual-stage diffusion model (Camagni 1985). The first stage refers to diffusion between firms belonging to a specific manufacturing sector, and the second stage is inter-sectorial in which the diffusion takes place between firms belonging to different sectors. The reason for this emanates from the process which, over time, causes the innovation itself to undergo an incremental change, and the information on advantages resulting from its adoption is widely known. The logistic model is also capable of describing the behavior of this inter-sectorial diffusion.

An additional assumption is that innovation by itself does not vary during the diffusion process. That is, adjustments of innovations and their exposure to new technology are nonexistent during the adoption period. Moreover, it is assumed that the innovation under consideration is independent of other existing innovations. Therefore, the adoption of any innovation does not represent a complementary one or a substitute, a reduction or an inducement, with respect to the adoption of another innovation, and vice-versa.

Applications of the Basic Model

Despite existing criticisms and binding constraints of the basic model depicted above, it was extensively applied when part of the later extensions attempted to deal with and resolve its drawbacks. One of the extensions deals with the dynamic nature of the basic model but assumes that the number of potential adopters during the process period is fixed (Mahajan and Peterson 1979). Implementation of the basic model presented for the dynamic diffusion process will yield an incorrect estimate for the parameters or the number of the adopters $\overline{\mathrm{N}}$. Therefore, a correction is suggested which converts the basic static model into a dynamic model, whereby $\overline{\mathrm{N}}$ may vary with time. Therefore, it is defined that $\overline{\mathrm{N}}(t) = f(\underline{S}(t))$,where $\underline{S}(t)$ is the vector (potential) of relevant exogenous and endogenous factors, controlled or not controlled, which influence $\overline{\mathrm{N}}(t)$. Thus when the expression $(\underline{S}(t))$ replaces $\overline{\mathrm{N}}$ in the equation of the basic model, a dynamic diffusion model is obtained:

$$(6) \qquad \frac{dN(t)}{dt} = [a + bN(t)][f(\underline{S}(t)) - N(t)]$$

Examples of relevant variables include: socio-economic conditions of the social system in which the diffusion process takes place; increase or decrease in the size of the population of the potential adopters; government initiated programs; and programs designed to induce the diffusion process, such as advertising etc. The number of variables desired to be included in $\underline{S}(t)$ is a function of a number of conceptual and practical factors. The character of innovation under examination is a limiting factor, as well as a degree of data availability. The level of precision of the dynamic diffusion model depends, in part, on the definition of the variables for $\underline{S}(t)$ which really influence $\overline{\mathrm{N}}(t)$.

A more comprehensive development of the basic diffusion model is related to simultaneously combining time and space dimensions. In the basic model, the fundamental assumption is that the process is static, whereby no changes occur in the time and space dimensions, and the model is not designed to deal with these changes. Most diffusion studies do not handle the complexity involving such a dual-dimension combination, and instead, resort to dealing with one dimension only. While the time dimension is dealt with extensively in studies related to diverse disciplines, the space dimension is investigated primarily by geographers, one of the most outstanding of whom is Hagerstrand (1967). He perceives diffusion to be a process causing change in the population, from a region having a small number of adopters to one with a large number of adopters. This change is observed through information transfer by means of communication and inter-personal interactions. Hagerstrand defined three empirical laws in his studies: a) the process is characterized by an S-shaped curve; b) the process is characterized by an hierarchical effect, whereby diffusion is expected to spread from large to small centers; and c) the process is characterized by the 'neighborhood effect', whereby diffusion is expected to spread in a wavy or oscillatory fashion to outside city centers, initially mostly to locations close to these centers and less to more distant locations.

One attempt to develop a model which simultaneously deals with the time and space dimensions suggests examining the diffusion process, not only in the context of predicting the cumulative number of adopters over time, but also of evaluating the way innovation spreads over different geographic areas. This model can supply information to allow for a comparison to be made between the level and quantity of adopters and between different geographical regions, and to assess the degree of innovation dissemination into different regions. In this way, the model will help determine a dissemination policy suitable for attaining the process (Mahajan and Peterson 1979).

Two of the three empirical laws documented in the spatial diffusion literature are incorporated into this model: a) the S-shaped curve; and b) the 'neighborhood effect'. Firstly, it is assumed that it is possible to express the growth in the number of adopters in every region with the diffusion model, consisting of unique parameters a, b and N. Secondly, it is also assumed that, relatively speaking, the number of adopters will be greater in areas close to regions where innovation has been created[1]. The model simplifies the complexity of the problem by determining that the innovations initially appear in one region only, and that the distance parameter (x) between the innovation region and the other regions be measured by the distance of the center of gravity of one region to that of the other. The number of cumulated adopters, N, is therefore a function of two variables: time and distance - $N = f(x,t)$. The combined model is expressed by the following equation:

$$(7) \qquad \frac{dN(x,t)}{dt} = [a(x) + b(x)N(x,t)] \times [\overline{N}(x) - N(x,t)]$$

Inter-regional gaps may be expressed using this model not only by physical distance measures but also by economic measures showing the economic differences among regions (Camagni 1985).

One of the more interesting recent developments of the spatial diffusion model is the dynamic incubator model (Davelaar 1991). It is a conceptual model, not tested empirically, which examines several basic principles relating to the time and space dimensions. The model is based on two fundamental assumptions: the first determines that a radical change in technology and in the framework of the socio-economic system, expressed by the appearance of new technological systems, also brings about a structural

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[1] If innovation is created in more than one region (and frequently at different times), it may be assumed that every region will be influenced simultaneously by different waves of diffusion (see also: Corvers and Giaoutzi 1995).

change in the spatial economics. The second determines that a change occurs as a result of the spatial diffusion process, and is itself naturally expressed in the resulting technological changes of different types of products and services. The model focuses on spatial applications both regarding the launching of new technological trajectories and the diffusion process of these trajectories. The model defines three stages of the process (similar to the stages of the product life cycle model): a) the incubation stage related to the first stage of agglomeration processes (it primarily applies to metropolitan areas); b) the competition stage related to the adoption processes stage and the migration of firms to intermediate and peripheral regions; and c) the decline stage in which the new products and processes created over the technological trajectories reach saturation on the market place in all regions. Market demand places limitations on the expansion possibilities of new industries, and the cost is dominant in determining competitiveness.

Spatial Diffusion Research of Technological Innovation

Interest has significantly grown in the 1980's in the multi-disciplinary subject of innovation research: economists have shown interest particularly in innovation inputs (such as expenditures on R&D), technological opportunities and innovation yields such as patents (Cohen 1992); geographers dealt with location considerations of R&D activities (Malecki 1986), or hi-tech industries (Markusen, Hall and Glasmeier 1986); and regional planners examined the organizational and institutional structures necessary for the development of innovation activities (Feldman and Florida 1992).

Technological innovation research up until the 1960's was primarily illustrative, bibliographical or purely technical and very little empirical research, despite the awareness of economists as to the importance of innovation fostering productivity and competitiveness. In the 1950's, most innovation research was carried out by geographers and sociologists, particularly in the field of diffusion. Only in the 1960's did economics begin to carry out more systematic research, including empirical studies, in their innovation research. Up until the early 1970's, most studies focused on specific individual innovations, whose goal was to identify characteristics of innovation ensuring technical and commercial success (Freeman 1991).

One of the important early empirical studies concerning innovation is the SAPPHO project, in which attempts were made to identify the success factors of innovation by making a comparison between pairs of innovations which succeeded or failed (Rothwell et al. 1974). A comparison was made in this research between about 100 characteristics of 40 pairs of innovations in two industrial branches: the chemical industry and the precision instruments industry. Later studies dealing with the mechanical and electronics industries arrived at similar findings (Lundval 1985, Maidique and Zirger 1984). Some of the main contributing factors which were identified in this latter study, were an early understanding of the special need of potential users of the new products (or of the new processes) under development (see also Lundvall 1985, 1988). Chances for success of innovation depend, to a great extent, on the development of joint techniques in the early stage of the development process, production, and marketing of the innovation. This finding was later confirmed in other studies (see Lami et al. 1985, Takeuchi and Nonaka 1986).

Although many pioneering efforts in diffusion theory have been made by geographers (see, for example, Hagerstrand 1967, Brown 1981, Clark 1984), research of the ways by which new technologies penetrate into individual firms is a subject in which the success of the tools developed by geographers was very limited (Alderman 1990). Geographers dealing with innovation and research related to regional development, especially emphasized the location of R&D activities and basic technology industries, indicating that spatial distribution of hi-tech industries and employment are interrelated (Malecki 1980, 1985, 1986, 1990). Other studies pointed out the influence of wage level in the region and the strength of the labor union, on the location considerations of hi-tech industries, and on employment (Markusen, Hall and Glasmeier 1986). Other studies focused on the influence of organizational and institutional factors on the creation of conditions for innovation development which usually included case studies such as: Route 128 near Boston (Dorfman 1983, Roberts 1991), Silicon Valley (Saxanian 1985) or Orange County (Scott and Stroper 1988).

Other studies dealing with innovation processes focused on the spatial factor and its effect on the process and its intensity, and the important of regional characteristics on industrial innovation processes (Bramanti and Senn 1991). The influence of the central city, the metropolitan region and the periphery, was investigated in other studies dealing with the creation and transfer of innovation (Davelaar and Nijkamp 1989). (Concerning this important point, see also Aydalot and Keeble 1988, Nijkamp 1986, Oakey, Thwaites and Nash 1980, Malecki and Nijkamp 1988, Aydalot 1984, Camagni 1984, Ewevs 1986, Perrin 1986, Malecki and Variya 1986).

Stohr (1986) emphasized the combined effect emanating from the interaction between the innovation and additional regional characteristics, such as acquiring skills and getting information and business advice on decision-making. Perrin (1988) identified new organizational types having reciprocal relations between large firms, medium-sized and small firms, and public institutions. One of the important pre-conditions for creating innovation potential is the proximity between the "players". Based on Camagni (1991), the importance of spatial proximity stems, amongst other things, from greater intra-regional mobility of human capital than inter-regional. Camagni suggests that the relation between "players" is often based on personal contact, therefore, common cultural aspects, psychological factors, and shared political backgrounds help create the cumulative effect.

In the area of industrial innovation, most theoretical and empirical studies were almost exclusively carried out by economists (Alderman and Davies 1990). They focused on the reciprocal relationship between inputs and outputs of innovation and generally ignored the spatial dimension. Despite this, much importance must be placed on defining the environmental milieu in which the diffusion process takes place, and on the attributes of the competing technologies. It is not enough to describe the adoption of a new technology in terms of its properties. New technology is not transferred into a vacuum, but rather into a known environment which determines the advantages and disadvantages of existing technologies. To the same extent that new technology could make an improvement, mature existing technology could also make an improvement under the pressure of competition, thus eliminating the advantages of a new technology. The diffusion process depends on the competitive advantage of the innovation. In certain cases, existing technology reaches its optimum level only after being placed in fierce competition with a newly developed technology (Metcalfe 1990).

Summary

Interest in the contribution of technological change to development and economic growth has recently taken an important role in regional science research, especially owing to the role of new technologies as one of the primary factors bringing about structural change in the spatial economy. Understanding the relationship which exists between economic efficiency and innovation activities has brought about a change in regional development policies aiming at encouraging firms to develop (or adopt) new technologies. In parallel, the new policy of creating the environmental milieu to encourage the attraction of innovative firms to preferred regions and influence economic growth is being pursued. This policy concentrates on the influence of the production milieu component on the firm's ability to innovative. This component includes environmental characteristics representing the necessary economic and infrastructure conditions for information transfer. The environment provides a psychological, cultural and social basis for defining the willingness to take risks, high organizational ability, and accessibility to technology.

The life cycle model helps determine the role played by economic development policies in the country. Based on this model, the attractiveness of the region and its regional economic development are changing in accordance with the requirements of labor skills for producing at different developmental stage. Changes in the time-space dimension, which generally occurs as a result of the employed variety of technologies, by the industries, affects new products at different development stages, and influences requirements for skilled labor during this changes.

Much importance may be placed on the economic characteristics of new technology and its application potential with respect to the diffusion process. The early users of newly developed technologies may not fully enjoy them and have limited application opportunities. Therefore, in many occasions, support of embryonic technologies must be provided by the government. Technology diffusion requires a selective competitive environment open to changes, which produces profits in comparison to the relative economic vitality of competing technologies. The profit element holds utmost importance from the point of view of manufacturers and users of new technologies. The profits allow investment in R&D activities and in training manpower. Despite this, a shortage in skilled labor may limit the diffusion process. Here, the government plays a significant role in ensuring national support for R&D of new technology and in providing the required level of skilled labor.

Many studies emphasize the considerable importance of the technology diffusion process on economic development, but despite this, it is surprising how few policies are designed to enhance this process. If the process does not occur and new technologies are not transferred, their influence on the economy is particularly small. Therefore, the creative ability of the firms and national research institutions are not sufficient conditions. There is a need to continue to invest in new technologies which will completely or partially replace existing ones. Without the diffusion process, the expected return on the creation of new technology will be insignificant. Numerous empirical studies from diverse disciplines pointed out that many new technologies were not transferred or duplicated immediately to all parts of the economy, and the difference in the diffusion process between technologies and industries could be significant.

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Do Regions Matter for R&D?

ALFRED KLEINKNECHT and TOM P. POOT
SEO, Foundation for Economic Research, University of Amsterdam, Roetersstraat 11, 1018 WB Amsterdam, The Netherlands

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KLEINKNECHT A. and POOT T. P. (1992) Do regions matter for R&D?, *Reg. Studies* **26,** 221–232. We examine the urban hierarchy and filter-down theory, drawing from the SEO national survey on R&D and innovation in The Netherlands. Our logit and regression analyses reveal that differences in R&D performance between regions can largely be explained by non-regional factors. In particular, we find no evidence that firms in urban agglomerations undertake more R&D than firms in rural areas; a notable exception is service industries in the four major cities. Moreover, smaller firms do not seem to be more dependent on their regional environment than their larger counterparts. Furthermore, we find no indication that branch plants of larger firms are typically located in the periphery of The Netherlands. However, our finding that firms in more rural areas tend to have relatively higher shares of process-related R&D is consistent with the urban hierarchy and filter-down theory.

Innovation R&D Regions Urban agglomerations Filter-down Urban hierarchy

KLEINKNECHT A. et POOT T. P. (1992) Les régions, importent-elles à la R–D?, *Reg. Studies* **26,** 221–232. On examine la théorie de hiérarchie urbaine et de filtrage vers le bas à partir de l'enquête nationale SEO sur la R–D et l'innovation aux Pays-Bas. Des analyses logit et de régression démontrent que la variation régionale de la R–D s'explique largement par des facteurs qui ne relèvent pas de la région. Notamment il s'avère que les entreprises situées dans les agglomérations urbaines ne font pas davantage de R–D par rapport aux entreprises situées en zone rurale; à l'exception près des industries de services dans les quatre grandes villes. En plus, les petites entreprises ne dépendent pas de leur milieu régional plus que les grandes entreprises. En outre il n'est pas du tout évident que les établissements des grandes entreprises se localisent nécessairement à la périphérie des Pays-Bas. Cependant la conclusion que les entreprises en zone rurale ont tendance à avoir des parts relativement plus élevées de la R–D opérationnelle est d'accord avec la théorie de hiérarchie urbaine et de 'filtrage vers le bas'.

Innovation R–D Régions
Agglomération urbaine Filtrage vers le bas
Hiérarchie urbaine

KLEINKNECHT A. und POOT T. P. (1992) Sind Regionen für Forschung und Entwicklung von Bedeutung?, *Reg. Studies* **26,** 221–232. Dieser Aufsatz untersucht die Theorie der städtischen Hierarchie und des Durchsickerns, wobei von der landesweiten SEO Umfrage über FuE und Innovation in den Niederlanden gebrauch gemacht wird. Die angestellten Logit- und Regressions analysen zeigen, dass Unterschiede im FuE Verhalten zwischen verschiedenen Gebieten sich grösstenteils durch nicht auf die Region zurückführbare Faktoren erklären lassen. Vorallem gibt es keine Beweise dafür, dass Firmen in Ballungsgebieten mehr Forschung und Entwicklung betreiben als solche in ländlichen Gebieten: eine bemerkenswerte Ausnahme sind die Dienstleistungsindustrien in den vier grössten Städten. Kleinere Firmen scheinen ausserdem von ihrer regionalen Umgebung nicht abhängiger zu sein als grössere Firmen. Darüber hinaus wurden keinerlei Anzeichen eines für Zweigstellen grösserer Firmen typischen Standorts an der Peripherie der Niederlande festgestellt. Der Befund dagegen, dass Firmen in ländlicheren Gebieten meist relativ höhere Anteile an prozessbezogener F & E aufweisen, stimmt mit der Theorie der städtischen Hierarchie und des Durchsickerns überein.

Innovation Forschung und Entwicklung
Regionen Ballungsgebiete Durchsickern
Städtische Hierarchie

INTRODUCTION: URBAN HIERARCHY AND FILTER-DOWN

During the last ten to fifteen years, much has been written about the relationship between the regional environment and the innovation behaviour of firms. Notably, the regional shift of US industry from the north-east to the sunbelt, as well as the concentration of high-tech industries and associated service functions and company headquarters in South East England and in the West Midlands has attracted attention (see, for example, BUSWELL and LEWIS, 1970; OAKEY *et al.*, 1980; NORTON and REES, 1979). In attempts at explaining such phenomena, one basic theoretical concept occurs repeatedly and in various versions: the life cycle of industrial development, which has its repercussions on regional industry structure and innovation behaviour.

The idea that industries and new technologies pass through a life cycle of slow introduction, rapid growth, maturity and decline can be traced back to the early work of KUZNETS, 1930, and BURNS, 1934. During the 1950s, the life cycle idea was rediscovered and applied to foreign trade. The most famous contributions came from POSNER, 1961, and VERNON, 1966, who tried to explain foreign trade patterns between countries or even between continents (US, Europe and underdeveloped countries). Other versions of life cycle theory have been adopted in marketing for the description of the career of individual products within a country, as well as by regional economists and geographers in order to describe disparities between regions within a country.

An early version of a regional life cycle or urban hierarchy hypothesis can be found in the work by THOMPSON, 1965, which has since been followed by a large literature (for a survey see MALECKI, 1983). It is usually argued that, due to specific agglomeration advantages, large urban agglomerations function as a seedbed, an incubator or a breeding place for innovations. Agglomeration advantages can consist of the availability of: a highly educated labour force and a high degree of labour market diversification; positive externalities from universities; R&D laboratories of large companies and other knowledge centres; the availability of business services; cultural amenities; and so on. Connected to such agglomeration advantages are information density and physical proximity of business partners, facilitating direct face-to-face contacts and the formation of networks which create confidence and increase the quality of information supplied (EWERS and WETTMANN, 1980; DE JONG, 1987; LAMBOOY, 1988; PERRIN, 1988).

Major product innovations are associated with a high degree of risk and uncertainty and, in the early stage of their life cycles, they often undergo drastic changes due to unforeseen technical problems, consumer reactions, actions by competitors, and so on. The availability of information consequently appears to be a crucial bottleneck factor for innovation. As a result, the above-mentioned agglomeration advantages may be of considerable importance for the emergence of innovations and for the probability of their success or failure. Against this background it seems plausible that firms in large agglomerations have an innovative advantage as compared to their counterparts in rural regions. On the other hand, in later stages of a technology's life cycle, with an increasing degree of maturity and standardization, and with a growing number of suppliers bringing down profit margins, these agglomeration advantages may lose importance, and firms may transfer production to locations in more rural areas (filter-down process) where factor prices are lower (see, for example, MARKUSEN, 1985).

So far the urban hierarchy or filter-down theory sounds plausible. It is therefore remarkable that it has unleashed considerable controversy, both on theoretical and empirical grounds. For example, TAYLOR, 1986, gave a strong theoretical criticism of the way the product cycle model is generally used by economic geographers. According to Taylor, the latter tend to neglect points such as important properties of the invention, innovation and diffusion process, the conceptualization of the firm, as well as a number of critical assumptions, caveats and limitations of the original product cycle concept, leading to 'disembodied, unilinear, technological determinism', and, 'simple spatial fetishism' (*ibid.*, p. 753, p. 755).

Apart from such theoretical criticism, there are also contradictory findings in empirical research. For example, from his analysis of eighty-three pharmaceutical manufacturing firms in the UK, HOWELLS, 1983, p. 147, concludes that 'there is no significant technological bias in favour of firms or plants located in larger settlements, in more urbanized areas, or within more centrally located regions . . . The survey data also revealed that on an intracorporate basis there was no evidence that more distant plants, in relation to their main innovation or headquarters location, tended to be less technologically sophisticated'. But there is also evidence in favour of the filter-down theory. For example, ERICKSON, 1976, concludes from his analysis of enterprise locations in non-metropolitan Wisconsin that 'considerable filtering down has been occurring . . . through the mechanism of corporate branch plants'. The latter were comparatively footloose and sought low-wage, unskilled labour for routinized production processes (*ibid.*, p. 259). Moreover, evidence of an innovative advantage of metropolitan regions was found in an analysis of significant product innovations in Great Britain: OAKEY *et al.*, 1980, p. 235, found that 'both large and small establishments in the South-East Region were more innovative than those located in other regions'. This conclusion is consistent with earlier findings on the geographical distribution of industrial research activity in the UK by BUSWELL and LEWIS, 1970. Furthermore, in their studies of the diffusion of various process technologies, MARTIN *et al.*, 1979, in Canada and EWERS *et al.*, 1979, in Germany found that urbanized areas generally had a lead when compared to less urbanized or assisted areas.

Even if this list of research papers is not exhaustive, one can say that empirical investigations of the urban hierarchy and filter-down theory are still sparse. Moreover, the findings are based on relatively limited sets of data. There is therefore a clear need for further examination. In this paper, we use a national database in order to test whether the location of a firm in a certain region in The Netherlands has an influence on its innovation behaviour. Rather than analysing new firm settlements or discrete numbers of innovations or rates of diffusion, we use as an innovation indicator data on R&D activities obtained from the SEO national survey on R&D and innovation in The Netherlands.

It should be noted that R&D data are an input indicator of the innovation process whereas the above-mentioned studies focused on the output side of the innovation process and on technology diffusion. Nonetheless, the urban hierarchy theory may also be tested with R&D data. For example, MALECKI, 1980, 1983, suggested that, due to agglomeration advantages, R&D facilities (and notably long-range basic research) should be strongly concentrated in metropolitan areas, close to company headquarters. If this is correct, we can expect that firms located in urban agglomerations have an R&D behaviour distinct from firms in more rural areas in at least two respects: (1) they should have a higher probability of engaging in R&D; and (2) if they engage in R&D they should do so more intensively than similar firms in rural areas.

We start with a short description of our database, and then have a look at the regional distribution of R&D performing firms and their R&D intensities in The Netherlands. Following this descriptive information, we analyse whether the regional variation in R&D behaviour visible in the raw data can be attributed to the regions or whether it is due to other factors, such as the specific industry structure (sectors, firm size, export orientation, and so on) of the various regions. In the third section, we analyse, with the help of the logit model, whether the probability of a firm engaging in R&D is influenced by its location. Next, we run multiple regressions which include determinants of R&D intensities of firms. Both the logit and the regression model allow us to control for a number of non-regional determinants of R&D behaviour of firms which reduces the risk of finding pseudo-correlations. In both cases, we are particularly interested in the impact of location on R&D behaviour of firms. Following some additional examination of the 'urban hierarchy' and 'filter-down' theory, the final section covers our conclusions.

THE DATA

The SEO survey sample is drawn from the records of the Chamber of Commerce and is representative of firms with ten or more employees in all sectors of manufacturing and services. The survey was mailed in 1989 to about 7,500 firms, referring to firm behaviour in 1988. The response rate was 58·1% (4,352 firms) and was quite equal across sectors and regions, although smaller firms responded slightly less than larger ones. About half of the sample firms are from manufacturing, the other half are service firms. Besides some general characteristics of the firm and information on its innovation activities, we know from each of the respondents the branch of principal activities, as well as the exact location (for details, see KLEINKNECHT *et al.*, 1990).

As regional units of analysis we use COROP regions. It should be noted that our sample is *not* stratified by regions. However, the stratification by sectors and size classes, and the overall size of the sample should warrant that we also obtain a representative picture by region. Nonetheless, in the case of relatively small COROP regions, we pooled several neighbouring COROP regions in order to obtain a higher number of enterprises per region. As a consequence, the forty COROP regions of The Netherlands were reduced to thirty-two regions which are detailed in Table 1 and illustrated in Figs. 1–2. For each of the thirty-two regions, Table 1 gives the average R&D intensity of firms for manufacturing and services separately. These R&D intensities are defined as the sum of R&D man years (intramural and contracted out) for all firms in the regions as a percentage of all employees in firms which perform some R&D. Figs. 3 and 4 give an indication of the percentages of manufacturing and service firms in the various regions which have some R&D activity.

It can be seen that there is some regional variation in these indicators. At least part of this variation is against our expectations. For example, large parts of the north and of the south of the country (Groningen and Limburg) which are usually considered as weak regions, have surprisingly high scores on both indicators of R&D behaviour. On the other hand, with a few exceptions, the Rim City (*Randstad*), the core region of The Netherlands, does not show an above-average R&D performance. Notably the R&D performance of the four large cities and their surroundings (Utrecht, The Hague, Rotterdam and Amsterdam) does not seem to confirm the above-mentioned urban hierarchy theory.

DO REGIONS MATTER FOR A FIRM'S DECISION TO PERFORM R&D?

The choice of variables for inclusion in the logit model

In this section we apply the logit model in order to find out which factors influence the probability that a firm will perform R&D and, in particular, whether its location plays a role. In this case, our dependent variable is discrete and can take only two states—a firm does or does not perform R&D. We can therefore confine ourselves to the most simple form of the model, the so-called binomial logit model (for details on the logit model, see CRAMER, 1991).

Table 1. Average R&D performance of manufacturing and service firms in thirty-two regions of The Netherlands, 1988

		Manufacturing		Services	
	Region	RDI^1	n^2	RDI^1	n^2
1+2	East-Groningen, Delfzijl	5·4	23	–^{3}	2
3+7	Rest of Groningen and North Drenthe	3·8	39	2·6	14
4	North-Friesland	3·5	30	2·1	6
5+6	South-west and South-east Friesland	4·7	28	2·1	9
8+9	South-east and South-west Drenthe	4·4	29	2·0	7
10+11	North and South-west Overijssel	2·8	46	2·5	12
12	Twente	3·8	71	0·8	13
13	Veluwe	4·0	62	1·0	21
14	Achterhoek	2·6	59	1·7	7
15	Agglomeration Arnhem and Nijmegen	3·7	49	2·1	30
16	South-west Gelderland	2·5	22	1·7	6
17	Utrecht	4·6	67	2·7	60
18+19	North of N-Holland and Alkmaar	3·5	27	1·5	9
20+21	Ijmond and agglomeration of Haarlem	3·3	23	2·3	9
22	Zaanstreek	2·9	24	–^{3}	4
23	Greater-Amsterdam	5·3	69	2·0	85
24	Gooi and Vechtstreek	0·3	11	1·3	10
25	Agglomeration Leiden, Bollenstreek	9·4	14	1·3	19
26	Agglomeration of The Hague	2·0	21	1·9	32
27	Delft and Westland	11·0	20	4·9	9
28	Eastern-South-Holland	2·8	36	1·5	11
29	Greater-Rijnmond (Rotterdam)	2·7	64	1·3	79
30	South-east South-Holland	3·7	45	1·7	21
31+32	Zeeland	2·6	27	4·7	9
33	West-North-Brabant	3·8	60	1·7	20
34	Middle-North-Brabant	3·4	69	11·1	19
35	North-east North-Brabant	6·6	72	2·2	17
36	South-east North-Brabant	7·0	83	1·0	19
37	North-Limburg	10.6	48	0·7	6
38	Middle-Limburg	2.8	26	3·4	7
39	South-Limburg	7.7	49	3·4	8
40	Flevoland	3.5	14	–^{3}	5
Total of manufacturing		4·2	1,329		
Total of services				2·0	585

Notes: 1. RDI = average R&D intensity, i.e. the sum of R&D man years as a percentage of the sum of all employees of R&D performing firms in the region.
2. n = number of firms in the sample which perform some R&D.
3. Not published for confidentiality reasons.
Source: SEO survey.

For an adequate assessment of the impact of the regional environment on the probability that a firm will engage in R&D, we need to include a number of non-regional determinants of a firm's R&D behaviour in our logit model. As to the latter, the following appear to be obvious candidates: firm size; market structure; the growth of demand; export intensity; the status of a firm (whether it is an independent firm or part of a group of firms); or whether a firm belongs to certain high or low technological opportunity sectors. We also include dummies for certain R&D related activities such as the purchase of advanced equipment, licences, or software. Let us discuss these variables in more detail.

There is a large literature about the two famous Schumpeterian hypotheses that: (1) large firms are relatively more innovative than smaller ones: and (2) market power is conducive to innovation (see BALDWIN and SCOTT, 1987, for a recent survey). This justifies the inclusion of firm size (i.e. numbers of employees) and of market structure in our model. Unfortunately, the most recent measurement of market structure in The Netherlands relates to 1981, while our data are for 1988. Moreover, earlier exercises have shown that market structure has, at least in the Dutch context, relatively little impact on R&D (KLEINKNECHT and VERSPAGEN, 1989). We therefore decided to leave out the market structure variable.

SCHMOOKLER, 1966, argued that market demand has a strong influence on innovation behaviour, proxied by patents. From recent re-examinations of Schmookler's hypothesis we can conclude that the

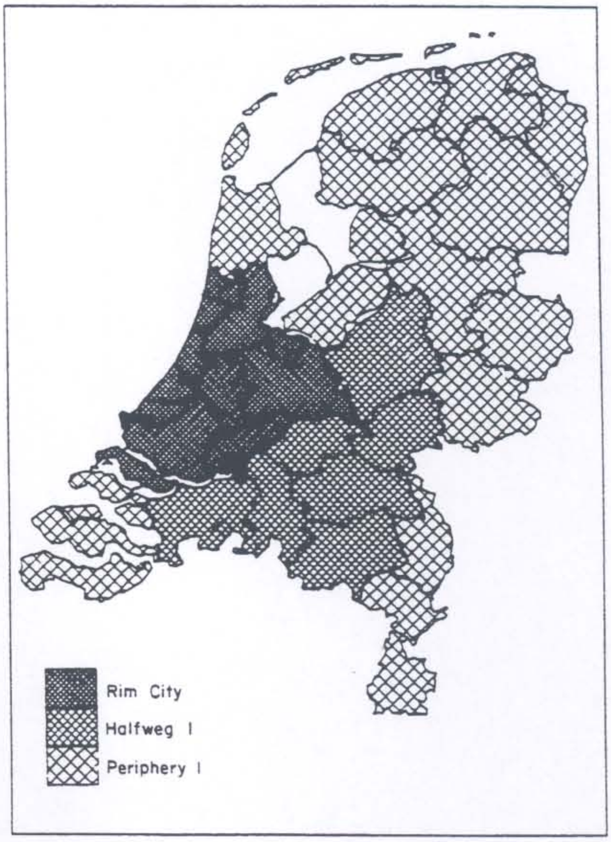

Fig. 1. Subdivision of The Netherlands into Rim City, Halfweg 1 and Periphery 1

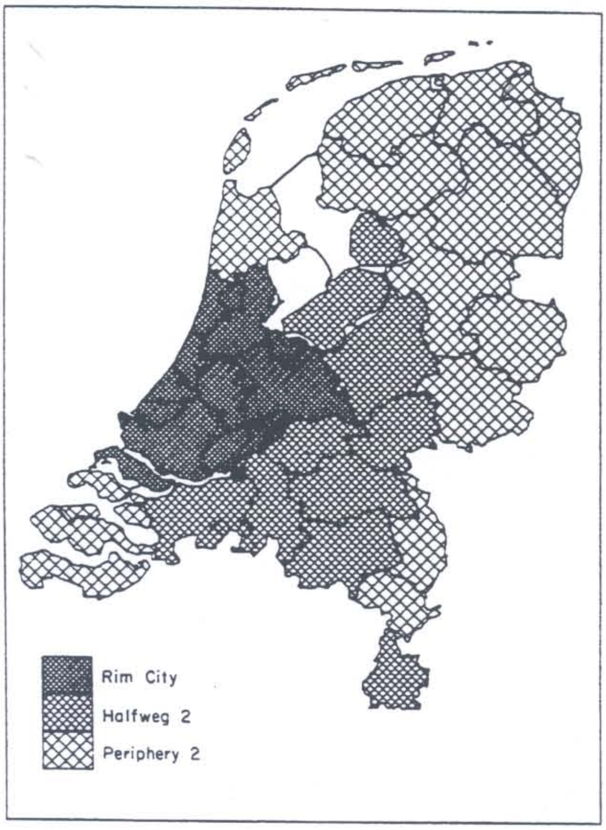

Fig. 2. Subdivision of The Netherlands into Rim City, Halfweg 2 and Periphery 2

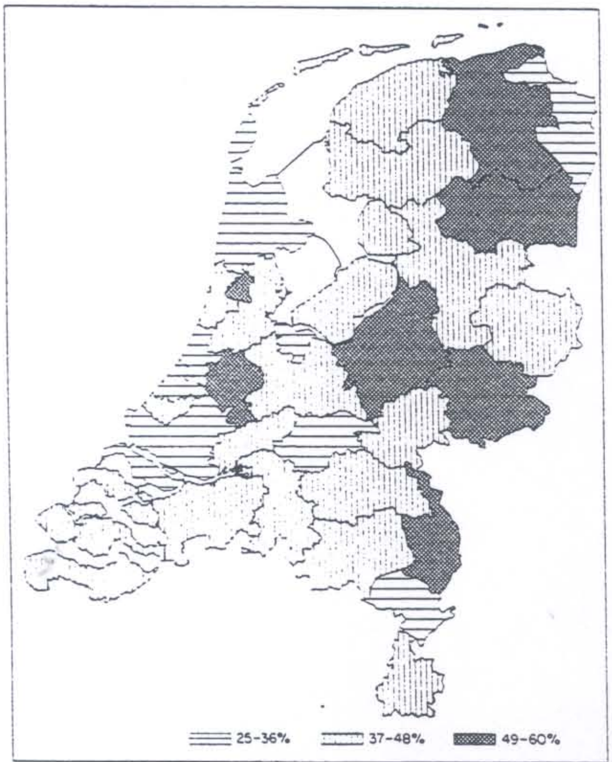

Fig. 3. Percentages of manufacturing firms by region which have R&D activities, 1988

Source: SEO survey.

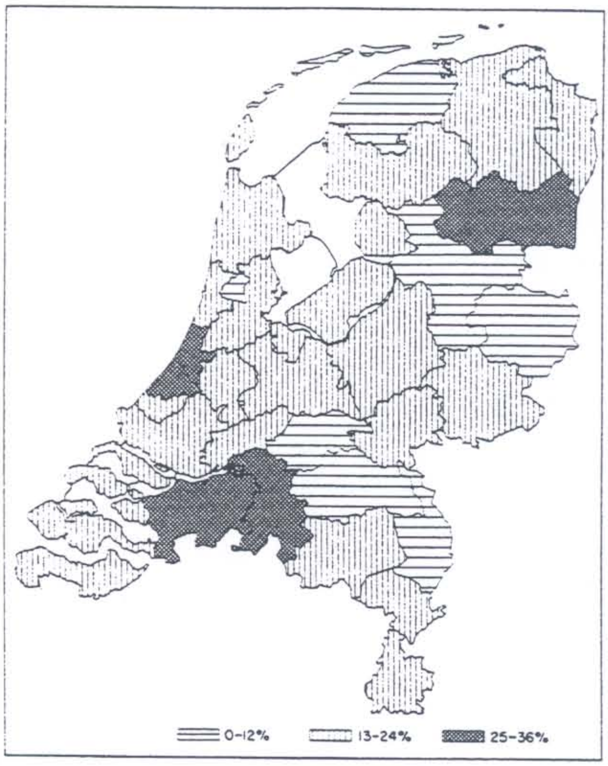

Fig. 4. Percentages of service firms by region which have R&D activities, 1988

Source: SEO survey.

effect of demand on innovation is indeed significant, although considerably weaker than suggested by Schmookler (SCHERER, 1982; WALSH, 1984; KLEINKNECHT and VERSPAGEN, 1990). We therefore include in our model the rate of sales growth (from 1987 to 1988) of the individual sample firms as a proxy of Schmookler's demand-pull argument.

Recent work on the relationship between R&D and exports by HUGHES, 1986, suggests that there is a simultaneous relationship between these two variables. In other words, there is also a positive influence of exports on R&D. We therefore include in our logit estimates a dummy for export-intensity i.e. whether a firm exported more or less than 50% of its sales. Our earlier work on the SEO database revealed that firms which are part of a group of firms are more R&D intensive than independent firms (KLEINKNECHT *et al.*, 1990). By including a dummy for these two types of firms we can test whether they also have a different propensity for undertaking R&D work.

As to sector dummies, we can again draw from earlier work. Looking at R&D figures, it turns out that Dutch manufacturing can be roughly split into two groups—traditional and modern sectors.[1] It is interesting to note that what we called traditional sectors comes very close to what in PAVITT's, 1984, analysis of British innovation patterns is defined as supplier-dominated sectors. These are characterized by a relatively low propensity to engage in R&D, a low R&D intensity and a bias towards process (other than product) innovation, a high share of their innovations being bought via capital goods and other intermediary inputs. Our modern sectors coincide with what Pavitt called specialized suppliers, science-based and production intensive firms.

Given the strong differences in R&D performance between manufacturing and service industries we estimate the logit model for these two groups of firms separately. Within services, we include dummies for public utility enterprises (gas, water and electricity supply), as well as for non-commercial services (including R&D laboratories) which both have an extraordinarily strong R&D performance (Kleinknecht *et al.*, 1990). Finally, we include dummies for firms which bought advanced equipment for office or production automation, acquired licenses, and produced or bought software. Such activities may in part be substitutes for R&D (and hence reduce the probability of doing R&D); in part they may be also complementary to R&D (increasing the probability of undertaking R&D).

Table 2. The significance of variables which are expected to increase the probability that a firm will engage in R&D

Variable	Significance	
	Manufacturing	Services
Size (log of numbers of employees in a firm)	+	+
Dummy variables		
Independent firm (i.e. not part of a conglomerate or group of firms)	0	0
Export intensity (at least 50% of sales are exports)*	+	+
Positive sales growth (>0% from 1987 to 1988)**	+	0
Firm belongs to 'modern' sector (see endnote 1 for a definition)	+	
Firm is a public utility firm or belongs to non-commercial services		+
The firm bought:		
advanced equipment or machinery	0	+
licences	+	0
software	+	+
The firm developed software itself	+	+
The firm had activities in the field of:		
information technology	0	+
biotechnology	+	+
new materials technology	+	+
10% to 25% of the firm's personnel participated in training courses	0	+
Regional variables		
Rim City (COROP 17,20–30)	0	0
Halfweg 1 (COROP 13,15,16,33–36)	0	0
Periphery 1 (COROP 1–12,14,18,19,31, 32,37,38,39,40)	0	0
Halfweg 2 (COROP 13,15,16,33–36, 39,40)	0	0
Periphery 2 (COROP 1–12,14,18,19, 31,32,37,38)	0	0
Index of density of manufacturing activities[1]	0	
Index of density of service activities[2]		0
Index of concentration of industrial activities[3]	0	
Index of concentration of service activities[4]		0

Notes: 1. The log of the percentage of the population working in manufacturing.
2. The log of the percentage of the population working in services.
3. The log of the percentage of the population working in manufacturing, weighted with the share of the working population of the region in national manufacturing totals.
4. The log of the percentage of the population in a region working in services, weighted with the share of the working population of the region in national totals in services.

\+ = significantly positive relationship (t-values $\geq 1{\cdot}96$; level of significance $\geq 95\%$).
\- = significantly negative relationship (t-values $\geq -1{\cdot}96$; level of significance $\geq 95\%$).
0 = no significant relationship.
* = an alternative dummy for firms which exported at least 25% of their sales was also significant.
** = an alternative dummy for firms which had a >10% sales growth proved insignificant.

A detailed documentation of the density and concentration indices can be found in Kleinknecht and Poot, 1990.

Results

Table 2 is confined to documenting the signs of the coefficients of the various above-mentioned variables, detailed by manufacturing and services. A more detailed documentation (coefficients and t-values) of our logit estimates can be found in Kleinknecht and Poot, 1990. From Table 1 we can see that most of the variables behave as expected. The probability of a firm engaging in R&D is positively related to its size, to its export intensity, to technological opportunity (i.e. whether it belongs to the traditional or modern sectors as listed in note 1), to the production and acquisition of software and, not surprisingly, to activities in the fields of biotechnology and new materials. It is remarkable that the status of a firm, while influencing the R&D intensity (see our next section), has no influence on the probability that a firm will engage in R&D. Moreover, the growth of sales increases the probability of a firm engaging in R&D in manufacturing, but not in services. The same holds for the purchase of licences. On the other hand, firms which bought advanced machinery, firms which had activities related to information technology and firms which undertook substantial manpower training have an increased probability of undertaking R&D in services, but not in manufacturing.

The most important outcome for the purpose of this paper is the insignificance of the various dummies for the location of the firms. Following earlier regional studies (Molle, 1985), we subdivided The Netherlands into three types of region: an urban core region (i.e. the 'Rim City'); a rural region; and, in between these two, some type of semi-periphery (in Dutch referred to as Halfwegzone). As to the latter two, we tried out two alternative classifications: Halfweg 1 (or 2) and Periphery 1 (or 2). According to Halfweg 1 and Periphery 1, the three Southern COROP regions of Limburg are classified as part of the periphery. From the viewpoint of The Netherlands, they are indeed part of the periphery. However, from a European point of view, Limburg may also be classified as part of the semi-periphery (Halfweg 2), given its linkages with neighbouring industrial locations in Belgium and Germany. A documentation of the two regional classifications can be found in Figs. 1 and 2. Besides the above classifications, we also tried out indicators of the density and of the concentration of manufacturing and of service activities, as explained in the notes to Table 2.

Table 2 indicates that whichever regional classification we choose, we find no evidence of an impact of regions on the probability of a firm engaging in R&D. It can be added that we also tried out separate dummies for each of the various COROP regions as distinguished in Table 1. The latter are not included in Table 2 as they all proved insignificant. From the performance of the various regional dummies in Table 2 we have to conclude that the location of a firm in a specific region has *no* impact on the probability that the firm will engage in R&D activities. In other words, the variation in percentages of R&D performing firms between regions shown in Figs. 3 and 4 can be explained by a number of non-regional variables.

While the location in a certain region does not seem to induce firms to engage more often in R&D than they would do in a different region, the regional environment of a firm may still be relevant to the intensity of its R&D efforts. This possibility will be examined in the next section.

DO REGIONS MATTER FOR A FIRM'S R&D INTENSITY?

In the following we use multiple regression analysis in an attempt to explain the differences in R&D intensities between regions which were visible in Table 1. The R&D intensity of a firm is defined as the number of its R&D man years (including contract R&D), divided by its total employment. From our initial estimates we learnt that, in order to correct for heteroscedasticity, we need to use the *logs* of R&D intensities as the dependent variable as well as *logs* of numbers of employees (as an independent variable for firm size). In a first step, we include in our regression model a number of variables which were also used for the logit model in the previous section, assuming that these factors may influence not only the probability of undertaking R&D, but also the R&D intensity. Among these variables are: firm size; status of the firm; export intensity; sales growth; and dummies for modern versus traditional sectors.

The regional dummies are the same as in the case of our logit estimates in the previous section. In addition to these variables, we define several dummies which stand for the use or non-use of government innovation support facilities. Among these are:

INSTIR = a subsidy for R&D work, notably in small and medium-sized firms
PBTS = an R&D subsidy for specific technology fields such as new materials, biotechnology, information technology, environmental technology and medical instruments
TOK = a credit for technical development work
TNO = a subsidy for research pooling
TRAIN = subsidies for manpower training efforts.

These government facilities are included in our regression model since it turned out in an earlier panel analysis that several of them had a positive influence on the growth of R&D efforts of the panel firms (KLEINKNECHT *et al.*, 1990).

We initially included all the above-mentioned variables in our regression model. Table 3 documents the signs of the regression coefficients for manufacturing and services separately. We then included only those variables which in Table 3 turned out to be significant. The coefficients and *t*-values of the latter estimates can be found in Tables 4 and 5.

In Table 3, the dummies for technological opportunity, for export intensity, for R&D co-operation, for *TOK*, *INSTIR* and *PBTS* behave as expected.[2] To our surprise, subsidies for manpower training appear to have a negative effect on R&D intensity in manufacturing, and subsidies for research pooling have no effect. The insignificance of the latter may have something to do with the relatively low number of firms which received these subsidies. As expected, it turns out that independent firms have a lower R&D intensity than firms which are part of a group of firms although, in the case of manufacturing, the coefficient is significant only at a 90% level.

The coefficients of the sales variable suggest that Schmookler's demand-pull effect has a significantly positive impact on R&D intensity in services but, against our expectations, not in manufacturing.[3] Interesting to note is the quite peculiar behaviour of the size coefficients in Tables 4 and 5. As we took logs of both R&D and employment, these coefficients can be interpreted as elasticities. From these elasticities we can conclude that a 1% increase in employment implies an 0·41% decline in R&D intensity in manufacturing (in services, this effect is even larger: 0·60%). In other words, while the absolute

Table 3. The significance of variables which are expected to have an impact on the R&D intensity of firms in manufacturing and services

Variables	Level of significance	
	Manufacturing	Services
Size (log of numbers of employees in a firm)	−−	−−
Dummy variables		
Independent firm (i.e. not part of a group of firms)	−	−−
Export intensity (at least 50% of sales are exports)*	++	++
Positive sales growth (at least 10% from 1987 to 1988)**	0	++
Firm belongs to high technological opportunity sector (see note 1 for definition)	++	
Firm is a public utility firm or belongs to non-commercial services		++
Firm engaged in R&D co-operation with another firm or R&D institution	++	++
TOK (firm received technical development credit)	++	++
INSTIR (firm received R&D subsidies)	++	++
PBTS (firm received R&D subsidies for specific technologies)	++	++
TNO (firm received subsidies for research pooling)	0	0
TRAIN (firm received subsidies for manpower training)	−−	0
Regional variables (dummies)		
Rim City (COROP 17,20–30)	0	0
Halfweg 1 (COROP 13,15,16,33–36)	0	0
Periphery 1 (COROP 1–12,14,18,19,31,32, 37,38,39,40)	0	0
Halfweg 2 (COROP 13,15,16,33–36,39,40)	0	0
Periphery 2 (COROP 1–12,14,18,19,31, 32,37,38)	0	0
Index of density of manufacturing activities[1]	0	
Index of density of service activities[2]		0
Index of concentration of industrial activities[3]	0	
Index of concentration of service activities[4]		++

Notes: 1. The log of the percentage of the population working in manufacturing.

2. The log of the percentage of the population working in services.
3. The log of the percentage of the population in a region working in manufacturing, weighted with the share of the working population of the region in national manufacturing totals.
4. The log of the percentage of the population in a region working in services, weighted with the share of the working population of the region in national totals in services.

++ = significantly positive relationship (t-values ≥1·96; level of significance ≥95%).

0 = no significant relationship.

− = significantly negative relationship (t-values ≤−1·65; level of significance ≥90%).

−− = significantly negative relationship (t-values ≤−1·96; level of significance ≥95%).

* = an alternative dummy for firms which exported at least 25% of their sales was also significant.

** = an alternative dummy for firms which had a >0% sales growth proved insignificant.

Table 4. Coefficients and t-values of variables which explain a significant share of the logs of R&D intensities of firms in manufacturing

Variables	Coefficients	t-values
1 (constant term)	−2·63	−18·76**
Size (log of numbers of employees in a firm)	−0·41	−15·15**
Dummy variables		
Independent firm (i.e. not part of a conglomerate or group of firms)	−0·09	−1·76*
Export intensity (at least 50% of sales are exports)	0·40	7·27**
Firm belongs to high technological opportunity sectors (see note 1 for definition)	0·34	6·43**
Firm engaged in R&D co-operation with other firms or R&D institutions	0·29	5·38**
TOK (firm received technical development credit)	0·64	5·81**
INSTIR (firm received R&D subsidies)	0·64	11·80**
PBTS (firm received subsidies for specific technology areas)	0·61	6·70**
TRAIN (firm received subsidies for manpower training)	−0·14	−2·18**

n = 1,234, adj. $R^2 = 0{\cdot}33$.

* Significant at 90% level.

** Significant at 95% level.

Table 5. Coefficients and t-values of variables which explain a significant share of the logs of R&D intensity of firms in services

Variables	Coefficients	t-values
1 (constant term)	−1·72	−8·85**
Size (log of numbers of employees in a firm)	−0·60	−17·70**
Dummy variables		
Independent firm (i.e. not part of a conglomerate or group of firms)	−0·19	−1·99**
Export intensity (at least 50% of sales are exports)	0·38	2·59**
Positive sales growth (10% or more from 1987 to 1988)	0·23	2·34**
Firm is a public utility firm or belongs to non-commercial services	0·82	4·63**
Firm engaged in R&D co-operation with other firms or R&D institutions	0·25	2·57**
TOK (firm received a technical development credit)	1·04	3·22**
INSTIR (firm received subsidies on R&D)	0·88	8·23**
PBTS (firm received subsidies for specific technologies)	0·64	3·06**
Index of concentration of service activities	0·15	3·52**

n = 539, adj. $R^2 = 0{\cdot}45$.

** Significant at 95% level.

number of R&D man years increases with increasing size, the *share* of R&D workers in total employment diminishes, implying that larger firms are less R&D intensive than smaller ones. It should be added here that our measure of R&D intensity includes only R&D performing firms and that a considerable part of small and medium-sized firms have *no* R&D activities. The relatively high R&D intensities of smaller firms in our sample have to do with our capturing of large amounts of small-scale and informal R&D which is likely to be neglected in the official R&D surveys.[4]

An important message from the above results is that, as in our previous logit analysis, the various regional dummies do *not* matter for R&D. An important exception is the significant influence of the concentration of services variable. This comes down to indicating that service firms which are concentrated in the four major cities (Amsterdam, Rotterdam, The Hague, Utrecht) have a higher than average R&D intensity.[5] This suggests that the urban hierarchy theory may hold for services but not for manufacturing, i.e. we find no evidence of above-average manufacturing R&D efforts in the four large cities. Nor do we find any other above-average R&D effort that can be ascribed to regional factors.

When drawing such conclusions, some caveats should be noted. First, The Netherlands is a small country, and what is understood as a region is of course much smaller than in Britain or in the USA (US regions are often larger than the entire Netherlands!). Even if nobody doubts that The Netherlands does have typical urban agglomerations and rural areas, physical distances are considerably less. Second, MALECKI, 1980, emphasized that long-range basic research in particular should be concentrated in large agglomerations, whereas development work may be more decentralized, following the location pattern of production plants. Our R&D data do not allow us to distinguish between these types of R&D. Our above test is based on the assumption that, if Malecki's hypothesis is valid, we can expect firms in urban agglomerations to show above-average R&D intensities.

FURTHER INVESTIGATION

Besides the above logit and regression analyses, we examined four related aspects of the urban hierarchy and filter-down theories:

1. In our survey we asked firms whether their R&D work is done within a formal R&D department (given that many firms have R&D activities without having such a separate department). Assuming that basic and applied research usually occur in a formal R&D department, whereas development work may more often be done in a more informal way, we examined whether firms in the agglomeration zones have more often a formal R&D department. However, this was found not to be the case.
2. We examined whether rural zones have more firms which reported that they were strongly dependent on the mother company in their decisions about product or service innovations (taking this as an indication of filter-down branch plants). Again, this was found not to be the case.
3. We examined the hypothesis by EWERS and WETTMANN, 1980, p. 166, that the regional environment may be more important to smaller than to larger firms. However, when estimating the above regression equations (Tables 3–5) for firms with less than a 100 and 100 and more employees separately, we got essentially the same results; in other words, the hypothesis had to be rejected.
4. In our survey we also asked firms which percentage of their total R&D was related to each of the following three categories: (1) product and service innovations; (2) process innovations; and (3) R&D difficult to group by either category (because product and process renewal are intertwined). It should be noted that, in manufacturing, the average percentage share of product-related R&D is 68·8%, the share of process-related R&D is 23·3%, and 7·9% cannot be grouped by either category. We assumed that basic and applied research (being concentrated in urban agglomerations and related to technologies in an early stage of their life cycles) has a relatively high share of product-related R&D, whereas development work (in rural branch plants) is likely to be related to technologies in a later stage of the life cycle and hence has a higher share of process-related R&D. In other words, we tested whether the percentage share of process-related R&D in total R&D was higher in rural areas as compared to the more central regions. In order to control for pseudo-correlations, we included some other variables which may account for the product-to-process ratio of R&D, estimating the following equation (*t*-values in brackets):

$$\begin{aligned} PROC = {} & \underset{(6{\cdot}56)}{23{\cdot}12} - \underset{(-6{\cdot}08)}{4{\cdot}30}LRDI - \underset{(-5{\cdot}07)}{8{\cdot}83}dHTO \\ & + \underset{(2{\cdot}60)}{5{\cdot}63}dDEP + \underset{(1{\cdot}89)}{3{\cdot}96}dSEM + \underset{(3{\cdot}78)}{7{\cdot}54}dPER \end{aligned} \qquad (1)$$

where:

PROC = percentage share of process-related R&D in total R&D
LRDI = log of R&D intensities of firms
dHTO = dummy for firms in high technological opportunity sectors (definition: see note 1)
dDEP = dummy for firms which are strongly dependent on the mother company when developing new products or services

dSEM = dummy for firms in semi-periphery (Halfwegzone: see Figs. 1–2)
dPER = dummy for firms in periphery (definition: see Figs. 1–2)
adj. R^2 = 0·07
n = 1,255 (only manufacturing firms which have some R&D activity.

Equation (1) indicates that highly R&D intensive firms have a lower share of process-related (or a higher share of product-related) R&D. As expected, firms in modern sectors have a lower share of process-related R&D than firms in traditional sectors, and the same holds for firms which indicated that they were strongly dependent on the mother company when developing new products or services. As opposed to the three tests named above, the regional dummies in equation (1) are consistent with the filter down theory. Compared to firms in the Rim City, firms located in the semi-periphery (Halfwegzone) have, on average, an almost 4% higher share of process-related R&D in their total R&D; for firms in the periphery, this percentage is 7·5% higher than in the Rim City. This can be taken as support of filter-down theory: manufacturing firms in the less central regions of The Netherlands may have a bias towards technologies which are already in a mature stage of their life cycle, when process-related R&D becomes more important than product-related R&D. This result holds for manufacturing industry. When estimating a similar equation for the service sector, we found no significant impact of location on the process-to-product ratio. However, it should be added that, compared to manufacturing, product and process innovation may have a different meaning in services, as the new service (or the new 'product') of a service firm often consists of a new procedure.

DISCUSSION AND CONCLUSIONS

The question of whether regions matter for R&D cannot be answered with a simple 'yes' or 'no'. A 'no' could be justified because we find little evidence that firms in centralized regions engage more often in R&D or undertake relatively more R&D than is done by similar firms in other regions. Moreover, we find no indication that firms in the centralized regions more often have a formal R&D department. Neither is there any evidence that firms located in rural regions are more often strongly dependent on the mother company when developing new products or new services (taking this information as a proxy for branch plants in rural areas). Nor can we confirm the hypothesis by Ewers and Wettmann, 1980, that small firms are more dependent on their regional environment than are large firms.

However, our regression analysis shows that service firms in the four major cities are more R&D intensive than service firms in the rest of the country. Moreover, our analysis of the composition (other than volume) of R&D gives some indication that the urban hierarchy or filter down theory may be realistic. After control for several other variables, it turns out that firms in the central region (Rim City) have a higher share of product- and service-related R&D in their total R&D.

Unfortunately, our data do not allow for a breakdown of R&D into basic research, applied research and development work, which would have allowed for a more adequate test of the filter-down theory. On the other hand, if filtering-down exists, one would expect to find a higher than average percentage of firms performing R&D and firms with above-average R&D intensities in the Rim City, which is not the case, except for services in the four large cities. In this respect, our findings coincide with those by Howells, 1983, who discovered no regional differences in the R&D performance of eighty-three pharmaceutical firms in the UK (*ibid.*, p. 151).

Our conclusion must therefore be that the R&D intensity of service firms in the four large cities, as well as some process-bias of R&D in the rural regions seem to support the urban hierarchy and filter-down theory in The Netherlands. However, the probability of a firm engaging in R&D as well as a firm's R&D intensity do not seem to be influenced by its location. One explanation of this may be taken from recent in-depth case studies by Vaessen and Wever, 1990. They suggested that due to the relatively compact and well developed communication infrastructure in The Netherlands, together with the overall size of the country, physical distance does not really matter for knowledge transfer. This interpretation is consistent with the argument by Dieperink and Nijkamp, 1988, that the regional distribution of innovative abilities is not related to the uneven distribution of knowledge centres (i.e. university and non-university research institutes and R&D departments of the five big Dutch multinationals) across the country. This implies that the creation of universities or other knowledge centres in designated areas is likely to be a less efficient tool of regional policy than is often assumed (Andersson and Johansson, 1984; Pred, 1977)—at least in a small country such as The Netherlands.

When arguing that the variation in R&D performance between regions (shown in Table 1 and in Figs. 3 and 4) can largely be explained by non-regional factors, we are still left with the question of why these non-regional factors are so unevenly distributed across regions; in other words, why do certain regions succeed more than others in attracting or developing a certain type of (more advanced or more backward) industry structure? In particular, why does manufacturing industry in the four big cities have such a weak R&D performance?

One explanation may be that, due to congestion and residential preferences of R&D workers and entrepreneurs for visually attractive areas, large agglomerations are losing ground and innovative entrepreneurs tend to shift towards suburban rings and medium-sized towns. This hypothesis has been advocated by KEEBLE, 1988, in the UK, as well as in WEVER's, 1984, analysis of birth and death rates of new firms in The Netherlands.

Another explanation may refer to regional policy. An impressive example of successful regional policy is Limburg. The province of Limburg experienced high unemployment after the closure of the coal mines at the end of the 1960s. Since then it has become one of the most prosperous regions in The Netherlands, and our raw data given earlier indicate a relatively strong R&D performance in Limburg. Without doubt, the recovery of Limburg has much to do with a strong commitment to regional policy by local and national authorities. Taking the relative R&D performance of a region as a predictor for future economic performance, it is tempting to conclude that The Netherlands is going to experience a north to south shift in economic activity (similar to what happened in Great Britain and Germany and, on a much larger scale, in the US), with Brabant and Limburg taking a lead in economic development, and the traditional core regions (notably the Rim City) continuing to lose ground.

The case of Limburg suggests that regional policy does not need to be a zero-sum game but can help a region to attract and develop a high quality industry structure. However, our above results indicate that, with a *given* industry structure, regional policy seems to be a zero-sum game in that it does not succeed in inducing firms to undertake R&D more frequently or to be more R&D intensive than one would expect them to do in any other region.

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NOTES

1. The following sectors were selected as traditional (or low technological opportunity) sectors: food; beverages and tobacco; textiles and clothing; leather and shoes; wood and furniture; paper and cardboard; printing and publishing; building materials; earthenware and glass. Modern (or high technological opportunity) sectors are: chemicals and petroleum; rubber and plastics; basic metal and metal goods industry; machinery; electrotechnical and electronics industry; automobiles and other transportation equipment; instruments and optical industry (KLEINKNECHT *et al.*, 1990).
2. One could plausibly argue that in the case of *INSTIR*, *TOK* and *PBTS* causality may also run in the opposite direction: R&D intensive firms make more use of government innovation support facilities. It seems nonetheless justified to include them as explanatory variables in the above equations as our panel analysis for the period 1983–8 showed that not only the level of R&D intensity, but also the *change* over time is positively related to the use of these instruments (KLEINKNECHT *et al.*, 1990).
3. Defenders of Schmookler's hypothesis might argue that by taking sales over one year only, the demand-pull hypothesis is inadequately tested. It would probably be better to take sales performance over several years and, perhaps instead of taking a firm's sales, one should take an indicator of demand of the entire market in which a firm operates.
4. We feel quite safe with our alternative assessment of R&D in small and medium-sized firms, as our results have meanwhile been indirectly confirmed by an analysis of records on R&D subsidies. A more detailed treatment of the implications of such measurement differences can be found in KLEINKNECHT *et al.*, 1991.
5. A dummy variable including the COROP regions of Amsterdam, Utrecht, Rotterdam and The Hague also proved significant.

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Academic research and industrial innovation *

Edwin Mansfield

Department of Economics, University of Pennsylvania, Philadelphia, PA 19104-6297, U.S.A.

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1. Introduction

The purpose of this study is to estimate the extent to which technological innovations in various industries have been based on recent academic research, and the time lags between the investment in recent academic research projects and the industrial utilization of their findings. Because no attempt (to my knowledge) has been made to estimate the social rate of return from academic research, [1] we also make some rough and tentative estimates of this sort. While the results are subject to many limitations discussed below, they should be of interest to public policy-makers concerned with science and technology, as well as to economists and others that study the process of technological change.

At the outset, it should be noted that I am concerned primarily with recent academic research —that is, academic research occurring within fifteen years of the commercialization of whatever innovation is being considered. [2] A great many new products and processes are based on relatively old science that to some extent was due to academic research. In estimating the social rate of return from academic research, I ignore such long-term effects of academic research because they are very difficult to measure, because benefits occurring many years after the relevant investment in research are so heavily discounted, [3] and because the effects of relatively old science may not be a reliable guide to the present situation. This, like many other features of my estimation procedure, tends to impart a downward bias to the estimated rate of return.

2. New products and processes based on recent academic research

A random sample of 76 major American firms in seven manufacturing industries—information processing, electrical equipment, chemicals, instru-

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[1] Relatively few detailed studies of the contribution of academic research to industrial innovation have been carried out. Most seem to have focused on the drug industry. For example, see Mansfield et al. [15, ch. 8] and Schwartzman [24]. Also, Mushkin [26] estimated social rates of return for biomedical research, much of which is carried out at universities and colleges. In addition, Project Hindsight and the Traces study dealt with about 20 weapons systems and five major innovations, and Gellman [7] provided relevant data bearing on this topic.

[2] By "recent", we mean recent in relation to the time when the innovation occurs. Some observers, particularly in the drug industry, have argued that 15 years is too short, because it often takes longer than this for academic research to be applied. Our reason for using 15 years is to be very conservative. Results based on other time intervals would, of course, be interesting and valuable.

[3] For example, a dollar of benefits occurring 20 years hence is worth now only about 3 cents if the interest rate equals 0.20.

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Table 1
Percentage of new products and processes based on recent academic research, seven industries, United States, 1975–85

Industry	Percentage that could not have been developed (without substantial delay) in the absence of recent academic research		Percentage that were developed with very substantial aid from recent academic research	
	Products	Processes	Products	Processes
Information processing	11	11	17	16
Electrical	6	3	3	4
Chemical	4	2	4	4
Instruments	16	2	5	1
Drugs	27	29	17	8
Metals	13	12	9	9
Oil	1	1	1	1
Industry mean [a]	11	9	8	6

Source: See section 2.
[a] Unweighted mean of industry figures.

ments, drugs, metals, and oil—was chosen. [4] This sample accounts for about one-third of these industries' total sales in 1985. Data were obtained from each firm's top R&D executives concerning the proportion of the firm's new products and processes commercialized in 1975–85 that, according to these executives (and their staffs) could not have been developed (without substantial delay) in the absence of academic research carried out within 15 years of the first introduction of the innovation. [5] As indicated in table 1, about 11 percent of these firms' new products and about 9 percent of their new processes could not have been developed (without substantial delay) in the absence of recent academic research. [6]

The percentage of new products and processes based in this way on recent academic research seems to be highest in the drug industry (which has an obvious interest in the large amounts of medical, biological, and pharmaceutical research carried out at universities) and lowest in the oil industry. To a considerable extent, these interindustry differences with respect to new products can be explained by differences among firms in R&D intensity. A firm's percentage of new products based in this way on recent academic research seems to be directly related to the percentage of its sales devoted to R&D. Holding R&D intensity constant, interindustry differences are not statisti-

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[4] The frame for this survey was the list of major firms in these industries in *Business Week*, 23 June 1986. This list includes all firms spending over $1 million (or 1 percent of sales, if sales were at least $35 million) on R&D in 1985. A random sample of 76 of these firms was chosen, and data were obtained from all of them (sometimes after considerable discussion and negotiation) through questionnaires and interviews. The number of firms included in each industry is: information processing, 25; electrical equipment, 14; chemicals, 15; metals, 6; instruments, 7; drugs, 6; oil, 3. An attempt was made to allocate the sample optimally among industries (that is, with sample size being proportional to the total number in each industry times the relevant standard deviation). The sample size of 76 was chosen because it seemed large enough to result in the desired precision. See Cochran [4, ch. 5]. The firms in our sample accounted for about one-third of the sales in the population of firms in these industries in 1985.

[5] While our initial requests for information and cooperation were made to the firms' chairmen, the respondents were often the top R&D executives who based their responses in part on detailed data obtained from people at lower levels of their organizations. (For further comments on the data, see footnote 11.)

By "substantial delay", we mean a delay of a year or more. Of course, it is always hard to rule out completely the possibility that, in the absence of the relevant academic research, industrial or government researchers might have provided the necessary information; but according to the firms, this would have been extremely unlikely for the innovations they included in this category. As pointed out in section 5 below, they believe that, without the completion of the academic research, it would have taken at least 9 years longer, on the average, for these new products and processes to have been introduced.

[6] The figures in table 1 for each industry are weighted means of the firm percentages, the weights being the 1985 sales of the firms. The unweighted means of the firm percentages tend to be higher than the weighted means in table 1. The standard errors of the unweighted means are about 2 percentage points.

mation processing, and electrical equipment industries seem to have the largest sales of new products of this sort, these differences could be due in substantial measure to sampling errors. Given our objectives, the important figures are the seven-industry totals ($24 billion and $17.1 billion) which, although they have substantial sampling errors, are sufficiently precise to be useful. (Note too that these totals are quite consistent with McGraw-Hill [10] data. [12])

Turning to new processes, data were obtained from each firm in our sample concerning the savings during 1985 from new processes first commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research. From these data, estimates were made of the total savings during 1985 from such new processes for all major firms in each industry. [13] The seven-industry total was about $7.2 billion, as shown in Table 2. The information processing industry seemed to have greater savings than the other industries, but the sampling errors in the figures for individual industries are very large. The important figures are the seven-industry totals ($7.2 billion and $11.3 billion) which, while they contain substantial sampling errors, are accurate enough to be useful.

4. Time lags between academic research and industrial innovation

To understand the relationship between academic research and industrial innovation, we need data regarding the length of the time lags between academic research findings and the commercialization of the innovations based on these findings. Information concerning these time lags was obtained from the firms in our sample. For each firm's new products and processes introduced in 1975–85 that could not have been developed (without substantial delay) in the absence of recent academic research, data were obtained concerning the mean time interval between the relevant academic research finding and the first commercial introduction of the product or process. If more than one such research finding was required for the development of the innovation, this time interval was measured from the year when the last of these findings was obtained. [14]

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[11] To make this estimate, we multiplied the number of major firms in each industry by the mean 1985 sales of such products of the firms in the sample. A major firm is defined here as one that is big enough to be included in the *Business Week* list cited in footnote 4. Many of the firms went to a considerable amount of trouble to provide reasonably accurate data. For other firms, the data are rough, but we tried in a variety of ways to make sure that the executives had what seemed to be a solid basis for their estimates. Nonetheless, data of this sort have obvious limitations, and should be treated with appropriate caution.

[12] The results in tables 1 and 2 seem to be quite consistent with McGraw-Hill's survey of business plans for research and development expenditures [10], which provides data for five of our seven industries. In its 1982 survey, McGraw-Hill asked the respondents what percentage of their 1985 sales would be in new products introduced for the first time in 1982–85. If this percentage for the kth industry is L_k, if the kth industry's 1985 sales equal M_k, if the percentage of new products in the kth industry that could not have been developed (without substantial delay) in the absence of recent academic research is N_k, and if the total sales during 1985 of new products commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research is Y_k:

$$Y_k = L_k M_k N_k.$$

Inserting our estimates of N_k in table 1 into this equation, together with McGraw-Hill's estimates of L_k and the actual values of M_k, we find that the resulting estimates of Y_k for these five industries are close to our estimates of Y_k. The differences generally can be attributed to sampling errors.

The McGraw-Hill data cannot be used to check our results for the drug and information processing industries, because these data are not available for them. To obtain data concerning L_k for these two industries, we contacted leading firms in each industry, which provided us with rough estimates. For the information processing industry, the resulting estimate of Y_k is reasonably similar to our estimate of Y_k. But in the drug industry, it is much lower than our estimate of Y_k. According to some leading R&D executives in the drug industry, this is because our estimate of L_k for this industry is too low. But if this is not the case, and if our estimate of Y_k for this industry is too high, our final results will not be affected very much. For example, even if this estimate were double what it should be, the social rate of return in table 4 would be 26 percent, which is not very different from the figure of 28 percent given now.

[13] To make this estimate, we multiplied the number of major firms in each industry by the mean 1985 savings from such processes of the firms in the sample. For some firms, these savings data, like the sales data discussed in footnote 11, are rough. Our comments at the end of footnote 11 apply to these data as well.

[14] Because not all of the firms could provide data of this sort, and because others sometimes could only approximate these dates, the results contain errors, but the averages in table 3 should be reasonably accurate.

Table 2
Estimated sales of new products based on recent academic research and estimated savings from new processes based on recent academic research, seven industries, United States, 1985 [a]

Sales or savings	Innovations that could not have been developed (without substantial delay) in the absence of recent academic research	Innovations that were developed with very substantial aid from recent academic research
Total 1985 sales by major firms of new products first commercialized in 1982-85 and based on recent academic research:		
Billions of dollars	24.0	17.1
Percent of total sales of major firms	3.0%	2.1%
Total 1985 savings by major firms due to new processes first commercialized in 1982-85 and based on recent academic research:		
Billions of dollars	7.2	11.3
Percent of total costs of major firms	1.0%	1.6%

Source: See section 3.
[a] The seven industries that are included are listed in table 1.

As shown in table 3, the mean time lag in these industries was about 7 years.[15] In general, it appears that the time lag tends to be longer in larger firms, which is consistent with the view that development often takes longer in larger firms. Also, some small firms are formed to commercialize the results of academic research. When size of firm is held constant, the average lag tends to be greater in the metals industry than in the others, but the sample size in this industry is rather small, so this finding should be viewed with considerable caution. Letting D_i be the mean time lag (in years) for the ith firm,

$$D_i = 5.72 + \underset{(2.25)}{0.38S_i} + \underset{(2.95)}{5.68Y_i} \quad (R^2 = 0.30), \qquad (1)$$

where S_i is the 1985 sales (in billions of dollars) of the ith firm and Y_i is a dummy variable that equals 1 if the ith firm is a metals firm and zero otherwise.[16]

For each firm's new products and processes introduced in 1975–85 that were developed with very substantial aid from recent academic research, similar sorts of data were obtained. As shown in table 3, the average lag for these innovations was 6.4 years, which is close to our result for innovations that could not have been developed (without substantial delay) in the absence of recent academic research.

It is interesting to note that Gellman [7] found almost precisely the same average lag for academic-research-based innovations in 1953–73 (his average was 7.2 years). Also, an analysis of Gellman's data indicates that academic-research-based innovations tend to be carried out by much smaller firms than other innovations. Whereas about 20 percent of other innovations were carried out by firms with under 100 employees, almost 60 percent of these innovations were carried out by such small firms, some of which were probably established to exploit the relevant academic research.[17]

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[15] The standard error of each of the overall means in table 3 is about 0.6 years.

[16] In equation (1), the t-statistics are shown in parentheses below the regression coefficients.

[17] Of course, one should bear in mind that Gellman's data are in many regards not comparable with ours. Besides the differences pointed out in the last paragraph of section 2, it is worth noting that, whereas the lag can be longer than 15 years for innovations in Gellman's sample, this cannot be the case in ours, because we are concerned entirely with innovations based on recent academic research. Also, in this comparison (but not in that in the last paragraph of section 2), his data pertain to all industries, not just to those included here. Nonetheless, it is reassuring to find that his results are so close to ours.

Note too that there is no contradiction between our finding here that academic-research-based innovations tend to be carried out by small firms and our findings in footnote 7. The latter are based entirely on data for major firms.

5. The social rate of return from academic research: The basic model

To calculate the social rate of return from the investment in academic research, we must compare the stream of social benefits if this investment takes place with what it would have been without this investment, holding constant the amount invested in non-academic research. In other words, we are interested in what would happen if the resources devoted to academic research were withdrawn—and not allowed to do the same or similar work elsewhere.[18] Specifically, suppose that all academic research were to be terminated permanently at the end of year $t-1$.

Without the investment in academic research in year t, the findings of this research (on which new products and processes are based) would not be available, thus preventing or delaying the development and introduction of the new products and processes based on these findings. According to the firms in our sample, it would have taken at least 9 years longer, on the average, for the new products and processes in tables 1–3 (that were based on academic research) to have been introduced. But since estimates of this sort obviously are subject to large errors, we make the more conservative assumption that it would have taken 8 years for this to occur. As we shall see, our findings change relatively little, even if we assume that this average delay is much less (for example, 3 years).

The social rate of return from the investment in academic research in year t is the interest rate that makes the present value in year t of the extra social benefits due to the earlier introduction of these new products and processes equal to the investment in academic research in year t. This is an incremental rate of return, since it is the rate of return from only the final installment of the total investment required to bring forth the relevant academic research findings. Absent the investment in year t, the findings of this research would not have been produced (without considerable delays), but this investment is not the total investment required to elicit these findings. Because of the cumulative nature of science, this total investment may have extended over decades or centuries. Nonetheless, for policy-makers who must decide how much to invest next year in academic research, this incremental rate of return is of primary significance. Past investments in academic research are sunk costs, and the social rate of return from next year's investment is what counts.

Table 3
Average time lag between a recent academic research finding and the first commercial introduction of a new product or process based on this finding, seven industries, 1975–85

Industry	Innovations that could not have been developed (without substantial delay) in the absence of recent academic research (mean number of years)	Innovations that were developed with very substantial aid from recent academic research (mean number of years)
Information processing	7.0	6.2
Electrical	5.3	4.9
Chemical	6.8	7.3
Instruments	4.2	4.2
Drugs	8.8	10.3
Metals	9.8	5.7
Oil [a]	N.A.	N.A.
Industry mean [b]	7.0	6.4

Source: See section 4.

[a] Reliable data could not be obtained for a sufficiently large number of innovations to allow us to present figures for this industry.

[b] Unweighted mean of industry figures.

To calculate this rate of return, we assume, based on the average time interval in table 3, that the new products and processes made possible by the investment in academic research in year t are introduced 7 years later (that is, in year t', where $t' = t + 7$). The social benefits from the innovations commercialized in year t' that are based on academic research in year t are assumed to con-

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[18] Note that we focus on the rate of return from the entire investment in academic research, not the rate of return from an extra dollar spent on academic research. While the latter rate of return is of great significance, we cannot estimate it with the existing data. Our objective is not to allocate the growth in output among various contributing factors, as in Edward Denison's pioneering work (for example, Denison [5]). Instead, it is to estimate the extent of the social benefits which would have been forgone in the absence of recent academic research, which obviously is a polar extreme. In interpreting the results, it is important that this be borne in mind (see section 7). For interesting discussions of other relevant considerations, see Kendrick [9] and Nelson [21].

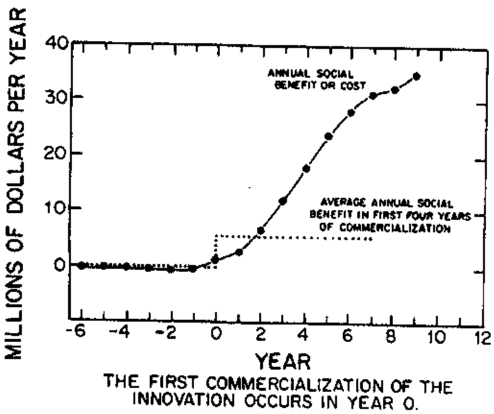

Fig. 1. Annual social benefit or cost, by year, from first commercialization of innovation, mean for 53 industrial innovations. *Source:* Foster Associates [6], Mansfield et al. [13], and Nathan Associates [17].

tinue up to year $t' + 7$ (and no longer) at their average annual level in the first four years after commercialization, and to be zero before year t'. This, as explained in the following paragraphs, is a very conservative assumption.

Figure 1 shows the average annual stream of social benefits and costs for the 53 industrial innovations studied in Mansfield et al. [14], Foster Associates [6], and Nathan Associates [17], the three principal sources of data on this topic.[19] For the innovations based on academic research in year t, we are replacing the time form of social benefits and costs in fig. 1 with the dotted line shown there. This dotted line underestimates the average social benefits in the years after the commercialization of the innovation, as well as the social costs (due to investment in applied R&D, plant and equipment, and startup activities) prior to year t'. On balance, this a very conservative assumption, if the time form of social benefits (savings from new processes, profits from new products, and benefits to those other than the innovator) and costs is at all similar to that of the 53 innovations included in fig. 1. If the interest rate is 0.25, the discounted net social benefits based on this assumption are about half of their actual value. If the interest rate is lower, this assumption is even more conservative.

The reason why the social benefits stop in year $t' + 7$ is that we make the conservative assumption that, in the absence of academic research, the relevant research findings would have been obtained (through industrial, government, or other research) in time to permit the introduction of the new products and processes based on these findings in year $t' + 8$—that is, 8 years after they would have been introduced if the investment in academic research in year t had been made. Hence, after year $t' + 7$, there are no social benefits in excess of those that would have accrued without academic research in year t.[20] Note once again that the firms in our sample regard this assumption of a 8-year delay as being conservative (that is, on the low side).[21]

Thus, based on the very conservative assumptions described in this section, if we want to estimate the social rate of return from the annual investment in academic research during 1975–78, we must find the value of i which satisfies the following equation:

$$X\left[\frac{1}{(1+i)^7} + \frac{1}{(1+i)^8} + \cdots + \frac{1}{(1+i)^{14}}\right] = C, \tag{2}$$

where C is the annual investment in academic research during 1975–78, and X is the annual social benefit from this investment.

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[19] Three of Nathan's innovations had to be omitted because of incomplete data. A fourth was excluded because the timing of the social benefits from this innovation was affected dramatically—and very atypically—by the outbreak of an epidemic. The costs and benefits in fig. 1 are in constant dollars.

[20] This assumes that the average social benefit during the first four years after commercialization is about the same if the innovation is delayed 8 years as if it is not delayed. Whether or not this is true will vary from case to case, but since benefits 8 years or more after commercialization are so heavily discounted, the results are not influenced much by this assumption. Moreover, it is a conservative assumption so long as the delay does not increase the annual social benefit from the innovation, which seems unlikely in most cases.

[21] In considerable part, this long delay occurred because industrial researchers often had little or no incentive to do the kinds of work that academic researchers carried out. Whereas the academic research underlying the innovations in tables 1–3 was of interest to academic researchers (and to the federal agencies that financed much of it), it often seemed to be of little or no direct use to firms; and even when it did seem to be of use, there often was no effective means for the firms to appropriate the benefits.

6. Academic research during 1975–78: Estimated rate of return

To solve equation (2) for i, we need the values of C and X. With regard to C, we use the worldwide investment in academic research, since academic science is in many respects an international enterprise, and firms in all countries draw on the findings of foreign as well as domestic academic research. OECD data and Campbell [2,3] are used to estimate the annual investment during 1975–78 in academic research (other than the social sciences and psychology) in the OECD countries and the Soviet Union (which, according to the National Science Foundation, [22] carry out almost all of the world's scientific and technological activities). Because of the difficulties in distinguishing R&D from teaching (and for other reasons), the resulting estimate of C (which is expressed in 1985 dollars [23]) is rough. [24] Fortunately, our results are not very sensitive to reasonable variations in this estimate.

To estimate X, the first thing to note is that, since there is a 7-year lag, the investment in academic research during 1975–78 results in new products and processes commercialized in 1982–85. Let b_{ij} be the social benefit during year $t' + j$ (where $j = 0, \dots, 3$) from the ith new product or process (based on academic research) commercialized in year t'. If we define $B(t')$ as $\Sigma_i \Sigma_{j=0}^{3} b_{ij}/4$, where the first summation is over all of the new products and processes commercialized in year t' that were based on academic research, it follows that $B(t')$ is the sum of the social benefits accruing annually from the new products and processes commercialized in year t' that were based on recent academic research, if one accepts the very conservative assumption in section 5—that is, if we assume that the annual social benefits equal their average annual level in the first four years after commercialization.

Under this very conservative assumption, X equals the mean value of $B(t')$ during 1982–85.

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[22] National Science Foundation [18, p. 4]. According to the National Science Foundation [18, p. 278] about 11 percent of academic R&D in the United States in 1975–78 went for the social sciences, psychology, and other research not concerned with engineering or the physical, environmental, mathematical, or life sciences. In other countries like Japan, this percentage may be higher [18, p. 206], but to be conservative, we assume that the U.S. percentage is true in all countries. This may tend to bias the estimated rate of return downward.

[23] Like the National Science Foundation, we use the GNP deflator to convert to 1985 dollars. As pointed out in Mansfield [11], this deflator has important weaknesses, but for present purposes it should be good encugh. While it may result in some downward bias in C, this bias will be too small to affect the results materially.

[24] For a description of the OECD data, see OECD [22]. Data for 1975–78 were provided by Allison Young of OECD. For the United States, the OECD figures exceed the NSF figures, because they include capital spending and federally funded research and development centers administered by universities. Since work by the centers is not included in our definition of academic research, the R&D performance of these centers is deducted from the OECD figures.

To estimate academic research expenditures in the Soviet Union, we use Campbell's figures [3] for 1975–78 and his dollar-ruble conversion ratio for 1976 and 1977. See Campbell [2].

There are several important problems in these data. For one thing, unsponsored research by U.S. faculty members is omitted. According to the National Science Foundation [19], about 16 percent of engineering research in universities was unsponsored in 1978, as well as about 22 percent of research in the physical sciences, 13 percent in the life sciences, and 16 percent in the environmental sciences. Thus, to take account of unsponsored research, the American figure should be increased. Also, some spending by states on research at state universities, if it is not designated as research, is omitted. On the other hand, Japan counts all of its university teaching budget as academic research, which means that its figure for university R&D is too high. See *Science*, 2 October 1987. According to experts in the field, there is no reason to believe that the OECD figures for all member countries as a whole are biased downward.

Martin and Irvine [16] have made a careful study of academic research financed by government in France, Germany, Japan, the Netherlands, the United Kingdom, and the United States. Including estimates of unsponsored research by faculty members, they estimate the amount that was spent on academic research financed by general university funds and academic, separately budgeted, research in these six countries in 1975. Since these countries account for about 86 percent of all OECD academic research, according to the OECD data, a reasonable estimate of the OECD total academic research supported by government in 1975 is their figure divided by 0.86. Including the Soviet Union, the total (excluding psychology, social sciences, vocational studies, and humanities) provides no indication that our estimate of C is on the low side.

Nonetheless, even if our estimate of C were 25 percent too low, our results would not be changed, except in detail. The social rate of return is 25 percent (rather than 28 percent, as shown in table 4). Neglecting the benefits to users from new products, the social rate of return is 8 percent (rather than 10 percent, as shown in table 4).

That is,

$$X = \sum_{t'=1982}^{1985} B(t')/4 = \sum_{t'=1982}^{1985} \sum_{j=0}^{3} B(t', j)/16, \tag{3}$$

where $B(t', j) = \Sigma_i b_{ij}$. (That is, $B(t', j)$ is the sum of the social benefits in year $t'+j$ accruing from the new products and processes commercialized in year t' that were based on recent academic research.) Under this conservative assumption, the sum of the social benefits during 1985 of all of the new products and processes first commercialized in 1982–85 that were based on recent academic research is:

$$B_{85} = \sum_{t'=1982}^{1985} B(t', 1985 - t'). \tag{4}$$

Assuming for simplicity that the effects of j on $B(t', j)$ are independent of those of t' on $B(t', j)$, [25] we can approximate X by $B_{85}/4$. (Note that X, like C, is in 1985 dollars.)

As is well known, the social benefits from a new process consist of the savings to the innovator plus whatever net benefits accrue to others, and the social benefits from a new product consist of the increased gross profits (cash flow adjusted for effects on displaced products) of the innovator plus the net benefits to users. [26] To make a conservative estimate of B_{85}, we begin by adding the savings from the new processes in the left-hand column of table 2 to the gross profits (cash flow adjusted for effects on the profits of displaced products) from the new products in the left-hand column of table 2. [27] However, this figure must be adjusted for three reasons. First, we have assumed that the investment in academic research resulted in no social benefits from the new products and processes developed "with substantial aid" from recent academic research. In fact, it seems reasonable to assume that at least half of these new products and processes would not have been developed (without substantial delay) in the absence of academic research. Thus, half of the savings from the processes and gross profits from the products in the right-hand column of table 2 are added to the above figure. [28]

Second, we have assumed that only American firms enjoy savings and profits from innovations based on academic research. Even in the 1960s, when America was far more dominant technologically than in 1982–85, the National Science

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[25] Put differently, we assume that the changes over time (during the first 4 years) in the sum of the social benefits accruing from the new products and processes commercialized in year t' (that were based on recent academic research) are the same, regardless of whether $t' = 1982$, 1983, 1984, or 1985. In other words, if we constructed an annual social benefits curve (like that in fig. 1) for the sum of all innovations commercialized in 1982, its slope (for number of years $= 0, \ldots, 3$) is assumed to be the same as for innovations commercialized in 1983, 1984, or 1985. This assumption seems to be a reasonable first approximation. Without much more detailed data (which do not presently exist), some assumption of this sort must be made.

For a simple case where the effects of j are independent of those of t', take the situation where $B(t', j) = f(t') + g(j)$. Under these circumstances, it follows from equations (3) and (4) that

$$X = \bar{f} + \bar{g}, \tag{5}$$

and

$$B_{85} = 4(\bar{f} + \bar{g}), \tag{6}$$

where

$$\bar{f} = \sum_{t'=1982}^{1985} f(t')/4$$

and

$$\bar{g} = \sum_{j=0}^{3} g(j)/4.$$

Obviously, $X = B_{85}/4$, which is the point made in the text.

[26] For a much more detailed and complete discussion of the measurement of the social benefits from a new process or product, see Mansfield et al. [13].

[27] As explained in Mansfield et al. [13], gross profit—that is, profit without depreciation being deducted—is the relevant concept here. To estimate gross profit, we multiplied the estimated 1985 sales of the products that could not have been developed without recent academic research by the average ratio of gross profit (net profit plus depreciation) to sales in 1985 in the relevant firms, the latter ratio being obtained from the firms' accounting records. Next, a rough adjustment was made to allow for the fact that the new products' profits were partly at the expense of older products (sold by other firms as well as by the innovators) they partially or entirely displaced [13]. Based on interviews with company executives, the resulting gross profit figures are reasonable, but rough.

[28] Here too we assume that there would be an 8-year delay in the absence of academic research. To see what the effects would be if we made the even more extreme assumption that academic research resulted in no social benefits from the new products and processes developed "with substantial aid" from recent academic research, see table 4.

Foundation [20] estimated that American firms carried out only slightly more than half of the major innovations in the leading OECD countries. Based on this and more recent evidence, [29] it appears that a conservative estimate of the worldwide savings and gross profits in 1985 from new products and processes first commercialized in 1982–85 that were based on recent academic research would be double the American figure obtained in the previous paragraph. (Note that, even if we were to assume that they were only 1.5 times the American figure, our results would change relatively little.)

Third, we have assumed that new products and processes based on recent academic research result in no social benefits other than to the innovator, which is ridiculously conservative. [30] For the product innovations in Mansfield et al. [13], the benefit to users during the first four years after their introduction was about eight times as great as the gross profit from these products, even though in some cases we must ignore the effects on the profits of displaced products, thus reducing the ratio of benefits to users to gross profit. [31] (For the product innovations in Foster Associates [6]) and Nathan Associates [17], the ratio was even higher.) Based on a small random sample of academic-research-based innovations, this 8-to-1 ratio seems to be too low. [32] Nonetheless, we make the seemingly conservative assumption that this ratio prevails for new products. [33] For new processes, we ignore social benefits other than to the innovator.

The resulting estimate of X, together with our estimate of C, implies that the estimated social rate of return—that is, the value of i in equation (2)—is 28 percent. Of course, the roughness of this figure should be emphasized, but it is noteworthy that the estimated rate of return is so high, given the many ways in which it has been biased downward. Among other things, we have ignored: (1) the social benefits from innovations based on academic research in all industries other than the seven in table 1; (2) the increases in annual social benefits from innovations based on academic research after their first four years of commercialization; and (3) the social benefits from innovations based on academic research findings that are commercialized more than 15 years after the findings or that are introduced by non-major firms.

Moreover, as shown in table 4, the estimated rate of return is 23 percent, even if we exclude all social benefits from innovations developed with substantial aid from academic research. Going to an even more conservative extreme, the figure is

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[29] According to the National Science Foundation [18, p. 203] the United States carried out 39 percent of the industrial R&D in these industries in seven countries (Japan, Germany, the United Kingdom, France, Canada, Italy, and the United States). Since many countries, including the Soviet Union, are omitted, the percent of world R&D must be well below 39 percent. According to Gellman's data [7], the proportion of innovations based on academic research in other countries (Canada, France, Germany, Japan, and the United Kingdom) was an high as in the United States, and the average time lag was not significantly different.

[30] For a description of methods to estimate the benefits to users, see Mansfield et al. [13]. Even without the work of the past decade or so, it is obvious that the exclusion of the benefits to industrial and individual users results in a gross under-estimate of the social benefits, since the benefits of new products are passed on (in substantial measure) to users (including consumers).

[31] This pertains to the first 4 years after commercialization, which is the period used here to estimate benefits. One reason why the ratio is relatively high is that profits often are lower than in later years.

[32] Because the direct estimation of the benefits of an innovation to users is a very laborious and expensive process, we have had to limit this part of our study to ten new products in these industries that were based on recent academic research. These products were randomly chosen. In every case, the ratio of the benefits to users to the innovator's gross profit (in the first four years after the product's introduction) exceeded 8. These results, taken in combination with the findings of Mansfield et al. [13], Foster Associates [6], and Nathan Associates [17], which provide detailed estimates for about 40 new products, seem to provide substantial evidence that the 8-to-1 ratio is conservative.

[33] It would be preferable, of course, to make direct estimates of the benefits to users, rather than to make crude estimates based on this ratio, but existing resources do not permit such an ambitious undertaking. In table 4, it is shown that the estimated social rate of return is 10 percent even if the benefits to users are assumed to be zero. Thus, even if this ratio were too high, the rate of return would still be substantial.

Note too that we ignore the benefits to imitators of new products based on recent academic research, as well as the benefits to customers of firms that carried out process innovations based on recent academic research. These benefits can, of course, be considerable.

Table 4
Estimated rate of return from worldwide investment in academic research in 1975–78, based on alternative assumptions

Assumption	Rate of return (%)
Including half of innovations developed with substantial aid from academic research	
Including estimated benefits to users from new products	28
Excluding benefits to users from new products	10
Excluding all innovations developed with substantial aid from academic research	
Including estimated benefits to users from new products	23
Excluding benefits to users from new products	5

Source: See section 6.

10 percent (not excluding all social benefits from innovations developed with substantial aid from academic research) or 5 percent (excluding all social benefits from innovations developed with substantial aid from academic research), even if we ignore all social benefits to users from new products based on recent academic research.[34]

7. Conclusions

Because the results of academic research are so widely disseminated and their effects are so fundamental, subtle, and widespread, it is difficult to identify and measure the links between academic research and industrial innovation. This paper presents, apparently for the first time, data concerning the percentage of new products and processes that, according to the innovating firms, could not have been developed (without substantial delay) in the absence of recent academic research. Since these data were obtained from key technical and managerial personnel of the innovating firms, they merit attention, although they, like other such survey data, are rough and contain sampling errors.

Our findings suggest that about one-tenth of the new products and processes commercialized during 1975–85 in the information processing, electrical equipment, chemicals, instruments, drugs, metals, and oil industries could not have been developed (without substantial delay) without recent academic research. The average time lag between the conclusion of the relevant academic research and the first commercial introduction of the innovations based on this research was about 7 years (and tended to be longer for large firms than for small ones). A very tentative estimate of the social rate of return from academic research during 1975–78 is 28 percent, a figure that is based on crude (but seemingly conservative) calculations and that is presented only for exploratory and discussion purposes. It is important that this figure be treated with proper caution and that the many assumptions and simplifications on which it is based (as well as the definition of a social rate of return used here) be borne in mind. While interesting, it is by no means a full or satisfactory solution to the long-standing—and extraordinarily difficult—problem of evaluating the payoff to society from academic research. It is at best a very crude beginning.

Nonetheless, our results provide convincing evidence that, particularly in industries like drugs, instruments, and information processing, the contribution of academic research to industrial innovation has been considerable. Needless to say, this does not mean that other inputs like industrial research, plant and equipment, labor and management have not been important as well. But whereas the contribution of these other inputs generally is taken for granted, the role of academic research sometimes has been regarded as far more questionable. Our results, while they do not address the very difficult question of how to allocate the social returns between academic and industrial research, indicate that, without recent academic

[34] There are sampling errors in the estimated rates of return in table 4. Since our sample was randomly chosen, rough estimates can be made of these sampling errors. Because there is considerable variation among firms and because the sample size in some industries is quite small, the figures for individual industries in table 2 contain very large sampling errors. However, what is important here is the sum of the industry figures for savings from new processes plus gross profits from new products. If we include half of the innovations developed with substantial aid from academic research, as well as the benefits to users from new products, the probability is 0.975 that the rate of return exceeds 15 percent, based on the assumptions in the previous section. Note too that the estimates by Mushkin [26] of the social rate of return from biomedical research are about 50 percent, which exceed those in table 4.

research, there would have been a substantial reduction in social benefits. This really is what the estimated social rate of return, as defined above, is saying.

To prevent misunderstanding, it may be worthwhile to conclude by recognizing that the rationale for academic research extends far beyond the sorts of narrowly defined economic benefits considered here. Obviously, knowledge concerning the universe is important for its own sake, and the education of students, which occurs in many academic research projects, is socially important as well. Nonetheless, it is interesting to find that, even if academic research is judged in these relatively restricted terms, its role seems to be substantial.[35]

[35] It should also be emphasized that our results do not rest on the so-called linear model of innovation, which assumes that universities first perform basic research, the results of which are transferred to industry, which in turn does the development leading to the innovation. As is well known, this linear model is often violated. For example, academic research frequently occurs in response to R&D carried out, and problems encountered, in industry. Our analysis in no way assumes that the linear model is true. It is just as valid if the relevant academic research is in response to industrial research.

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Fraunhofer Institute
Systems and
Innovation Research

Hariolf Grupp[*]
Shlomo Maital[**]

[*] Fraunhofer Institute for Systems and Innovation Research, Breslauer Str. 48,
D - 76139 Karlsruhe, Germany, Tel. +49 721 6809156, Fax +49 721 6809176,
e-mail GRU@ISI.FHG.DE
[**] S. Neaman Institute for Advanced Studies in Science and Technology, Technion
- Israel Institute of Technology, Haifa 32000, Israel, Tel. +972 4 8294500,
Fax +972 4 8235194, e-mail ierms01@techunix.technion.ac.il

Interpreting the Sources of Market Value in a Capital Goods Market: R&D Management in Industrial Sensors

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Abstract

This paper presents an integrated model for evaluating purchasers' perceptions of science-based products. 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 for the demand orientation is proposed, which shows the extent to which a product's „supply" of characteristics matches the „demand" for them in the market place. The model is illustrated using several types of industrial pressure sensors. The paper also demonstrates how the integrated model may be made effective for quality function deployment (QFD) during the R&D phase.

1 The sensor market as an innovation and quality strategy assignment

Companies working on innovations on a particular market tend to have commonality of scientifico-technical opportunity and, because of the specific nature of the technology concerned, the resulting potentiality for appropriation of innovation rents, see, e. g. Cohen (1995). This paper tries to examine the sensor market, a „conventional" market with monopolistic competition in which knowledge generation is largely uncoloured by state influence. It features both large and small companies, universal and special suppliers. At the same time it has something to do with modern science and is a market for capital goods.

The sensor market has been expanding over the last decade; characteristic growth rates for sensor sub-markets are between 10 and 30 per cent. The world market for sensors is currently worth over 5 thousand million US $ per annum; methods of calculation and the estimates however deviate very widely. By the year 2001, as Arnold (1991) notes, growth rates are expected to be 8 per cent per annum; the 2001 market volume could be 43 thousand million (43 US Billion) $. The uncertainty over sensor estimates stems directly from arbitrary drawing of sensor demarcation lines: Should supply lines, decoding electronics or calibration units be included or excluded? The price of a complete sensor system can deviate from that of the sensor element contained in it by one order of magnitude.

The sensor market is highly *segmented.* An overview by Grupp et al. (1987, p. 234) lists nigh on 90 measurands for which sensors are available commercially or which are in process of development. The number of types of sensors (in terms of product variants) however is clearly even larger since for each measurement parameter there are several if not many measurement processes available. Internationally, currently a total of approximately 10,000 different types of sensor are on offer; the number of brands is incalculable. In OECD countries, there are approximately 2,000 potential suppliers of sensors, most of whom are offering their own products.

Marked segmentation of the sensor market imposes one prime requirement on the R&D management of innovators: they must be stronger than others in *systematic early warning functions* and set up a strategic technology management. This is a defining parameter specific to the sensor industry and common to innovation behaviour in the intersectoral comparison. It would therefore seem apposite, prior to analysing technical properties (Section 4) and demand preferences (Section 5), to set out one or two general considerations for technology management. According to the above analysis of the basic structures of the sensor market, the corresponding technology management in the intersectoral comparison is problematical from both aspects: technological analysis, owing to the many technical processes and measurement parameters used for sensors is just as complex as formulating a competitive quality strategy taking segmented markets into account.

2 A new benchmarking concept

At the beginning of the eighties a series of „metrics“ for evaluating and comparing technological sophistication and quality were proposed. What was coined „technometrics“ in 1985 is a procedure designed along Lancaster's (1991) consumer theory and is based on the observation that every innovative product or process has a set of key attributes that defines its performance, value or ability to satisfy customer wants. Each of these attributes has a different unit of measurement. Problems then arise in aggregating attributes to build a single quality index. Mathematical details of the general procedure are not discussed here as they may be found in Grupp (1994). Suffice to say that 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 at a given point in time. The preferences may be derived from utility functions, by introspective or market observation, from expert knowledge or via hedonic prices.

When conducting a technology-oriented competition survey, a relative competition analysis is recommended, cf. Backhaus (1992, pp. 135 onwards) or Shillito (1994, p. 52 onwards). Usually, this is done by assessing the own position by reference to those of the relevant competitors. Owing to the lack of suitable metric data, competitor information is graphed qualitatively (e. g., „low“ versus „high“). The technometric indicator is available, in competitor analysis, as a substitute for qualitative scales if the corresponding data are available from the rival company.

From competitor observation, portfolios can be compiled which just like financial business portfolios tend to be referred to in R&D management circles as *technology portfolios*. The use of portfolio procedures for technology evaluation is considered the best method in the field of corporate R&D management, see, e. g., EIRMA (1985, p. 27). In view of the few comments that can be made about industrial technology management, product quality measurement is still the final resort. The latest keyword of „benchmarking“ is nothing other than the systematic comparison of the quality of products and services of a company in relation to those of the leading competitors, following Camp (1989) or Shillito (1994). Interest in benchmarking has grown enormously over the last 10 years. Technometrics applied in business management is nothing more than standardisation of product quality in terms of technical properties. Even now, technometric procedures still do not feature in benchmarking literature. First applications may be found in Shoham et al. (1996).

3 Data on technical characteristics of pressure sensors

In this Section, the problem of pricing of technically valuable goods and the effect of technical characteristics is tackled. The sensor market is thus regarded as a market with free and floating prices dictated by supply and demand factors. The first step must be to itemise the most important technical properties of sensors and then extract a selection from the wealth of conceivable measures. Koschatzky and others (1996) in a wide-ranging empirical survey were concerned primarily with pressure and temperature sensors (in addition to those for measuring acceleration, force and relative humidity). The inquiry related to earlier technometrics by Grupp et al. (1987) on sensors which reflected the 1986 market.

The primary data analysis thus involves large-scale gathering of exhibition material at the largest sensor fair in the world where not only exhibits, as is customary, are displayed but also specification sheets with the appropriate data.[1] Quite apart from the field survey conducted other companies were consulted so that in all 286 companies were approached in one way or another. Of these, 151 yielded comparable detailed information. Koschatzky and Frenkel (1996) also conducted 10 personal interviews with Israeli companies so that in all data from 160 sensor firms was obtained. When considering the breakdown of companies according to country, it should be remembered that European and primarily German speaking countries predominate since the fair in this year took place in Germany. Apart from companies from the United States and Israel, however, Japanese companies were also represented in the random sample.

The technical properties selected and compared were established by specialist discussions in the earlier investigation of the sensor market. In so doing, it became apparent that different specifications are important for different measuring principles and tasks. To illustrate the data, in this chapter only pressure sensor analysis is spotlighted. Conceptually, if four products are deliberately chosen from the databank and the technometric indicators calculated, then a technological or characteristic profile will be obtained as per Figure 1. In such case, it should be noted that for certain products, isolated numerical values are missing (not divulged by the manufacturer).

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[1] This is the SENSOR Fair which took place in May 1991 in Nuremberg.

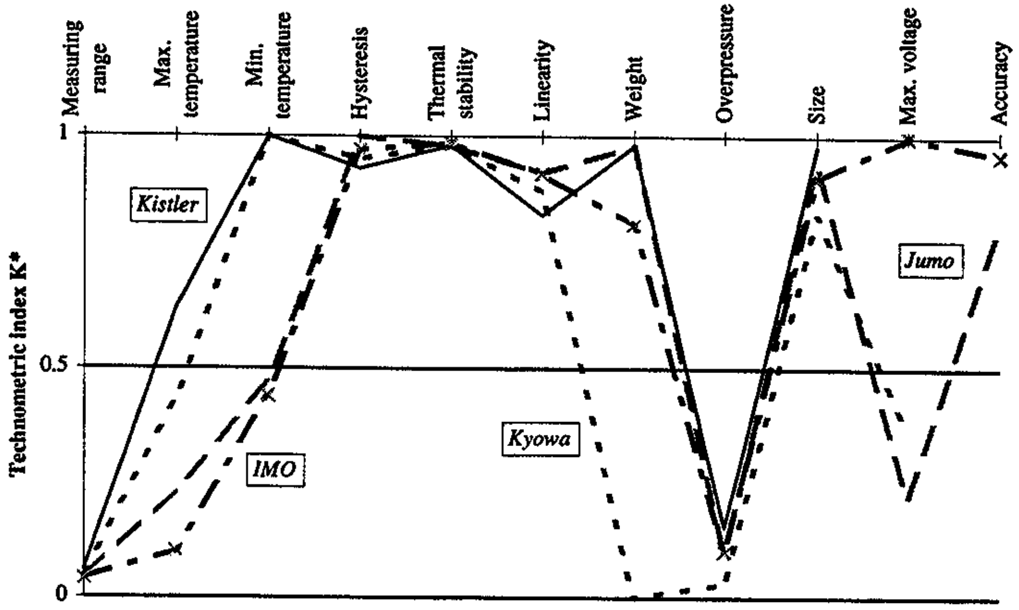

Figure 1: Technometric characteristic profile of four selected pressure sensors (1991).

4 Technical quality and hedonic prices

For the sensor market, which, according to the assessment in Section 1, can be construed as being functional, i. e. intensively competitive and efficient, an empirical relationship should be discernible between the quantitatively measured attributes of the product and product prices. It should be possible to solve the problem by multiple linear reggression (OLS), the dependent variable being market price and the independent variables being product properties. Thus, the absolute values of the coefficients show what value the market assigns to this property. The proposed approach has been considered sporadically in R&D management literature here and there as far back as the 60's and linked to the hedonic price concept, see Griliches (1961, 1971) and Chow (1968). The new literature encompasses Saviotti (1985), Trajtenberg (1990) and Dorison (1992).

In the regression analysis, it was felt expedient to omit sensors with many missing data. The hedonic price determination therefore related to 68 sensors and eleven properties. The regression calculation can account for precisely half of the variance ($R^2 = 0.50$). This is open to different interpretations depending upon viewpoint. On the one hand, this means that half of the price variation alone is explicable in terms of the physico-technical properties of the products. On the other hand, likewise one half is attributable to price variance which cannot be explained in terms of quality improvement but relies on the manufacturer's reputation or upon various marketing endeavours on service, maintenance, established practices or can be traced back to other preferences.

Of the eleven variables only two are significant. They originate from application of stepwise regression in which explanatory variables are arranged (according to an F - test) in order of their ability to raise the variance explained. The maximum coefficient occurs for the variable for maximum temperature; it is almost twice as great as the next largest coefficient for the weight. It can therefore be assumed that the maximum contribution towards price elucidation is made by the *maximum temperature* and *weight* of the sensor. These are the two decisive quality variables. Interestingly, both variables, on their own, virtually account for the entire quality-dictated price variance ($R^2_{adj} = 0.46$ in comparison to $R^2 = 0.50$ for all variables).

The hedonic price investigation for pressure sensors reveals that of the eleven technical properties two account, straight away, for the quality-determined part of sensor pricing, in all practically half of the price variation. The maximum permissible temperature has a direct bearing on the application potential in the industrial field. The supposition that lightweight versions would be among the most important consumer preferences does not hold. Higher prices are currently commanded by heavier weight sensors on the sensor market. This is presumably connected with the idea that the heavier units are more durable and can assimilate greater stress under extreme conditions.

The findings confirm the Lancaster (1991) new consumer theory according to which prospective customers are not interested in the goods as such but in their properties. From the sensor market analysis, this comment can be extended to: *„a particular handful of properties"*. It has thus been shown that for pressure sensors in 1991 questions of material saving or use of lighter materials are still not considered to be prime characteristics although this is generally postulated in literature for technical advances in sensors. Clearly, the properties associated with heavier units take precedence (durability, stability, etc.). A particularly lightweight sensor produced at high production costs which in all other respects does not differ from rival products commercially will not succeed in defraying the higher production costs. The only advice that could be given to a particular company which is bent on precisely this innovation is to „tune into the market" and at any rate so long as the demand for dearer lightweight sensors continues to be inadequate to refrain from embarking on a corresponding innovation venture. The use of hedonic prices in connection with technometrics appears to be a valuable analytical instrument for microeconomic as well as for business management use. Admittedly, there are more direct ways in establishing demand preferences which will be discussed in the next Section.

5 Preferences voiced by prospective industrial clients

It is possible to amass information about purchasers' preferences by direct market research. This is the usual and commonest way in practice for missing blocks of information to be obtained on free markets. An entire branch of the economy makes a living from this in market research. So, in order to include „appropriate" data on demand preferences in this context, here, too, a direct market survey has been conducted, see Frenkel et al. (1994). This was done by asking the purchaser of industrial sensors, via a questionnaire, to rate the importance of technometrically determined properties of sensors according to their importance on a scale of between 0 and 10. The same questionnaire was also handed out to sensor manufacturers (R&D personnel, production manager, sales manager) in order to establish the preference rating of their industrial clients as perceived by the manufacturer.

Table 1 shows that, of the 22 quality properties examined, eleven are known from the technometric investigation whilst a further eleven were not considered important to the inquiry. The choice of technometric characteristics was made with the help of the R&D personnel of manufacturers having coherent ideas about the important technical features of their innovative products from the dominant technical design standpoint. From these assessments, sales and marketing departments formulate the corresponding specification sheets which they offer to their customers in the context of general business relationships and supply at fairs, for example. In expert circles, the other eleven properties are to some degree contentious, as far as their importance is concerned, or only represent the individual opinions of outsiders. In some respects, they have been designated by individual prospective clients as „unfortunately defective" in the specification sheets.

Table 1 shows two different things:

- in fact the preferences mentioned for technometric specifications are higher than for the rest,

- and what is perhaps even more interesting, the variances in regard to technometric characteristics are smaller than for the rest.

For the 72 products chosen from eleven innovative companies in six countries which were analysed in greater depth in Section 3, it can be tested to what extent the technical quality of these products is in accordance with the disclosed demand preferences. This is based on the assumption that an efficient company with a good database on demand requirements sets greater store by highly preferred technical features which are reflected in a correspondingly high technometric index. With a view to arriving at a compromise between factor costs and mutually exclusive technical specifications the assumption must be made that the technometric indices for the properties less prized by the prospective purchaser (or as above, the more ambiguous ratings for the entire sub-market) are not endowed with correspondingly high quality. The technometric index must then be correspondingly lower.

Table 1: Comparison of demand preferences for pressure sensors sub-divided into technometrically relevant and irrelevant properties (N = 50).

No	**Characteristics**	**Average importance**	**Standard error**
	Technometric properties:		
1	Hysteresis	0.915	0.114
2	Accuracy	0.894	0.151
3	Linearity	0.868	0.157
4	Measuring range	0.715	0.370
5	Overpressure	0.711	0.312
6	Maximum ambient temperature	0.702	0.226
7	Minimum ambient temperature	0.692	0.233
8	Thermal stability	0.656	0.345
9	Size	0.600	0.272
10	Maximaum supply voltage	0.483	0.288
11	Weight	0.417	0.276
	Average	0.696 ± 0.151	0.249 ± 0.082
	Other properties:		
1	Repeatability	0.909	0.102
2	Response time	0.843	0.179
3	Sensitivity	0.764	0.256
4	Output signal	0.556	0.344
5	Minimum supply voltage	0.500	0.283
6	Insulation resistance	0.464	0.306
7	Resonant frequency	0.417	0.339
8	Bridge resistance	0.338	0.283
9	Maximum storage temperature	0.334	0.208
10	Minimum storage temperature	0.334	0.208
11	Output impedance	0.329	0.307
	Average	0.526 ± 0.206	0.256 ± 0.071

If the technometric profiles are compared to the requirement profiles using the numerical values in Table 1 (taking only the technometrically relevant part of the assessments into account), then an index can be calculated for the *demand orientation (DO)* from the mean quadratic deviation of both profiles.

By way of illustration, let us look at the best and worst sensor as oriented to demand wishes (Figure 2). The Kyowa (Japan) pressure sensor displays technometric specifications which in terms of the three most important properties (from the demand standpoint) are outstanding, but it is no longer appropriate for „average“ preferences. In the next ranking properties, this sensor displays moderate qualities which consumers might accept. Of the 72 products chosen, this unit was the best match to demand requirements, at least, in regard to the most important features.

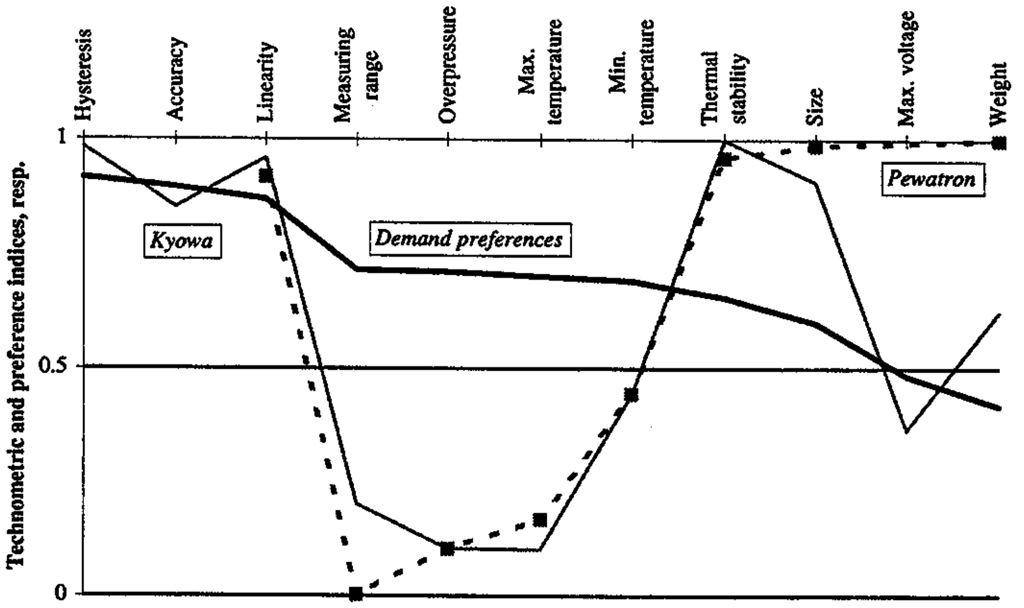

Figure 2: Revealed demand preferences and technometric profiles for two chosen pressure sensors (the technical property configuration shows preferences in decreasing order).

The reverse applies to the Pewatron pressure sensor whose best technometric characteristics materialise in the midst of those properties which users would put at the bottom of the list. This sensor shows high quality in regard to the less important properties. Also worth noting is the fact that the corresponding specifications in regard to both most important characteristics are hardly mentioned by the would-be supplier and might therefore be unknown to the user. This does not appear to be any general corporate marketing strategy because the corresponding data on hysteresis were produced properly for sensors other than the one considered here, from the same manufacturer. Figure 2 gives a visual impression of the technical quality dimension of the two contrasting products in regard to demand preferences, and thus refers to a method Pugh (1990) has described earlier. Whereas in a Pugh matrix scores are being used, here metric scales are involved.

6 Conclusions

Whether the empirical findings proposed hitherto can be corroborated via larger random samples remains to be seen. Against the background of general market equilibrium, a proportion of the resource costs must be attributable to information procurement as it promotes the new microeconomics. As far as that goes, the justified hope remains that the technometric findings for the sensor market can be substantiated by further projects and are not a random event. For QFD, starting points to improve the quality of products under the new technical paradigm can immediately be derived from the technometric portfolio.

In the *R&D management context,* the technometric benchmarking acquires additional importance in identifying niches on capital goods markets. Validation with the aid of market surveys shows that the approach is valid; the characteristics contained in the technometrics index are deemed more important to some prospective purchasers than others. In this respect, this paper can also be viewed as an extension of the common benchmarking literature with relevance for quality function deployment (QFD).

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