NEUTRALITY IN SCIENCE POLICY: THE PROMOTION OF SOPHISTICATED INDUSTRIAL TECHNOLOGY IN ISRAEL*

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This paper provides a review of Israel's science and technology policy and traces the growth and development of technology intensive industry in that country. Such policy has generally been neutral with regard to industry, technological field or class of product; concentrates on industrial R & D directly performed in industrial firms; and is an integral part of overall national industrial policy — being centred in the Ministry of Industry and Commerce. Drawing upon case studies and other statistical evidence, the paper argues that such policy has been partly responsible for Israel's success in building up an indigenous, export-oriented, high technology sector.

Keywords: science and technology policy, industrial R & D, high technology industry, Israel

The current system of promotion of industrial research and development in Israel began in 1967 with the establishment of the Industrial Research Fund in the Ministry of Commerce and Industry. The objective of this fund was to subsidise civilian research and development performed in the industrial sector, without any explicit preferences for any particular industrial branch, technological area or class of product. A flat subsidy of 50 per cent of all expenditures on research and development by the firm making the application was granted to all projects submitted to the Ministry and fulfilling a set of minimum requirements. These originally involved proof of technical feasibility and account was taken of the reputation of the scientists and engineers involved; only later on and gradually was information on the state of the market and the likely competitors required for approval. At present, there are requirements of a minimum of satisfactory answers to 22 questions in the applications to the Ministry for grants. These questions deal with the marketing and other capacities of the firm and with its marketing plan.[1]

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The original minimal requirements did not explicitly affect approval of grants in favour of any particular branch, product or technology, at least during the first decade of existence of the system. Thus, the system of support for industrial technology was at least formally neutral in this respect during that period.

GENERAL EVOLUTION OF THE SYSTEM OF RESEARCH AND DEVELOPMENT IN ISRAEL[2]

The emphasis on science and research is deeply rooted in the history of Israel, since the arrival of the first immigrants from Eastern Europe in the last quarter of the nineteenth century. At first, the emphasis was on applied research oriented towards solving concrete problems confronting the new society, e.g., epidemiological research, and research in agriculture; the first agricultural experimental research station was established in the early years of the twentieth century. A more varied picture emerges from the period of the Mandate, from 1918 to 1948, when the main institutions of scientific research were established: these were the Hebrew University of Jerusalem, the Technical University of Haifa (The Technion), the Agricultural Research Station of Rehovot and the Ziv Institute of Science, which later became the Weizman Institute. Scientific activities during the period of the Mandate were mainly concerned with the study of characteristics of the land — climate, soil, water resources — plant and animal life, plagues and illnesses, geography and geology. Basic research, conducted in accordance with the Western tradition of academic freedom, and agricultural research, achieved a high level relative to the standards of the period.

There was practically no industrial research, except for some connected with the Dead Sea Works. After Independence, Prime Minister D. Ben-Gurion himself headed the Research Council founded in 1949; its objective was to extend further the institutional structure of scientific work in Israel. The new government established a number of governmental research laboratories during the 1950s, for example, the Fibers Institute, the aim of which was to support the textile industry being developed to provide employment to the more than half a million Jewish refugees from Arab countries, and the national Physics Laboratory. It also established several new universities — Tel-Aviv, Bar Ilan, Negev — and founded other institutions such as the National Council for Research and Development (NCRD) in 1959 and the Israel Academy of Sciences in 1961.

By the mid-1960s, institutional arrangements for scientific work were well under way; additional efforts were made to reinforce existing institutions rather than to establish new ones. This period shows also the first attempts at a more systematic approach towards research and development. Thus among the objectives of the National Council for Research and Development we find planning governmental policy towards research and development and defining 'national research needs' in various fields. The most significant event, however, was the nomination in 1966 of a committee for the organisation and administration of government research — the Kachalsky committee. The committee's recommendations were: that bureaux of chief scientists be created in ministries such as the Ministry of Commerce and Industry in order to co-ordinate their activities in research and technology and to stimulate applied research; that the governmental research institute be reorganised into three research authorities, each headed by the chief scientist of the corresponding ministry, e.g., the Ministries of Agriculture, Commerce and Industry, and Development; that the National Council for Research and Development be organised in a way which would enable it to perform such functions as the design of a national policy for research and development, to deal with scientific manpower and to co-ordinate the activities of the various chief scientists.

The first of these recommendations was the most significant since it led to substantial increases in applied research and development, especially in industry by means of the Industrial Research Fund of the Ministry of Commerce and Industry. The 50 per cent rate of subsidy of all approved projects in research and development was not part of any law or regulation governing the functioning of this fund, which was probably viewed as a scheme that was simple to administer and involved a reasonable distribution of the resources for research and development between governmental and industrial firms. The Kachalsky committee's last recommendation was not carried out; each ministry in fact acted independently, with the total government budget for research and development being simply the total of the budgets for research and development of each ministry — each being part of the total budget which the individual ministries negotiated with the Treasury. The magnitude and structure of civilian research and development does not seem to be the result of an explicit policy framed in quantitative terms.

THE PROMOTION OF INDUSTRIAL RESEARCH

Until the mid-60s, almost no civilian research and develoment was conducted in private industry in Israel and there was no governmental support of such research as there was.[3] Most of the existing industrial research was connected with exploitation of deposits of potash and bromine in the Dead Sea.

Two main developments probably account for the emergence of new arrangements for governmental support in 1967. The major institutions and arrangements linking scientific research and technology were already well established. Israeli scientists and engineers were engaged in research in universities, in agriculture and in defence, but around that time it began to become clear that they could also be employed in research and development in private industry producing goods for civilian markets. The other factor which led to the new pattern emerging after 1967 was the realisation that the attainment of Israel's objective of increasing its income from exports required a major shift in the distribution of economic activities. The continued growth of exports could not be achieved by concentration on the exportation of oranges and textiles; existing exports of these products were being threatened by increased competition coming from producers with lower costs. It was necessary to increase the technological or scientific content of products through an increase in the intensity of research and develoment, design and marketing; this was thought to be the only way to overcome the competition based on lower costs. The alternative was to increase the size of plants in traditional industries, but this would have involved too much risk, given the small size of the domestic markets.

Since sophisticated exports are not an objective in themselves, governmental intervention to promote the underlying industrial technology can only be justified in terms of some kind of 'market failure' in the production of such goods. Technologically sophisticated exports require the development of a set of investments in at least a minimum of organisations, and manpower for research and development. Governmental support can easily be justified in terms of the unpriced benefits which any private firm undertaking such investments would provide — positive 'externalities' — to other firms or users. Another reason for governmental support of this investment in organisation and staff for research results from the fact that capital markets were imperfect in the period considered. Japanese policies directed to similar ends included the subsidy of costs of penetrating certain export markets.[4]

The first chief scientist was a university professor with a background in medicine and research. His work included research on cancer. The second chief scientist was a former army officer with a degree in engineering who had previously headed the department of research and development of the Ministry of Defence. His experience in linking research and development performed in the defence sector to the needs of the armed forces was probably responsible for the increased emphasis given to the market and to marketing by the Office of the Chief Scientist in approving projects. Another factor was the accumulated collective experience showing the critical role of these facts in the commercial success of technological innovations. The main features of the system of promotion of industrial technology, which affected its subsequent performance, were its adherence to a policy of neutrality with respect to branch of industry, technological field or class of product; and its concentration on the support of civilian research and development directly performed in industrial firms. Its location in the Ministry of Commerce and Industry made it an integral part of general industrial policy.

REVIEW OF PERFORMANCE OF RESEARCH AND DEVELOPMENT IN CIVILIAN INDUSTRY

The main trend in civilian research and development in the natural sciences and engineering in the first years of the new policy was a very significant increase in total expenditure on civilian research and development from $34 million in 1965 to over $230 million in 1978. There was an almost threefold increase in the share allocated to civilian research and development performed in private industry out of total expenditure on such activities. This share rose from 11 per cent in 1966 to 43 per cent in 1978 (Table 1). Expenditure on civilian industrial research and development rose from $12 million in 1969 to $75 million in 1977 (in current dollars). The number of qualified scientists and engineers in research and development rose from 886 in 1969 to over 3,000 in 1981 (Table 2).

The growth in civilian research and development carried out in industry is partly accounted for by the growth of support by the government. The share of governmental expenditure in the total expenditure on civilian industrial research and development rose from 16 per cent in 1966, before the establishment of the new system, to 32 per cent in 1975; other figures show an increase from 13 per cent in 1971 to nearly 50 per cent in 1979. The grants of the Ministry of Commerce and Industry rose from $1.2 million to $32 million in 1979 (Table 3). In 1969, there were 210 industrial establishments performing civilian research and development (Table 4). The numbers fluctuated considerably during the next six years without any significant net growth, attaining a maximum of 228 in 1975. There was a significant growth in numbers after 1975, reaching about 500 or more industrial establishments performing research and development in 1980.

The results of this expansion of activity in research and development in private industry may be seen in the figures on exports from this sector. We are at present in no position to undertake a realistic analysis of costs and benefits of the introduction and development of the Israeli system of promotion of industrial technology. Exports from the industrial sectors utilising sophisticated and intensive research and development, such as electronics, transportation equipment, chemicals, metal products, machinery, and rubber and

TABLE 1

Civilian Research and Development Expenditure on Natural Sciences and Engineering, including Agriculture, Mathematics and Medicine

Year	Total	Distribution of all expenditure among institutions conducting research and development[a]			Governmental share in expenditures		
		Industrial firms	Academic institutions	Govern-	Total research and development[b]	Research and development conducted in: Industrial firms	Research and development conducted in: Academic institutions
	(Current US$ in millions)	(Percentage)			(Percentage)		
1965-66	34						
1966	42	11	62	27	51	16	39
1967							
1968							
1969							
1970	70	21	62	17	57	25	56
1971							
1972							
1973	120	19	62	19	59	24	59
1974	127	24	62	14	62	29	66
1975	115	23	59	18	62	32	65
1976	183	35	53	13	56	(61)[c]	
1977	220[d]						
1978	230[d]	43	45	12		(56)[c]	

Sources: *Science and Technology in Israel 1975-76,* National Council for Research and Development, Jerusalem, March 1977; S. Hershkovitz, *Government Allocation to R & D in Israel: 1976-77-1978-79* (in Hebrew), National Council for Research and Development, Jerusalem, February 1980.

Notes:
a Agricultural research and development is performed in governmental laboratories.
b Includes civilian research and development in the social sciences.
c Percentage of governmental funds in total research and development (including military) performed in industry.
d Lower boundaries, assuming share of governmental funds to be 50 per cent.

plastics, which have received most of the subsidies for research and development, have increased very markedly. Exports from projects supported by the Ministry of Commerce and Industry grew from $1.6 million in 1967 to $750 million in 1979 and to over a billion dollars a short while later. This figure understates Israeli exports from industries of high technology because there are exports from these sophisticated industries sectors which are not the result of research and development or of research and development projects supported by the Ministry. There can be no doubt that the composition of both industrial exports and of output changed considerably in the 1970s. Between 1970 and 1980, industrial exports, excluding diamonds, grew at an average real rate of 11 per cent; nominal industrial exports, except diamonds, rose from nearly $400 million in 1970 to over three billion dollars in 1980. In the same period, the share of the technologically sophisticated sectors increased from 40 per cent to 66 per cent (see Table 5). The average annual real growth of exports of sophisticated sectors was 17 per cent during the 1970s while it was only 6 per cent for exports of the conventional industrial sectors.

In 1970 only one technologically sophisticated branch of industry, namely chemicals, was in the first five exporting industries. In 1979,

TABLE 2

Scientists, Engineeers and Technicians in Civilian Industrial Research and Development[a]

Year	Qualified scientists and engineers		Practical engineers and technicians		Total skilled manpower in research and development
	Number	Percentage of all persons employed in industry	Number	Percentage of all persons employed in industry	
1966					
1967					
1968					
1969	886	0.45	671	0.34	1557
1970	1013	0.49	999	0.48	2012
1971	1141	0.51	1124	0.51	2265
1972	1254	0.53	1259	0.54	2513
1973					
1974	1438		1105		2543
1975	1653	0.66	1410	0.56	3063
1976	2052	0.79	1649	0.64	3701
1977	2212	0.84	1669	0.64	3881
1978[b]	(1013)		(987)		(2000)
1979[c]	2600		3200[c]		
1980					
1981	3000[d]				
1982					

Sources:
- a Central Bureau of Statistics, *Survey of Research and Development Industry 1977-78,* Research and Development Statistics Series 13, reprinted from Supplement to *Monthly Bulletin of Statistics,* 11, 1980.
- b Figures for 1978 are full-time equivalents. Data from Office of Chief Scientist, internal sources.
- c From Ministry of Industry, Trade and Commerce, *Industry R & D Opportunities of Israel,* Jerusalem, January 1977.
- d Private communication from National Council for Research and Development.

there were three such industries: chemicals, transport equipment and metal products. The rank of the electronics industry rose from ninth to sixth place. (The data on the electrical and electronics branch underestimates the contribution of all-pervasive electronics technology.) Textiles fell from fourth to eighth place in the 1970s. The rate of growth of output and of the share of output exported was higher during the 1970s in the technologically sophisticated industries than in the more traditional ones. The average share of output exported by the former at the end of the decade of the 1970s was about 45 per cent while that of the traditional exporting industries was only 26 per cent, reversing their ranking of 1970 (see Table 5). The growth of output and exports in industries with intensive research and development since 1967 is sufficiently impressive to justify a presumption that the arrangements for the support of industrial research and development have been successful.

Before proceeding it is important to mention that the founding of a number of firms after 1967 and their success after this date was favourably stimulated by support received from the Office of the Chief Scientist. This was particularly true for electronics firms. Among such firms are Elbit — a minicomputer firm 'spun-off' from the defence sector; Elscint — which initially specialised in nuclear instrumentation generally, then more specifically in nuclear medical technology, and, since 1977, diversified into computerised axial tomography and ultrasound medical instruments; AEL — a partly foreign-owned firm producing microwave components and communication systems; Scitex — a firm developing and producing computer-aided design systems for the textile, printing and electronics industries; Beta Engineering — a firm initially producing specialised instruments for a wide variety of fields ranging from measurement of blood pressure and dental technology to numerically-controlled sewing machines. In the chemical and plastics industry, there were 20 firms active in research and development in 1971. These were concentrated in a few firms, such as Machteshim owned by Histadrut and founded in 1952.

THE NON-DISCRIMINATORY (NEUTRAL) CHARACTER OF THE INCENTIVES

The system of promotion, established in 1967, offered the same rate of subsidy for research and development for all approved projects, regardless of the branch of industry, class of product and technological area. An approved project in textiles would receive proportionally the same grant for research and development as one in electronics. If there was a bias, it was in favour of projects for research and development which might lead to exports; these received a subsidy of 50 per cent, compared to projects which might lead to import substitution which received a subsidy of only 25 per cent. This formal discrimination was not, however, a real one since all projects had to be 'directed' towards exports, as was explicitly stated in the application forms for grants for research and development. Discussions with officials responsible for deciding about the applications for grants in the Office of the Chief Scientist, and an analysis of the share of total grants in the total research and development budgets of projects approved by the Office, support this view of the neutrality of the policy. This share approached 50 per cent, even when a significant number of the approved projects did not in fact lead to exports. Related to this point is the fact that the policy followed in the early years of the system was one of 'force-feeding' of grants — the Office of the Chief Scientist was more interested in increasing the number of firms doing research and development, and in extending the kinds of research and development of firms engaged in them, than in controlling the fulfilment of the specific obligations accepted by the firms, including that of exporting their products.

The policy of neutrality has changed; the change began in 1976. The first major change was the introduction of the National Programmes Scheme which provided for a higher rate of subsidy for research and development than that granted under the scheme then existing. While the new scheme did discriminate among firms — it was open only to firms who had succeeded in the past — it still was neutral with respect to branch. The projects approved had to be relatively large, to involve large risks, and to have a high expected return. Thus, there might have been some, probably justifiable, departures from strict neutrality with respect to class of product or technological field. Most of the funds of the new scheme have apparently gone to electronics and some of the projects supported have been significant commercial successes.

The National Programmes were not intended to compensate for deficiencies in the work of the Office of the Chief Scientist and the policy of neutrality. They were a response to changed circumstances, especially the emergence of a group of firms which had succeeded in the past, and the potential contribution of which to the expansion of exports was estimated to be great, provided special support could be given for research. This scheme has since been discontinued: most of the firms which benefited from it now have access to the local and sometimes to the international capital markets. More significant departures from neutrality occurred in the late 1970s and early 1980s.

FORMAL AND EFFECTIVE NEUTRALITY

The formal or nominal neutrality of a uniform rate of subsidy for all projects of research and development is not necessarily equivalent to effective neutrality of the promotion of innovations. It certainly does not treat all sectors of industry equally; there are considerable differences in the proportion which research and development makes up in the total costs of innovation in the various industrial sectors, types of technology of classes of product. A uniform rate of subsidy for research and development favours electronic innovations more than innovations in the chemical industry, since, in the latter, investments in plant are a larger part of the total costs of innovation.[5] It does not seem to favour electronics innovation more than innovation within the mechanical engineering industry. Effective neutrality with regard to innovation need not mean effective neutrality with regard to the different sectors of industry, since the proportion of the investment of research and development to sales or to total investments may vary from one sector of industry to another.

There are two additional reasons why formal neutrality does not necessarily result in effective neutrality in Israel. First, grants for research and development for the military are not neutral *vis-a-vis* civilian technology since they are presumably directed to particular kinds of technology, especially in electronics, and particular classes of products such as communications equipment. At most, we may say that the promotion of civilian technology is nominally neutral, if one sets aside the non-neutral development of military technology. Thus, while the high proportion of the approved projects in electronics did not result from a preference, on the part of the Office of the Chief Scientist, for civilian electronics over other civilian projects, it did in part result from the fact that the development of electronics technology was given special preference in the defence sector. Furthermore, the 'minimum requirements' for approval of projects may have implications of non-neutrality, because the fulfilment of these requirement is much simpler in some industries than in others.

EVIDENCE OF NEUTRALITY

Has the system for the promotion of industrial technology really been neutral? The system in Israel was — at least formally — neutral during the first decade of its existence. This is evident not only from the regulations governing the activity of the Office of the Chief Scientist, but also from the accounts given by officials responsible for allocating the grants, and from some statistical data on the development in a variety of sectors of industry. There was no shortage of funds at least until 1975; the total expenditures on grants for projects meeting the minimal requirements were always smaller than the funds available, even when the number of approved projects increased (Table 3). In 1976, governmental support for research and development made up approximately similar proportions of the total expenditure on

TABLE 3

Growth in Government Support of Research and Development in Industry

Year	Research and development grants to industry from Ministry of Commerce and Industry	Exports resulting from grants for research and development	Total exports from technologically sophisticated industries
		(Current US dollars in millions)	
1967	1.2	1.6	
1968	1.5	3.7	
1969	2.5	5.9	
1970	3.0	8.0	158
1971	3.5	10.2	196
1972	3.7	20.8	220
1973	5.4	100.9	266
1974	9.0	233.4	478
1975	10.0	289.9	530
1976	20.0	283.6	756
1977	25.2	416.3	985
1978	27.0	550.0	1284
1979	32.0	750.0	1680
1980			2143
1981		1000.0	
1982	60.0	1400.0	

Sources: Office of the Chief Scientist, Ministry of Commerce and Industry, *Industrial R & D,* Jerusalem, 1976; N. Guttentag, 'The effect of R & D on the structure of industry: part I: R & D in Israeli industry — inputs and outputs', (typescript), December 1981; Central Bureau of Statistics, *Statistical Abstract of Israel,* Jerusalem, various years; Bank of Israel, *Annual Reports,* Jerusalem, various years.

research and development in the various branches of industry. They range from 28 per cent for chemicals and oil to 37 per cent for basic metals and metal products. In electronics and scientific instruments, it was 35 per cent while in rubber and plastics it was 33 per cent.[6] There was wider variation between branches of industry in 1970, but this may be explained by obstacles incidental to the beginning of the system, such as the insufficient knowledge of new firms about the opportunities for obtaining grants.

There is clear evidence of effective non-neutrality in the policy for promoting innovation during the second half of the 1970s. After a certain point, a growing shortage of funds did not enable the scheme for grants of 50 per cent for research and development to be followed completely and a number of other criteria were introduced. Some of these changes in policy were probably intended not to be neutral; there

TABLE 4

Industrial Establishments Performing Research and Development, Number of Continuing Projects, and Contracts of Industry with Universities

Year	Industrial[a] establishments conducting research and development (Number)	Continuing[d] projects (Number)	Industrial contracts wtih universities (Current IL in millions)
1969	210		
1970	308		
1971	273		
1972	294		
1973		200	2
1974	216		5
1975	228	400	10
1976	289		20
1977	305		
1978		581	
1979	350[b]		
1980	500[c]	600	
1981	300-400[e]	1000[f]	

Sources:
- a Figures until 1977 are from Central Bureau of Statistics, *Survey of R & D in Industry* 1977-78.
- b From National Council for Research and Development, *Science in Israel,* Jerusalem, 1979.
- c From Ministry of Commerce and Industry, *Industrial R & D Opportunities in Israel,* Jerusalem, 1980, p. 3.
- d Various internal sources, Ministry of Commerce and Industry. They refer to projects supported by the Ministry only.
- e Companies receiving support from the Office of the Chief Scientist (presentation of Dr Lavie, June 1983).
- f Estimated number, communication from the Office of the Chief Scientist.

was for example an apparently increasing preference for the support of research and development in electronics at the expense of other projects in other industries such as chemicals. Thus, in 1979, while 32 per cent of all research and development in electronics and scientific instruments were financed by the government, only 4 per cent of research and development in rubber and plastics were so financed.

DESIRABILITY OF DEPARTURES FROM NEUTRALITY

The Israeli system of promotion of industrial research began without any explicit preference for particular classes of products, branches of industry or types of technology; it then gradually began to depart from that neutrality. It did so apparently in consequence of a financial constraint.

The departure from strict neutrality could be justified on grounds of principle; there were also grounds of expediency. At the beginning there was, at best, very little information on the prospects of success of particular projects involving research and development in any one firm for the profitability of other firms. Under these circumstances, a policy of neutrality seemed better than any alternative; furthermore it did not stifle initiative in the use of research. One of its important advantages in the early stage was that it permitted the accumulation of a wide variety of experience and information. Once acquired and assessed, this information and experience could indicate certain branches which had better prospects for commercial success for themselves and for beneficial effects for other firms. The policy of neutrality might then be revised.

My inclination is to justify only moderate departures from neutrality, except where there is a severe financial constraint. It is naïve to assume that enough information can be collected to justify a radical departure from the principle of neutrality. A complete abrogation of neutrality could stifle the emergence of initiative and creativity in the less favoured fields. The spirit of this conclusion is similar to that reached by L. Westphal, who in the area of industrial policy in general has emphasized the desirability of providing strong preferential support for a small number of industries rather than to a very wide range.[7]

Although the first decade's neutral policies were probably justified, it does not follow that the departures from neutrality actually followed later on by the Office of the Chief Scientist were adequate or optimal. To the best of my knowledge, not enough effort was made to collect, organise and analyse information about the experience of the early years. Thus, it might have been that the Office was not in the best position to predict 'winners' among the various industries or those where externalities might be particularly large.

STRATEGIES FOR THE PROMOTION OF INDUSTRIAL TECHNOLOGY

There were two alternative ways in which the newly created system for the promotion of industrial technology could have been established. One was to incorporate it into existing research institutions like universities and research institutes, through the support of higher education and science; the other was to place it in the Ministry of Commerce and Industry.

Similarly, there are two possible direct beneficiaries of governmental efforts to promote industrial technology: the universities and governmental laboratories (research institutions) on the one side, and business firms on the other. The idea behind the first set of alternatives is that universities and governmental laboratories would develop prototypes which would then be transferred to industry. Industrial firms would then produce on a commercial scale prototypes developed elsewhere. Thus, a large share of governmental support for industrial research and development would go to the academic and independent research institutions for joint projects in which those institutions collaborated with industrial firms. This alternative might have given too much emphasis to the aspirations and demands of the research institutions rather than to the promotion of 'high-technology' industries.[8] Thus the criterion of technological or scientific 'novelty' or originality rather than the criterion of 'commercial prospects' might have become paramount.[9]

The central feature of the Israeli system for the promotion of industrial technology since about 1967 has been its direct support to business fims and its location within the Ministry of Commerce and Industry. It was a departure from hitherto existing arrangements for the support of research in scientific and higher educational institutions, and to a large extent it was able thereby to avoid the dangers of an excessively academic approach to research and development. The Office of the Chief Scientist reduced the share of funds for research and development in the semi-autonomous industrially oriented governmental laboratories, and shifted resources to support research and development performed by private industrial firms in their own laboratories. The share of total civilian research and development in natural science and engineering performed in governmental laboratories declined from 27 per cent in 1966 to 12 per cent in 1978 (Table 1).

A system for the promotion of industrial technology on the lines followed in Israel — oriented to business firms and centred in the Ministry of Industry and Commerce rather than in a Minstry of Science — does not imply that the development of an industry using high technology and manufacturing high-technology products does not have certain scientific and academic preconditions. But how much and what kinds of investments in academic and governmental laboratories and expenditures for scientific training at home and abroad are required? Support of the development of the basic scientific and technological prerequisites — including manpower — should not be the main target of a governmental scheme for supporting the development of technology for use by Israeli industries, although such support is important and even critical in order to develop capacities in new fields of technology like robotics, bioengineering and electronics.

The separation of the promotion of industrial technological research from the support of higher education and science in universities may in fact be in the best interest of the scientific community in the long run. An industry successfully using high technology will require increased numbers of scientists and engineers as well as research institutes and, by producing a demand for them, will contribute to their development. Special social, economic and political factors led Israel to introduce a particular system for the promotion of industrial technology rather than the type of system which emerged in a number of other countries. In the middle of the 1960s, the difference between scientific research and industrial technology, and the understanding that the latter is not the automatic result of the former, were already well established in the minds of the Israeli authorities. Despite Israel's distinguished achievements in scientific research, the recommendations of the government committee, headed by the eminent Israeli scientist Kachalsky, decided on the location of the system of promotion within the Ministry of Commerce and Industry. This decision was affected by reflection on what had been achieved in agriculture and defence, where, through considerable practical experience, scientific research had been effectively harnessed to the advancement of technology.[10]

IMPLICATION OF NEUTRALITY

"Natural Selection"

A consequence of the policy of neutrality was the initiation of a process of natural selection simultaneously both of firms and of industrial fields. The process of selection may be designated as 'natural' because one determinant of a firm's survival was its competitive success in the market, and not its success in being pleasing to officials by agreeing to undertake projects of a particular type or in belonging to a particular industrial field which officials regarded as urgent. 'Natural selection' is more efficient than other selective mechanisms when there is little information in advance about which areas will be 'winners' or about which will have especially valuable 'spin-offs' or externalities; this has been the case in the early stages of industries using and producing high technology. The process of selection in Israel occurs simultaneously among firms and among industrial fields. Israel could not have developed an advantage in computerised tomography without having an unusually capable private firm which decided to enter this area. It was reasonable to believe that Israel should develop an industry of high technology but it was not possible to ascertain simply on the basis of the relative abundance of skilled manpower, which particular branch of industrial high technology or which firms would be profitable. Much has depended on the capacities of the entrepreneurs entering the various branches. Nor is the survival of enterprises independent of the particular areas they have chosen to engage in.

The process of natural selection seems to have been particularly strong until 1975-76, when a considerable search for new areas of likely commercial success took place, with many new firms being created and many failing. Between 1969 and 1975 there was no significant net increase in the number of industrial establishments engaged in research and development (Table 3); there remained about 200 throughout the period, but there was considerable change in the particular firms so engaged over the period in question. From an increase of 50 per cent in the numbers of particular establishments engaging in research and development between 1969 and 1970 — a rise from 210 to 308 — we see an almost steady decline until 1975, although there was an increase between 1971 and 1972. Only from 1976 do we observe a continuous increase in the number of firms engaging in research and development (Table 3). Within biomedical electronics, of the eight firms active in the field until 1973, two firms did not survive, and a third, while formally surviving, suspended practically all activities until a few years later; two other firms, while not disappearing, left the biomedical electronics instrument industry altogether. Between 1969 and 1975 — a period when the number of industrial establishments engaging in research and development remained constant — the share of the subsidy for research and development granted to electronics firms increased from 46 per cent to 60 per cent of the total subsidies for research and development granted to all firms. This change in the distribution of funds for research and develoment is a result of the process of natural selection.

There are two additional points worth mentioning in relation to the feasibility and efficiency of natural selection among firms and fields. Natural selection may be more or less efficient in generating firms of high quality and areas of high profitability. The existence of a pool of scientifically and technologically trained persons and the high quality of the higher educational system of the country enhanced the efficiency of the process. Similarly, the efficiency of the process was enhanced by the possibility of providing substantial financial support for research and development.

The natural selection of entrepreneurs or firms may be possible in some areas with divisible technologies, that is in areas where small firms may acquire technical and economic efficiency, but it may not be possible in others with indivisible technologies. It is impossible within steel or petrochemicals, where a small country can maintain at most one plant. Certain areas within electonics, for example, have an advantage over 'basic' industry with respect to their potential contribution to the economic growth of developing countries.

Entrepreneurial learning

Since even the ultimately successful firms seem to have experienced considerable difficulties, including commercial failures, at the early stages of their existence, it is likely that the surviving firms are, on average, 'fast learners' rather than that they have, by chance, selected at the outset a 'good' programme in research and development. It is possible that the initially excessive optimism of the eventually successful firms in some areas was a general phenomena; it is also possible that their initially excessive optimism was a function of similar deficiencies in their understanding of the process of innovation and of the conditions for commercial success in innovation. A case study of the biomedical electronics industry suggests that the technological entrepreneurs at first thought that research and development were sufficient for success and that they could dispense with detailed, realistic knowledge of the market for their products. Thus over-optimism, at least in that segment of the electronics industry, arose from an underestimation of the importance of the market and of the marketing techniques necessary for commercial success.[11]

This initial misconception of the determinants of successful innovation implies something about the nature of 'entrepreneurial learning'. In general terms, 'learning' means both becoming aware of the need for taking account of the market and marketing requirements of new products, and becoming proficient in the assessment of the market and in marketing the new products. In biomedical electronics, this has involved, among other things, understanding the complex relationships between research and development and marketing. From a view which stressed the interchangeability of high quality in research and development with marketing knowledge and skill because the 'product is so good it sells itself', 'entrepreneurial learning' entailed acquiring a better understanding of the fact that the relationship between the two may be one either of substitution or of complementarity, depending on the character of the products arising from research. Thus, when higher quality or increased effort in research and development leads to products which are more novel from the point of view of the user, marketing requirements are almost inevitably greater. This is because of the greater difficulty in determining the nature of 'user needs', and of the 'users' themselves coming to learn the functional efficiency of the product, and 'accepting' it because of that. Only when high quality or more research and development leads to greater functional efficiency of products already standardised and well known to users — for example, via the enhancement of capabilities of data processing and display — might marketing efforts decline.

One implication of the importance of the marketing constraint on the commercial success of new entrepreneurs is that the conditions needed for realistic development of products include both technical feasibility and relatively low marketing requirements. This restricts the permitted degree of 'product novelty' — from the users' viewpoint. Thus, the limited capital available to new entrepreneurs probably determined the commercial failure — at least within the field of biomedical electronic instruments — of new products about which there was much uncertainty about the particular character of users' needs and the way in which the products worked. (The latter is especially relevant for users prior to their decision to purchase the product.) These products are generally novel products to the users. In fact, between seven and 13 of the 18 failures among the firms manufacturing biomedical electronic instruments occurred where the products were entirely new to their prospective users; the other important category of failure occurred in firms whose products had no significant superiority in functional utility over competing products, even though they were offered at lower prices.[12] New enterprises in industries of high technology, even outside the production of biomedical electronic instruments, are more likely to be successful when they launch new products which are 'known' to users and the main functions of which have been standardised. This conclusion applies to a wide variety of goods, especially industrial goods and especially those where a wrong choice on the part of the user may cause considerable damage — pacemakers, aircraft, and computers for process control are only extreme cases of such goods.

From the point of view of the national economy rather than from that of the individual entrepreneur, however, a range of projects in research and development should include some 'novel' and some risky ones. This is increasingly justified as the sector producing high technology grows and as groups of larger firms begin to emerge. The relative share of such projects in the early years of the system should not exceed, in my opinion, a very small percentage of the total.

The kind of entrepreneurial learning we are dealing with is that of new entrepreneurs with small firms in the 'scanning stage' — a stage where the initial knowledge, skills and capacities are used to search for a product on which they may base their subsequent growth and profitability. We are not dealing with subsequent stages in the growth of the firm, such as those associated with the establishment of manufacturing facilities, or with subsequent stages associated with reorganisation, formal financial controls and formal planning procedures. Learning of varieties other than that described above may be associated with these other stages. The types of areas associated with the type of entrepreneurial learning in question are those with dynamic innovation of products where a 'product decision' which is not at all obvious precedes a decision on process.

Thus we are not concerned here at all with learning of process industries which is usually analysed in the literature on the transfer of technology, i.e., learning associated with the selection of technology and with the installation and 'start-up' of productive facilities.

SIGNS OF MATURITY: EMERGENCE OF A GROUP OF LARGE FIRMS

As a consequence of natural selection, a group of larger firms emerged which, having succeeded in the past, were able to undertake more significant projects of research and development on possibly more complex varieties of existing products or in order to launch completely new classes of products. The risks and the opportunities associated with these firms in their post-scanning 'growth' stage are probably of a completely different character than those confronting recently founded firms.

A basic feature of a firm entering its 'growth' stage should be its past commercial success in innovation. This is proof of effective 'entrepreneurial learning' and hence evidence of a capacity to innovate successfully. One possible measure is the size of the firm's budget for research and development. Taking $120,000 (at 1974 prices) as the 'threshold level', the numbers of firms the yearly budgets of which for civilian research and development exceeded this figure were five in 1974, 30 in 1975 and 40 in 1976.[13] Similarly, in 1975 there were eight electronics firms engaged in research and development and five chemical firms so engaged with sales over $10 million annually. This information, even though incomplete, testifies to the emergence of a fair number of firms with a capacity to undertake larger and more significant projects in research and development. My hypothesis, still unproven, is that the contribution of these firms to the growth of all high technology industry was very significant. In electronics, for example, while the number of firms engaged in research and development increased from 24 to 53 between 1970 and 1976, their average budgets for research and development increased by 70 per cent from $250,000 to approximately $470,000 (at 1971 prices). This includes one very large firm spending several million dollars on research and development. Other sectors had even higher rates of growth in average size, although electronics remained the sector with the highest average of expenditure research and development in 1970.[14]

The policy for the promotion of industrial technology was adapted to the emerging maturity of the sector by the launching in 1976 and 1977 of a new scheme for the support of research and development entitled the National Programme. This scheme was intended for 'proven' firms only — i.e., those which had passed through the 'scanning stage' — and which wished to undertake significant programmes in research and development with high risks. The National Programme was not open to new firms or to existing but still unproven firms. Thus, in contrast to the scheme which supplied 50 per cent of the funds used for research and development but did not discriminate among firms, this new scheme did discriminate while maintaining substantial 'neutrality' with respect to branch of industry and class of product. A 'proven' firm was required to be willing to undertake a very significant programme of research and development such as the launching of complex new products which needed the incorporation of new technological inventions and possibly collaboration with scientists at universities, and which would capitalise on accumulated 'intangibles' such as knowledge from research and development, experience in marketing, and the reputation of the firm. Thus, the scheme, while still neutral in some respects, was oriented towards growth through the reinforcement of existing success, moving on to new and more complex kinds of products. This promotional scheme, which never provided more than 30 per cent of the total of all grants made in a particular year, probably contributed to the growth of industry after 1976 in a significant way. Meanwhile, the National Programme has disappeared. Most of the firms which benefited from it now have direct access to the Israeli and international capital markets. They have probably entered a phase of 'maturity' where they control at least a small percentage of the world market of the products they develop and sell.

REVEALED COMPARATIVE ADVANTAGES: TOWARDS THE UNDERSTANDING OF THE DYNAMICS OF GROWTH IN INDUSTRIES OF HIGH TECHNOLOGY

Israel had experienced a dramatic shift in the structure of its comparative advantages during the 1970s; it is a shift which favours a group of industries which may be called 'sophisticated' (Table 5). The share of 'sophisticated industries' in total exports, excluding diamonds, increased from 40 per cent in 1970 to 66 per cent in 1980. It is less dramatic if one examines the change in the share of this group of sophisticated industries in the total industrial output; still the average rate of growth in real output of this group was almost 50 per cent higher than that of traditional industries: 6.1 per cent against 4.2 per cent.

I believe that an analysis of the effects of the technology promotion policies of the Office of the Chief Scientist should be related to a description and analysis of changes in the structure of exports and

TABLE 5

Basic Features of Sophisticated (S) and Traditional (T) Industries

Year	Total exports (Current US$ in millions) S	T	Total	Share of S in exports (Percentage)	Share of S in total output (Percentage)	Share of output exported (Percentage) S	T	Total
1970	158	236	394	0.40	0.43	16.6	21.1	19.2
1971	196	281	477	0.41	0.45	17.7	23.8	21.0
1972	220	307	527	0.42	0.45	16.2	22.2	19.5
1973	266	360	626	0.42	0.45	17.2	20.4	19.0
1974	478	454	932	0.51	0.47	21.0	20.8	20.9
1975	530	440	970	0.55	0.48	20.3	18.9	19.6
1976	756	472	1228	0.62	0.49	28.6	19.5	23.9
1977	985	965	1553	0.63	0.49	35.1	21.3	28.0
1978	1284	638	1922	0.67	0.49	38.8	19.6	28.9
1979	1680	818	2498	0.67	0.48	39.7	21.2	30.2
1980	2143	1121	3264	0.66	0.48	45.0	26.3	35.2

Source: Calculations from data published in Central Bureau of Statistics, *Statistical Abstracts of Israel,* Jerusalem, various years.

TABLE 6

Exports of Various Branches of Sophisticated Industries: 1970-80

	1970 Dollars (Current US, in millions)	1970 Share (Percentage)	1975 Dollars (Current US, in millions)	1975 Share (Percentage)	1980 Dollars (Current US, in millions)	1980 Share (Percentage)
Rubber and plastics	24	15	45	8	128	6
Chemicals	53	33	183	34	648	30
Metal products	28	18 } 29	103	19 } 25	334	15 } 23
Machinery	18	11	31	6	171	8
Electronics	13	8	98	18	263	12
Transport equipment	9	6	40	7	372	17
Miscellaneous	13	8	30	6	227	10
Total	158	100	530	100	2143	100

Source: Central Bureau of Statistics, *Statistical Abstracts of Israel,* Jerusalem, various years.

output, at least of the research-intensive or sophisticated industries. Otherwise we may fail to understand the process that led to increased exports. For example, it seems that the increased exports stimulated by the grants for research and development were composed of products which would not have been developed and produced at all in the absence of such a support scheme. The Office of the Chief

Scientist apparently facilitated the transition to more complex and sophisticated products, and only through these were the increased exports achieved.

Our objective is thus to map the evolution of the comparative advantages of Israeli industries using high technology since 1967. One possibility is to focus on industrial branches or sectors and to their changing share in the total exports or output of the group of sophisticated industries. This would give us a first, although crude, indication. The branches the share of which in total exports of the sophisticated industries increased between 1970 and 1980 were transportation equipment, in which the share increased from 6 per cent in 1970 to 17 per cent in 1980; electronics, where the shift was from 8 per cent to 12 per cent and miscellaneous manufacturing. The share of all other sectors within this group of industries declined, especially rubber and plastics, but including chemicals, metal products and machinery. Electronic technology is intimately involved in all three of the industrial sectors where the share has increased ('optical equipment' is classified under 'miscellaneous') (Table 6).

These trends correspond with the trends in the share of total expenditures for civilian industrial research and development, both that supported by the Office of the Chief Scientist and others spent in the electronics and scientific instruments industries. This share increased from 45 per cent in 1970 to 59 per cent in 1976, which is an increase in share of almost 30 per cent.[15] Similar trends can be found in the share of grants by the Office of the Chief Scientist supporting projects in research and development in electronics: a moderate increase in share occurred in the period from 1967 to 1976 and a very significant increase between 1977 and 1981. The data, however, are incomplete and the two sub-periods are not comparable. The substantial increase in the share of the grants made by the Office of the Chief Scientist to electronics after 1976 is a result of natural selection within the context of a policy deliberately favourable to this technology.[16]

A description of the changing importance of the various industrial branches in the total exports of 'sophisticated product' is not sufficiently rich in detail to permit us to trace the effects of the various schemes of the Office of the Chief Scientist for the support of research and development. The main reasons are that support was aimed at particular innovations rather than at individual industrial branches; and that an important effect of the support was indirect, i.e., via the stimulus received to launch other related innovations in the future, over and above the particular innovations being supported.

In view of the deficiences of using industrial branch or sector as the unit of analysis, I suggest considering products or innovations as the starting point and proceeding to classify them into a set of areas where each area is defined by one, two or all of the following characteristics: class of product, field(s) of science and technology and users. Successful innovations up to 1975[17] are provisionally grouped by a certain number of characteristics which have some relevance for the explanation of success. For example, an important factor for commercial success in the category 'inputs to agriculture' has been the existence of innovative farmers who are 'sophisticated users'. More detailed knowledge of the classes of innovation within this group may eventually lead us to consider for example two 'areas': chemical inputs to agriculture and all others. For the time being, however, and in order to provide as much concreteness as possible to our discussion, we will group the innovations — all of which benefited from the grants for research and development from the Office of the Chief Scientist — as follows:

The pattern in agricultural innovation is one of supplying the local market first and then exporting. The existence of innovative farmers is significant here; some products were not new although the processes of producing and 'using' them were novel. Success depended on interest and involvement of 'users'. The products comprised components and systems for irrigation, including those related to novel drip-irrigation technique; hebicides, pesticides and products to protect plants; fertilisers based on local natural resources; poultry, veterinary products, etc. Most exports in this group, such as fertilisers, are in the chemical industry, others are produced by the electronics industry, e.g., devices for irrigation control. Innovation in mechanical technology, such as orange-pickers, have multiplied in recent years and are already being exported.

Certain innovations arise from or occur in more than one field of science or technology. They generally involve the application of electronic technology to some other field. In medicine, the application of this technology has led to nuclear medical-diagnostic instruments, coronary care units and laser-based operating instruments; in agriculture, it appears in computerised irrigation control; in textiles, dyeing machines based on microprocessor and computer-aided design systems for knitting and printing. Most exports in this group come from the electronics industry. Starting in the mid-1970s, numerically-controlled machine tools were developed and exported. Short lines of communication enable a small country like Israel to perform well in these areas. The influence of various fields of technology converging in a particular innovation or spreading from it often depends on the existence of sophisticated users, such as in medicine or agriculture.

The availability of large supplies of agricultural products opened up new opportunities for processing. Some of these involved innovations in products or processes, e.g., frozen and dehydrated citrus products and related items such as the extraction of sweet substances from orange peel. Presumably, exports from these innovations appear under the food and possibly chemical industries. Innovations in civilian industry occur in situations in which Israel's advantage derives from prior investments in defence, e.g., light aircraft and command and control systems. Specific local needs sometimes engender innovations such as solar energy products and desalinisation plants. The desire to use local natural resources such as bromine and magnesium for purposes for which they were not used before also stimulates technological innovation. The result of all this is that there has been a growing number of new products and processes of increased sophistication. Many of these products were not available before 1974.[18] Between 1971 and 1977 many new products were added. In communication equipment, there has been the addition of telephone exchanges, microwave radar, airport tower communication equipment, remote control and data transmission systems, etc.: in medical instruments, the launching of gamma cameras, CAT scanners, coronary care and intensive care units, and surgical laser devices; in electro-optical systems and other instruments the launching of CAD systems first for textile and then for the printing industry, 'fast fourier processor', airborne instruments, etc.; numerically-controlled sewing machines,, electronic packaging, numerically-controlled machine tools; in computer equipment, a variety of terminals and alphanumeric displays.

These innovations illustrate some of the consequences of the activities of the Office of the Chief Scientist in the support of research and development. Yet although the innovations benefited to some extent from governmental support, and in some cases it is clear that such support had a very strong impact, the precise mechanisms at work are still unknown. This may require assembling chains of interrelated innovations over a period of time.

CONCLUDING REMARKS

In contrast to other systems for the promotion of scientific industrial technology, the Israeli system has worked directly through individual industrial firms. The location of the Office of the Chief Scientist in the Ministry of Commerce and Industry has permitted the restricted application of the allocative criterion of 'commercial prospects' rather than that of scientific originality; the latter is not disregarded but is considered only if the former criterion is satisfied. The system operates through grants to specific research and development projects rather than attempting to stimulate innovation through selective procurement of industrial products benefiting local firms. This procedure, therefore, differs from that of other countries such as France, and it is probably best adapted to encourage the emergence of new, usually young, technologically sophisticated entrepreneurs. It remains to be seen whether the use of grants for research and development to promote industries using high technology is most effective after a stage where such promotion has already been furthered by procurement policies, or even whether it is necessary where there are well-developed capital markets.

The fruitfulness of the Israeli system has derived in part from the formal neutrality of its support to research and development at least during its first decade of existence. The practice has not been unqualifiedly neutral with respect to innovation, and of course it has favoured those firms which were already interested in using the results of their own research and development in order to make innovations in products and processes. It has been a neutrality intended to promote sophisticated technological innovation through research and development; it has not been neutral with regard to traditional as opposed to scientifically sophisticated technology, or with regard to the latter as opposed to imported technology. It has been very partisan indeed in the promotion of local scientifically sophisticated technology, but it has practised neutrality as a means to that end, at least during the ten years following 1967. This policy of neutrality has been successful in enabling new firms to find their way and to prosper through research and development. Can it be adapted to new circumstances to continue further technological innovation?

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