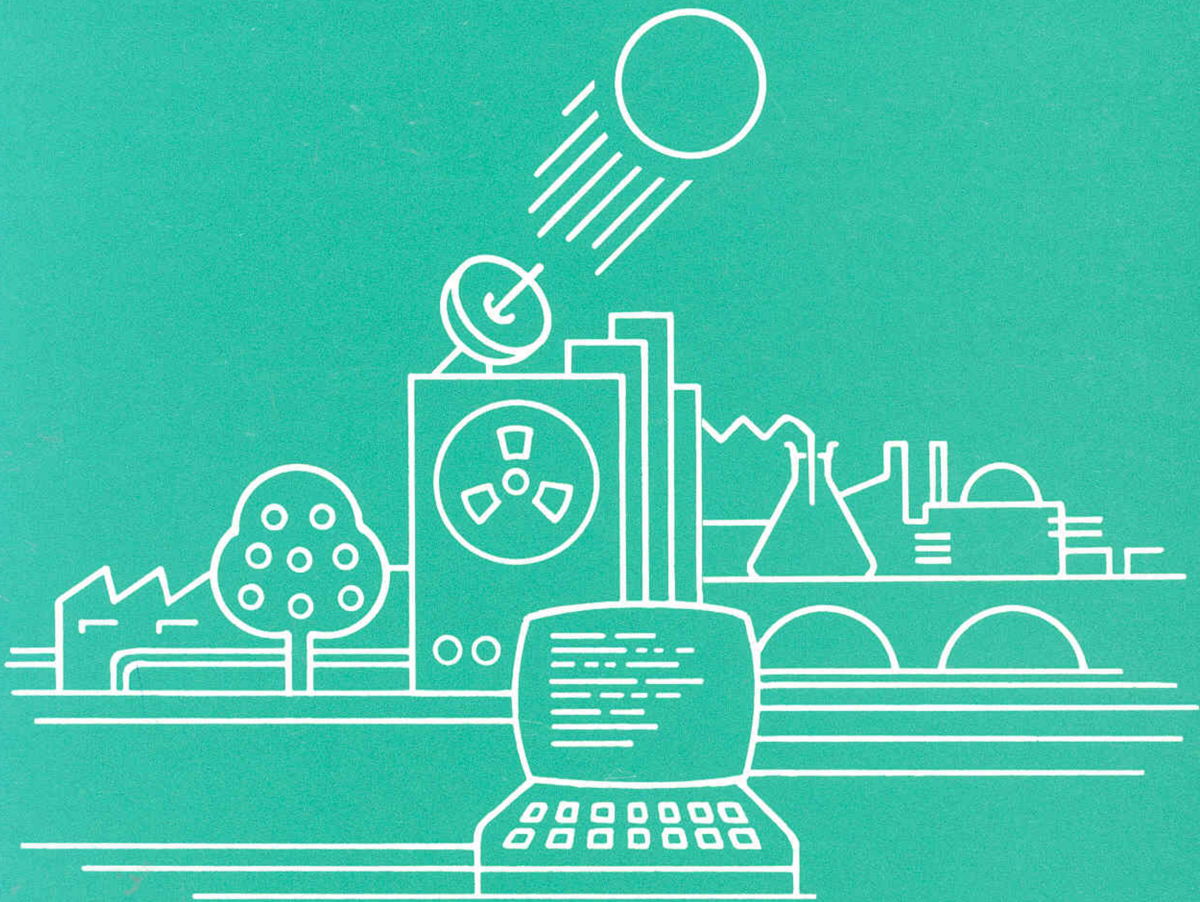
SCIENCE INDICATORS AND THE EVALUATION OF SCIENTIFIC ACTIVITY

Edited by **Bluma C. Peritz**



Studies in Science Policy

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

SCIENCE INDICATORS AND THE EVALUATION OF SCIENTIFIC ACTIVITY

Edited by ***Bluma C. Peritz***

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Preface

The evaluation of scientific activity has always been a difficult endeavor because of both its long-range effects and the intrinsic uncertainty of this kind of research. In these times of growing budgetary constraints, such evaluation has become a significant tool in assessing the "track records" of scientific organizations (universities and research institutes) and of funding agencies. The S. Neaman Institute, the Technion's policy-research institute, which has been active in this field for several years, has sponsored a session on indicators for the evaluation of science in Israel and abroad. The session took place at the Info-91 Conference, Israel premier Information Science forum, and the papers presented there are brought together in the present volume.

This collection of papers includes a wide variety of approaches. One of the leading scientometric researchers in the field, Dr. A. Schubert of the Hungarian Academy of Science presented an overview of the use of citations in the evaluation process. B. Peritz discussed the role and significance of citation-based measurements. G. Czapski looked at some of Israel's science indicators in a comparative context. Finally, S. Herskovic analyzed patent statistics as indicators of scientific and technological activity. The audience felt that this had been a useful and informative session. We hope, therefore, that this little volume too will serve as a valuable source.

We gratefully acknowledge the assistance and cooperation of Mr. A. Sofrin and Teldan, who organized Info-91, and helped make this session a reality. We also appreciate the efforts of Dr. B.C. Peritz, who turned a group of lectures into this valuable and cohesive volume.

Prof. D. Weihs
Director
The S. Neaman Institute

Novel Methods of Selecting Reference Standards for Citation-Based Assessments

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Introduction

It has long been stressed by the present authors [1-5] as well as by others [6-7] that citation counts can be used for evaluative purposes only after proper standardization.

Citation rates of papers of not necessarily the same age and topic cannot be compared directly, but each of them must first be compared to the citation rate of a set of papers sharing their main characteristics. Then, the relative standings of the papers in their respective **reference standard** set can then be compared. As Garfield [7] suggests: "Instead of directly comparing the citation count of, say, a mathematician against that of a biochemist, both should be ranked with their peers, and the comparison should be made between rankings. Using this method, a mathematician who ranked in the 70 percentile group of mathematicians would have an edge over a biochemist who ranked in the 40 percentile group of biochemists, even if the biochemist's citation count was higher.

There still remains the question: how to find the most suitable company of "peers" or reference set of papers to perform the primary comparison. In some fortunate cases one may rely upon the experts' opinion but, especially if a large manifold of papers is to be assessed, such help cannot be expected. Some simple methods are necessary, which, as it were, automatically assign the reference standards to the papers under investigation.

In the present study, three possibilities are outlined to "generate" such reference standards. Evidently, none of the suggested methods is as reliable as a well-considered expert selection. However, sometimes even a moderately sophisticated "automatic" method may require unduly large resources (time, computer capacity or money). The advantages of the proposed methods will, therefore, be compared to help the analyst find at least a "suboptimal" solution to the problem of selecting a reference standard for citation assessments.

The publishing journal as reference standard

Primary journals in science are generally agreed to contain coherent sets of papers both in contents and in professional standards. This coherence stems from the fact that most journals are nowadays specialized in quite narrow subdisciplines and the "gatekeepers" (i.e., the editors and referees) controlling the journal are members of an "invisible college" sharing their views on questions like relevance, validity or quality.

It seems, therefore, justified to expect the same level of citation rate for papers published in the same journal at the same time. If two such papers receive a different number of citations, one may rightly suspect that this reflects differences in their inherent qualities. By relating the number of citations received by a paper (or the average citation rate of a subset of papers published in the same journal - the **Mean Observed Citation Rate, MOCR**) to the average citation rate of all papers in the journal (the **Mean Expected Citation Rate, MECR**), the **Relative Citation Rate (RCR)** will be obtained. This indicator shows the relative standing of the paper (or set of papers) in question among its close companions: its value is higher/lower than unity as the sample is more/less cited than the average. In general, sets of papers under investigation are published in more than one journal; in that case, the mean expected citation rate (MECR) can be defined as the average citation rate of the journals. (The weights are - of course - the publication frequencies in the respective journals.) The mean observed citation rate (**MOCR**), i.e., the average citation rate per paper can again be related to the **MECR** to result in the relative citation rate (**RCR**), indicating the relative impact of the papers in question among the average papers of the publishing journals as reference standard.

There are some weaknesses inherent in using the publishing journal as reference standard. Papers published in multidisciplinary journals are measured by common standards, which might be clearly unfair, say, for a geoscience article published in Nature together with a molecular genetics paper. Since journals form a virtually continuous spectrum from highly specialized to multidisciplinary, and different research fields or even subcommunities in the same field may typically use different segments of this spectrum, the unbiasedness of the reference standards must be thoroughly checked whenever comparative assessments are based on the **RCR** indicator.

As a rule, it can be said that in coherent research fields, where papers are usually published in specialized journals (as is the general trend in contemporary science) publishing journals as reference standards and **RCR** as indicator can readily be proposed for comparative assessments. It must, however, be added that even in such cases extension from one to two dimensions may multiply the effectiveness of the analysis.

The set of related records as reference standard

"Bibliographic coupling" has first been suggested by Kessler [8] as a basis for document retrieval. This concept uses the number of references a given pair of documents have in common to measure the similarity of their subject matter. Comparing a set of papers that are "similar" in this sense to a given article of the same age will yield an ideal reference standard for citation assessments. This apparently simple and straightforward method has long been practically unaccomplishable because of the technical difficulties of collecting the "coupled" papers, by using any traditional version of citation indexes.

Fortunately, the situation has radically changed with the advent of the **CD-ROM edition** of the **Science Citation Index** database, which is now available for the 1980-1991 period. The **SCI CD Edition** uses bibliographic coupling under the name **related records.** Two records are considered "related" when they list a number of identical papers in their respective bibliographies. Related records of an article are other articles published during the same period that cite at least one of the same references that the "parent" article cited. Because they have references in common, an article and its related records are supposed to be also related by subject. In general, the more references in common, the stronger the subject similarity between two articles. The **SCI CD Edition** has a built-in possibility for searching related records: a maximum of 20 related records are available for any given record ranked by strength of relatedness.

In an exploratory study of using **SCI CD Edition** for comparative evaluation of citation impact, the publication output of the Hungarian pharmaceutical company CHINOIN in 1986 was investigated. This choice was motivated by the fact that a few attempts have already been made to assess the research activity of this company by other scientometric methods. In addition, the unique and unmistakable name of the firm gave an easy way to retrieve by corporate address search from the database the full publication list. By processing the search output, source data and related records were collected in separate files. Citation to all source papers and related records were then counted manually in the 1987 SCI Citation Index printed volumes. Average 1987 citation rates of papers published in 1986 were determined from the 1987 **SCI Journal**

Citation Reports [9] for all journals publishing at least one source paper or related record.

Citation rates of CHINOIN publications and of "related records" could then be compared to each other and to their respective "expected" citation rates based on the average citation rates of the journals. 74 Papers of the CHINOIN pharmaceutical company could be retrieved from the 1986 annual disk of the **SCI CD Edition**. 19 of them had no references and therefore no related records. Since these publication (mainly meeting abstracts) were not expected to be cited at all, they were excluded from the analysis. The other 55 papers received a total of 32 citations in 1987, instead of 57 that would be expected on the basis of the average citation rates of the publishing journals.

In the related record file, 924 occurrences of 718 articles could be found (34 of them were CHINOIN publications). In total (multiple occurrences taken by proper multiplicity), 1153 citations would be expected and 932 were actually observed. Without getting involved in any statistical arguments, three conclusion come to mind.

(1) Both for CHINOIN publications and for the "related records", observed citation rates per paper fall short of expected values. Thus, it seems that the research topics of CHINOIN are not the "hottest spots" of their respective subject field, which does not, however, qualify the research in any means.

(2) Although the expected citation rate of CHINOIN publications is rather close to that of the standard reference set ("related records"), their actual citation rate falls far below. Earlier studies concerning longer time periods did not show such a gap between expected and observed citation rates. The relatively low rate of subsequent year citations can most probably be attributed to insufficient informal, prepublication communication of research.

(3) The observed citation rate of the related records is conspicuously close to the expected citation rate of the "parent" CHINOIN publications. This finding, in a sense, validates the use of relative scientometric indicators based on the comparison of actual with expected (journal average) citation rates. At least in the case of the present sample, the much more sophisticated "customized" control group - compiled on the principle of bibliometric coupling - obtains the same citation level as reference standard as did the simple journal average.

In subject fields less coherent than pharmaceutical research, however, the differences might be much more substantial, and the use of the set of related records as a more reliable reference standard is certainly worth the additional effort.

The set of cited journals as reference standard

The set of publications to be assessed may represent various levels of aggregation, such as research teams, institutions, or whole research communities of a given subfield in a given country. In our experience, independently of the level of investigation, the publishing journal is a useful and reliable reference standard for citation assessments - bearing in mind the caveats earlier mentioned. In one particular case, however, this approach fails completely, namely, if journals themselves are subjected to comparative assessment. There is an ever growing interest in evaluation of journals by citation analysis (see, e.g., a bibliography of this topic in [9] or the review [10]), and one of the crucial questions, in this case too, is the comparison of journals publishing in science subfields of inherently different citation levels.

One possible solution might be again the use of related records. It is, however, practically impossible to retrieve the related records to every single article of just one volume of a medium size journal and to collect their citations.

Standardization of citation levels by subfields and comparing then the standardized scores has been attempted, among others, by the present authors [11,12]. This approach was found to be loaded with the inherent arbitrariness in the categorization of the journals into subfields and the ambiguity of treating inter- or multidisciplinary journals.

A method which now seems to provide the most satisfactory resolution at the lowest cost in terms of computer and/or manual search is based on the **journals in the reference lists of the articles of the journal in question**. These journals were selected by the most reliable persons, the authors of the journal as references (in both senses of the word) and, therefore, can justly be regarded as standards of the expected citation rate. Listings of journals cited by **SCI** covered journals are compiled in the **Citing Journal Package of the Journal Citation Reports** [9].

All but a very few journals fall far below the standard set by their references. This is perhaps because authors tend to base their statements on the most authoritative sources. In every research area, a hierarchy of journals is set up with one or just a few journals on the top, and all others tend to cite "upwards".

A detailed study has been made on 2459 journals covered continuously by **SCI** in the period 1981-1985 and publishing at least 50 papers in these five years. Only 140 of them proved to be cited above the average of their cited references. This subset may rightly by considered the "chosen few" of the community of journals.

A closer look at this subset reveals that a considerable number of these journals are **review journals**, some of them having the word "review" even in their title. This is not too surprising, since review papers are well known to be cited much above the average. It is, however, interesting to realize that analysis of cited journals provides a simple means to distinguish review journals from "ordinary" ones. The indicator is the fraction of journal self-citations in all citations. Evidently, this fraction is much lower for review journals (collecting, by their very nature, references from a much wider pool of journals) than for primary journals. In our experience with the above sample of 2459 journals, 10% is the dividing line under which, whatever its title, a journal is to be considered a review journal. In the Appendix, the top 140 Journals are divided into two categories: primary journals (97 titles) having at least 10% journal self-citation, and review journals (43 titles) under the critical 10%. In both categories, the journals are arranged in descending order of their relative citation score (as compared to the average of their cited references).

The lists are worth studying in detail, and only the most conspicuous features are commented upon here. It is not surprising to find CELL at number one; having one of the highest impact factors of all journals, its outstanding position is evident. Some of the runners-up are, however, clearly unexpected. The fact that some rather moderately cited journals score very high is partly due to the different hierarchical structure of different research areas. The relatively small number of chemistry journals in the top list can be attributed to the globally dominant position of a few journals, like J AM CHEM SOC or ANALYT CHEM, in a rather wide research area. At the other extreme, mathematics is represented by a fair amount of journals, since there a "local hierarchy" seems to be set up in every single narrow subfield, each having its own leading journal. Otherwise, there is a reassuring balance of science fields and subfields both in the primary and the review journal lists.

Conclusions

Three methods have been suggested to establish reference standards for citation based assessments. All the three have their pros and cons, some of the indications and counter indications for their use have been discussed.

Using the publishing journal as reference standard and **RCR** as indicator appears to be the most generally applicable choice. Some alleged flaws (like motivating authors to publish in low impact journals) can easily be refuted, some limitations (e.g., the problems of inter- and multidisciplinary journals) are unavoidable.

Related records of the **SCI CD Edition** seem to provide an excellent customized reference set for every single paper. Although one cannot overestimate the significance of **CD-ROM** as the first tool making analyses using the bibliographic coupling technique feasible, these analyses may still encompass only a limited number of papers, if the required time and energy is to be kept within reasonable limits

Using cited references as standard may open new vistas in citation analysis of journals as it has been demonstrated in a pioneering investigation in this study.

There are many open questions in connection with the results presented here, which may and hopefully will form the topic of future research.

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Appendix - List of Journals cited above their references

#	Rank Title	No. of papers	Avg. cit-rate	Ref. cit-score	% of self-cit	#	Rank Title	No. of papers	Avg. cit-rate	Ref. cit-score	% of self-cit
	A - Primary Journals										
1	CELL	2016	34.19	2.46	22	36	HUMAN FACT	292	1.16	1.24	68
2	ARCH G PSYC	981	8.51	2.01	36	37	BRAIN	233	6.93	1.24	11
3	J ACM	269	2.22	1.95	57	38	ULTRASON IM	113	3.51	1.24	55
4	PHYS REV L	6343	11.05	1.92	29	39	NEUROSCIENC	1201	9.86	1.24	14
5	CIRCULATION	2254	10.42	1.79	29	40	INT STAT R	91	2.46	1.24	25
6	J EXP MED	1579	22.94	1.76	21	41	CLIN PHARM	1073	6.34	1.22	18
7	J AM CHEM	9148	9.04	1.69	36	42	J CEREDR B	349	7.28	1.21	28
8	ACT METALL	1086	4.08	1.55	39	43	J EXP PSY A	158	4.22	1.21	42
9	ANALYT CHEM	3689	5.55	1.53	23	44	ANTIM AG CH	2016	6.79	1.20	40
10	APPL PHYS L	4297	6.25	1.52	33	45	JEEE PATT A	445	1.84	1.20	48
11	INVENT MATH	520	2.02	1.49	31	46	J CELL BIOL	2319	15.63	1.19	25
12	J CLIN PER	310	4.46	1.49	50	47	J COMP NEUR	1717	8.60	1.18	28
13	ANN MATH	191	3.16	1.48	41	48	INT J SOL S	437	1.41	1.18	54
14	J GRAPH TH	228	0.70	1.47	46	49	ADV APPL P	250	1.32	1.17	37
15	RADIOLOGY	3486	5.43	1.46	33	50	TECHNOMET	206	2.04	1.17	42
16	IEEE J O EL	1473	5.97	1.43	30	51	J MECH PHYS	128	2.59	1.16	40
17	NUCL SAFETY	231	0.68	1.42	44	52	SCIENCE	5738	13.59	1.16	13
18	IEEE AUTO C	1261	1.99	1.41	61	53	BR J ANAEST	947	4.09	1.15	39
19	SIAM J NUM	413	1.81	1.41	45	54	ANN PROBAB	451	1.56	1.14	54
20	P NAS US	8450	18.50	1.38	17	55	J ATMOS SCI	1139	5.11	1.13	55
21	J DAIRY RES	319	3.08	1.38	50	56	N ENG J MED	7299	7.74	1.12	22
22	ARCH R MECH	262	1.62	1.37	61	57	IBM J RES	323	2.90	1.11	85
23	ANN STATIST	587	2.35	1.36	56	58	SOL ENERG M	338	4.18	1.11	19
24	ANN SURG	1076	6.07	1.35	13	59	ASLE TRANS	316	0.98	1.11	58
25	NUCL PHYS B	2643	9.73	1.34	36	60	DIFF EQUA	483	1.06	1.11	37
26	J LOND AMTH	255	1.36	1.34	39	61	J CHEM PHYS	8945	5.99	1.10	41
27	J CLIN INV	2203	12.81	1.33	10	62	MATH PROGR	325	1.25	1.10	48
28	NATURE	8063	16.63	1.30	22	63	ECOLOGY	961	5.43	1.10	26
29	ASTROPHYS	362	9.17	1.30	10	64	J IEEE	908	2.84	1.10	19
30	PAP PUU	228	0.87	1.29	63	65	ANN INT MED	2740	7.24	1.10	18
31	SIAM J CON	283	1.82	1.29	49	66	AUST J. ZOOL	933	1.41	1.10	74
32	ASTROPHYS J	6168	8.09	1.28	61	67	J POL SC PP	952	3.39	1.09	30
33	CIRCUL RES	1036	10.47	1.26	19	68	J GEN PHYSL	421	10.51	1.09	19
34	INDI MATH J	271	1.31	1.26	38	69	NZ J AGR RE	361	1.26	1.08	66
35	ACT ODON SC	240	2.04	1.25	41	70	J CLIN END	2203	8.12	1.08	27

Appendix - List of Journals cited above their references

#	Rank Title	No. of papers	Avg. cit-rate	Rel. cit-score	% of self-cit
	A - Primary Journals (cont.)				
71	GUT	965	5.75	1.08	20
72	AM J SCI	245	5.55	1.08	30
73	AUTOMATICA	389	1.70	1.07	27
74	CARIES RES	367	2.67	1.07	48
75	BLOOD	2086	10.85	1.07	20
76	OPERAT RES	419	1.15	1.07	61
77	MOLEC PHARM	887	9.57	1.06	13
78	LIMN OCEAN	657	5.42	1.06	29
79	J MARINE RE	231	5.61	1.06	16
80	J ANIM ECOL	336	1.09	1.05	30
81	ANN NUC ENG	326	1.09	1.05	54
82	GASTROENTY	2176	6.86	1.04	28
83	DIOMITRIKA	468	1.94	1.03	44
84	MBTALL T-A	1314	2.52	1.03	46
85	SURF INT AN	222	4.19	1.03	32
86	PSYCHOL REV	132	4.39	1.03	43
87	J PHARM EXT	2361	7.41	1.03	15
88	J GEPH RES	5469	5.73	1.02	51
89	INT J HEAT	1160	1.50	1.02	28
90	J CATALYSIS	1660	5.06	1.02	49
91	DIABETES	1074	8.72	1.02	22
92	J NEURPHYSL	874	7.89	1.02	29
93	PHYS C GLAS	165	2.56	1.02	42
94	J BIOMECHAN	484	1.87	1.01	76
95	J FLUID MEC	1443	3.37	1.01	57
96	J PHYSL LON	2205	8.71	1.01	37
97	HYPERTENSIO	1034	6.93	1.00	20
	B.Review Journals				
1	REV M PHYS	106	39.12	6.04	1
2	ANN R BIOCH	152	63.11	5.14	1
3	PHYSIOL REV	101	36.42	4.19	0
4	ANN R PLANT	103	26.74	3.76	2
5	ENDOCR REV	108	27.52	3.17	1
6	CHEM REV	102	17.25	3.15	0

#	Rank Title	No. of papers	Avg. cit-rate	Rel. cit-score	% of self-cit
	B- Review Journals (cont.)				
7	MICROBIOL R	95	30.98	2.90	0
8	ANN R PH CH	102	17.11	2.79	1
9	ANN R ASTRO	76	19.62	2.74	2
10	ANN R PHARM	12	21.84	2.71	0
11	ANN R NEUR	81	27.05	2.68	1
12	ACC CHEM RE	309	15.40	2.40	3
13	ECOL MONOGR	101	10.02	2.09	7
14	PROG ENERG	53	3.75	2.06	9
15	REP PR PHYS	123	12.24	2.05	0
16	MEDICINE	152	10.85	1.91	2
17	CHEM SOC RE	83	10.22	1.87	0
18	PHAR REV	57	14.21	1.86	0
19	ANN R ENTOM	93	8.66	1.83	3
20	BRAIN RES R	86	13.74	1.83	5
21	IMMUNOL REV	287	26.12	1.81	2
22	ANN R PHYSL	226	16.15	1.72	1
23	PHYS REPORT	352	11.46	1.72	1
24	ANN R ECOL	90	9.18	1.70	3
25	STRUCT BOND	57	10.93	1.68	0
26	CATAL REV	81	7.27	1.64	4
27	CLIN PHARMA	194	7.66	1.64	4
28	ANN R FLUID	83	6.31	1.61	8
29	COORD CH RE	265	6.07	1.60	0
30	ANN R MICRO	118	14.25	1.41	1
31	ANN R GENET	78	22.21	1.40	0
32	T CURR CHEM	119	6.81	1.31	1
33	PROG CARD	106	9.67	1.31	1
34	CRC CR BI	84	17.27	1.29	0
35	ANN R BIOP	95	13.47	1.24	1
36	BIOL REV	80	7.74	1.16	0
37	MED RES REV	77	7.69	1.10	0
38	REV GEOPHYS	266	5.42	1.03	1
39	J PETROLOGY	130	5.63	1.03	8
40	CELL CALC	189	8.13	1.02	3
41	PROG NEUROB	83	8.65	1.02	0
42	J ELEC MAT	297	4.00	1.02	8
43	ANN R PSYCH	97	5.25	1.00	7

Scientific Activity in Israel: Publications and Citations

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1. Introduction

International collaboration among scientists is a major issue in science policy, in Israel and elsewhere. On the one hand, it encourages young scientists to perform within the scientific world at large, and on the other hand it makes them aware of research opportunities abroad. International collaboration is particularly important in a small country with a relatively large share of scientific research manpower, like Israel.

In order to study the scientific cooperation between Israel and other countries we availed ourselves of the large data-base set up by the Institute for Scientific Information (ISI) of Philadelphia. From this data-base the set of all publications in which at least one of the authors gave an Israeli address was copied and transmitted to us for analysis. Some of the results of this analysis are presented here.

The ISI data-base provides a full bibliographic record for all papers published in some 3000 scientific journals. The list of journals is updated frequently, in an attempt to make sure that the most "representative" periodicals - particularly those published in English - are covered. ISI also provides a citation index including all the citations in the above papers -

about ten million citations in 1986 from over 600,000 papers. (For a detailed description of citation indexes and their many uses see Garfield [1]). The "Israeli file" analyzed in this publication covers the years 1972-1984, and in a newer version also the years 1981-1990 (see Fig. 4).

Two previous publications in Hebrew [2,3] have been devoted to this subject. In particular, the more recent one of these reports, [3], presents data on a survey carried out at the Hebrew University and the Technion-Israel Institute of Technology, assessing the completeness of the ISI data base. The main outcome of this assessment was that of the 5223 papers included in the survey 16.8% were not included in the "Israeli data file", in many cases because an Israeli address was not mentioned on the ISI record or because the journal in question is not covered by ISI or for some other reasons. Nevertheless, it was felt that the Israeli file gives an adequate, if slightly upward biased picture of the citations to Israeli papers.

2. Methods

Three scientometric indicators are relevant for the present purpose:

a) the total number of publications per scientist over a defined period of time; a more crude variant of this indicator is the total number of publications per 10000 population.
b) the average number of citations per paper.
c) the total number of citations per researcher, over a defined period of time or lifelong - taking into account his age.

Only the first two of these indicators will be touched upon in the present publication. The numbers of publications will also be subdivided into those that have never been cited and those that have been cited.

3. Results

According to the ISI data file for 1981-1990 [4], Israel has one of the highest rates of publications per inhabitant in the world; 110 per 10,000 population, against 72 for the US and the UK. The data are presented in figure 1. (The reader is warned that the ISI covers English language journals to a larger extent than journals in other
languages). (Figure 1)

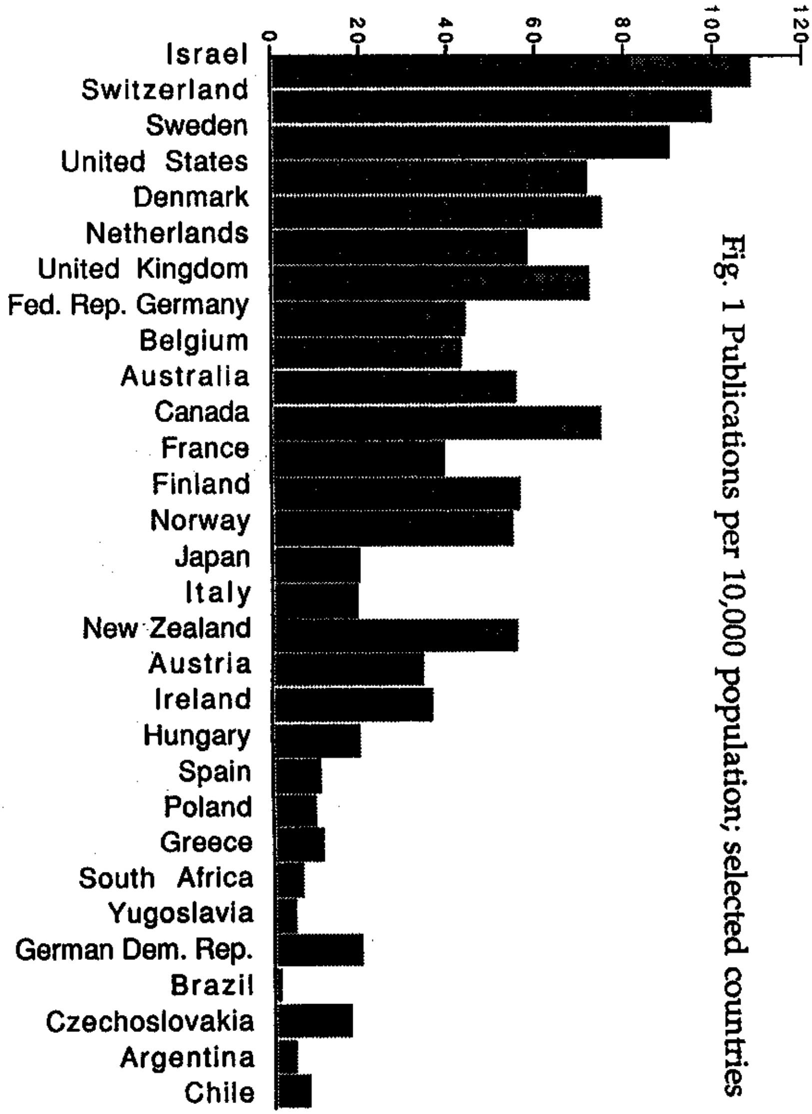
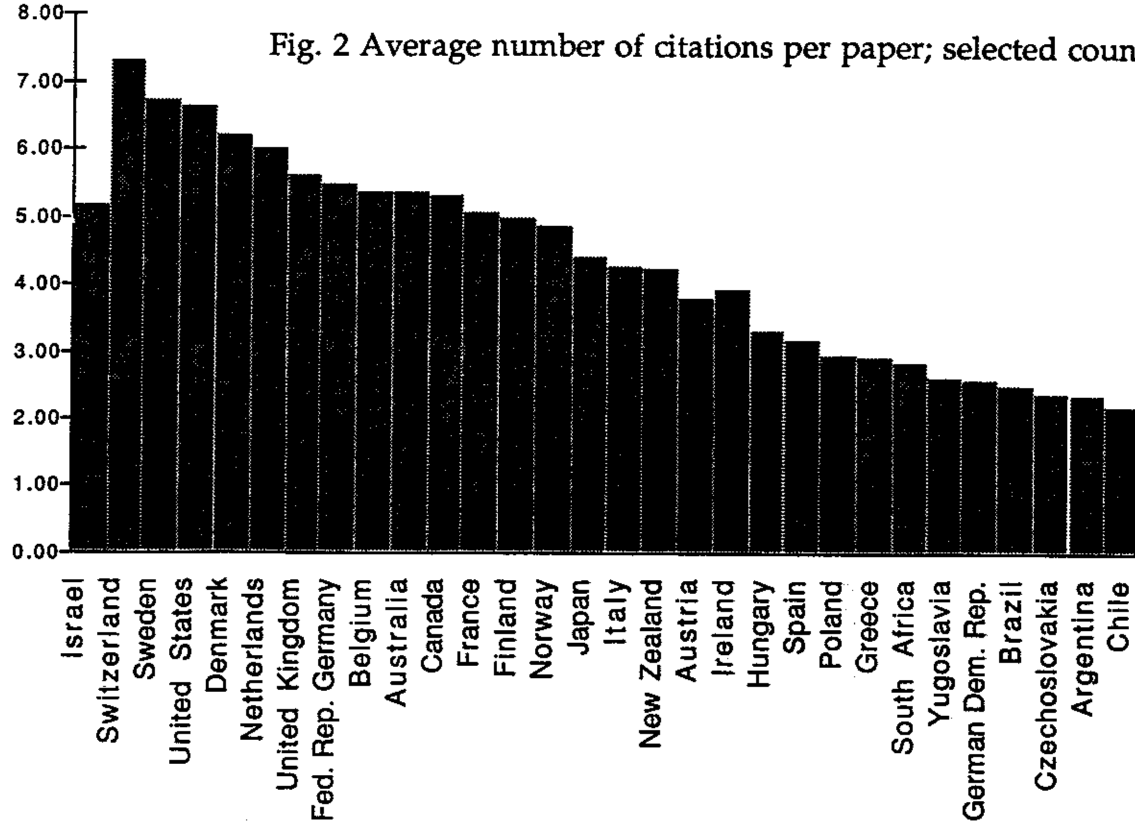


Fig. 1 Publications per 10,000 population; selected countries

Source: Based on ref. 4 with adjustments

Fig. 2 Average number of citations per paper; selected countries



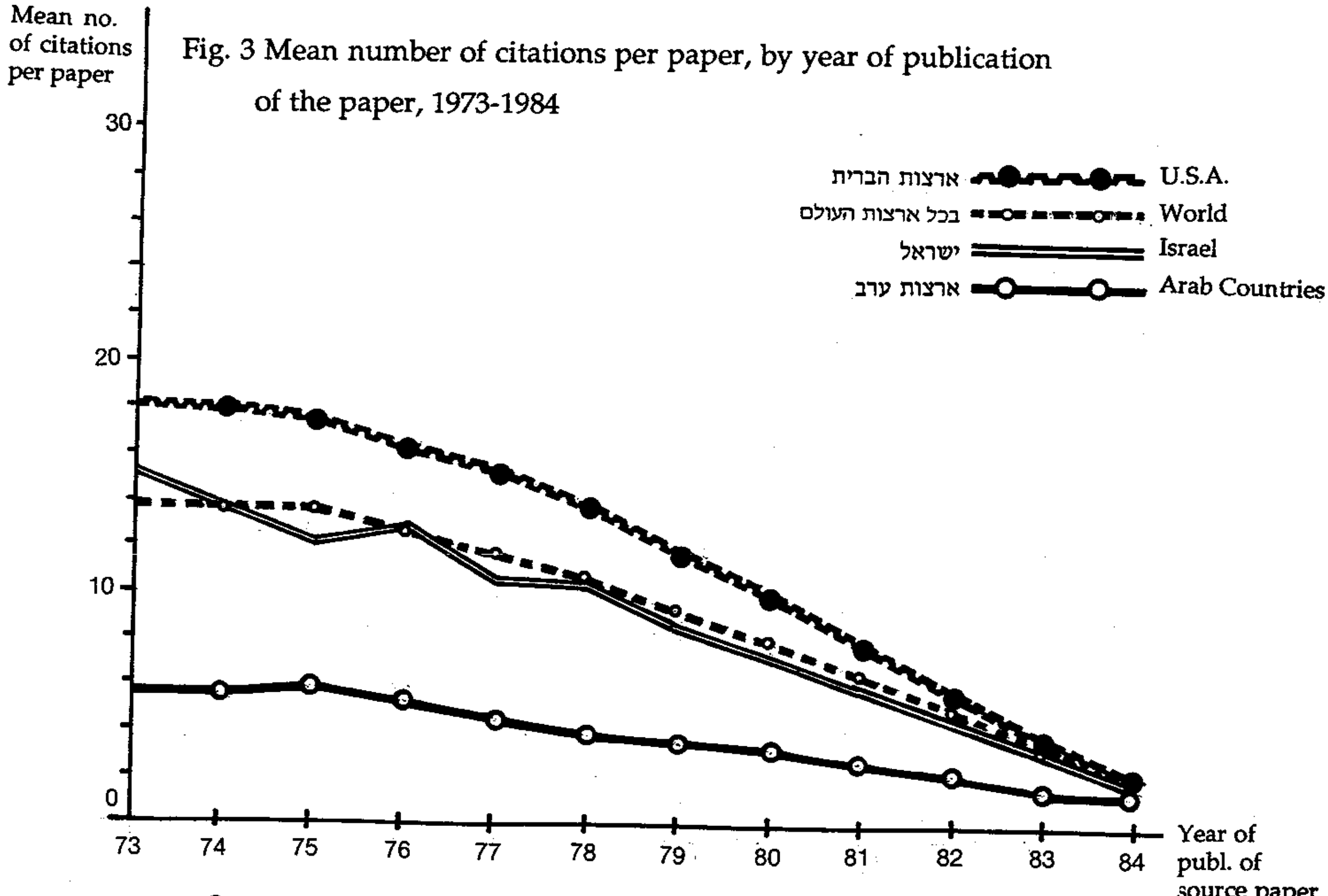
Source: Based on ref. 4

Another aspect of the situation is shown in figure 2. The average number of citations per paper is lower for Israel than for a number of other countries: Israel ranks twelfth in the list of countries compared by ISI. Loosely speaking it would seem, then, that while a disproportionately large number of Israeli papers are published, the numbers of citations of Israeli papers is not nearly as high, indicating a lower "quality" of their papers. (Figure 2)

The averages of figure 2 relate the number of citation in 1981-1990 to the numbers of papers published in the same period. A different approach is illustrated in figure 3. Here the number of citations during the period 1973-1984 is related to the number of papers published during each calendar year from 1973 till 1984. This calculation is being carried out for the entire world and for the USA, Israel and the Arab countries. These averages are not very meaningful in themselves, nor are they comparable to the data in figure 2. However, the position of these curves in relation to each other is meaningful; the difference between the mean number of citations in Israel and in the US is considerable; so is the difference between Israel and the Arab countries. (Figure 3).

What part of the Israeli output of research papers is produced by means of collaboration with another country? The reader is reminded that the "Israeli file" of ISI is defined by the fact that at least one author gives an Israeli address on the paper. Analogously, a paper produced by international collaboration is a paper for which at least one author gives an Israeli

Fig. 3 Mean number of citations per paper, by year of publication of the paper, 1973-1984



Source: Private communication from the late George Vladouz
ISI Philadelphia

address and at least one gives a foreign address. By this definition the percentage of collaborative papers rose from 14% in 1972 to almost 30% in 1990. Is is seen therefore that a substantial proportion, almost one third, of all Israeli scientific papers are created through the cooperation with some person or agency abroad. (In many of these instances most of the work was actually carried out abroad.). Most of this increase occurred during the years 1978-1990; in the previous period the averages were fairly stable. (Figure 4)

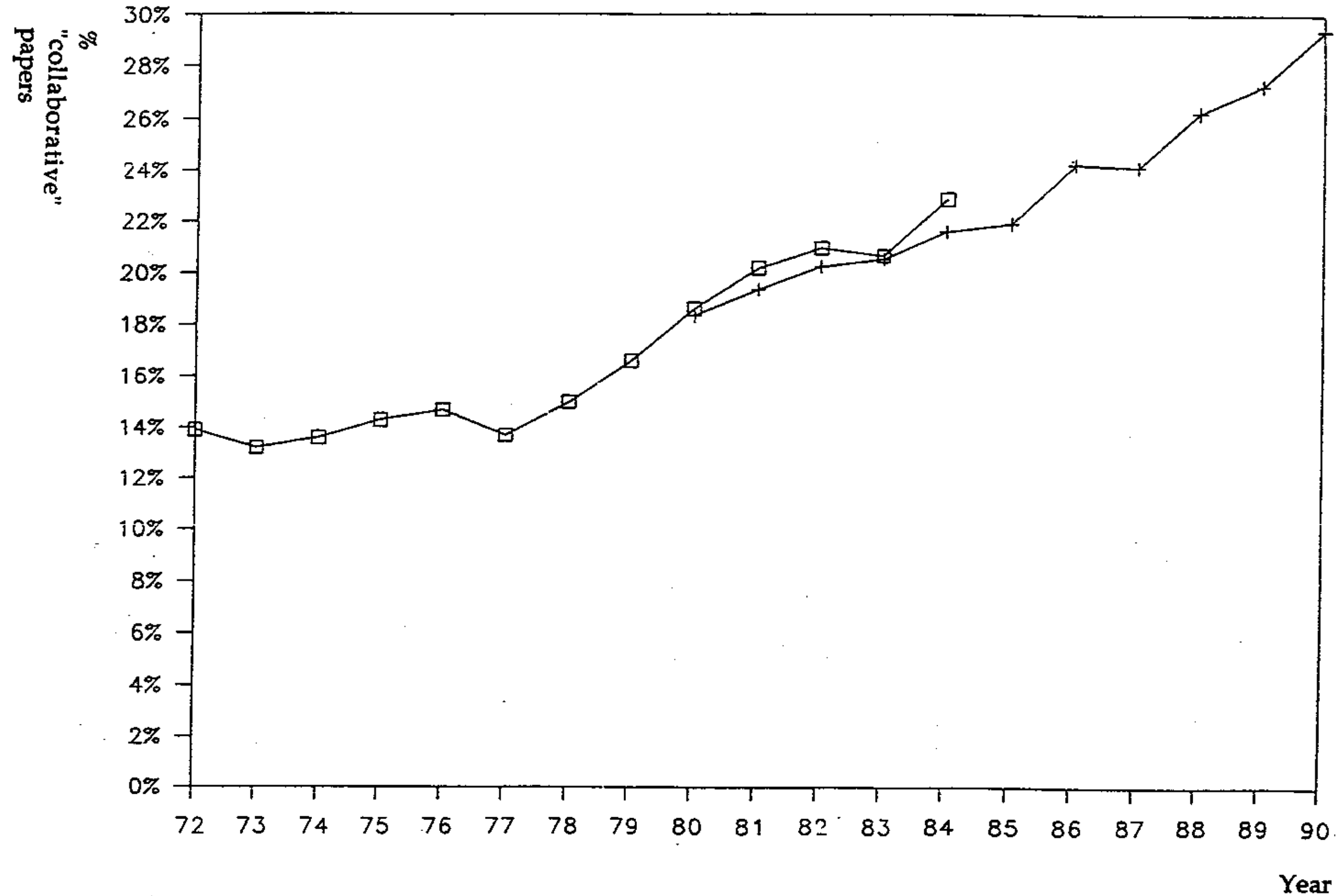
We now proceed to our final question, the average number of citation per paper among Israeli scientists according to whether or not the publication in question was the outcome of a collaborative effort. The data are given in table 1. (Table 1)

Table 1
The Average Number of Citations per Paper, and Percentage of Uncited Papers, according to the Collaborative Status.
Israeli Papers in the ISI file 1972-1984

"Collaborative" Status	No. of papers	Ave. no. of citations p. paper	% uncited papers
Collaborative	10941	11.6	36.5
Other	50241	8.6	46.5
Total	60731	9.2	44.8

It is seen that the papers produced by a collaborative venture with some other country are considerably more cited than those that are the outcome

Fig. 4 Percentage of Israeli papers produced by International collaboration, out of all Israeli papers, 1972-1990



Source: ISI Database

of local research. The ratio of these two averages is 1.35.

4. Discussion

An increasing share of Israel's scientific output is the result of a collaboration between Israeli and foreign researchers. Since Israel is a small country with a relatively large share of research personnel, concerned about avoiding isolation from the wider world of science, this collaboration is, on the whole, desirable. Nevertheless, there is always the possibility that a closer contact with research institutions abroad might lead to increased emigration.

On the face of it, the citation data seem to justify these fears. Not only are Israeli scientists less cited than those from other developed countries, but, in addition, the collaborative ventures of Israeli scientists are more cited than research carried out by Israelis alone. Furthermore, Israeli scientists tend to be prolific authors of research papers. It seems likely that the combined effect of these trends would make foreign research institutions look increasingly attractive. Nevertheless, the results of citation analysis may bear more than one interpretation and the above conclusion is uncertain. The reasons for these doubts are as follows:

a) Most institutions tend to be selective so that scholars who participate in collaborative ventures tend to be more able then those who do not. It is therefore only natural that their research product should be more cited than that of their peers at home.

b) Binational research has the advantage that it combines the natural audiences of two "invisible colleges". The outcome of this kind of work is likely to influence research in both countries and to be cited in both centers.

c) It is known that citation frequencies vary widely from one discipline to another. Therefore the range of disciplines of scientists engaged in collaborative research may be different from that of scientists who are not engaged in it. This in itself may explain the higher citation averages of collaborative studies. Similarly, this may explain at least partially the difference in citation averages between Israeli and, say, American scientists, or the difference between the high rate of citations per paper between a research center like the Weizmann Institute, with its strong emphasis on the life sciences, and other institutions in Israel and abroad.

Whatever the reasons for the trends outlined above, they should be studied closely. Their consequences may well be innocuous, yet it is also possible that they are danger signals, predicting serious difficulties for Israeli science.

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Citations: Their Role in the Evaluation of Scientific Activity

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1. Introduction

In recent years, the evaluation of scientific activity has become a major preoccupation for policy-makers in the field of science. This has happened because, on the one hand, science is now viewed as a major driving power in economic and social development and, on the other hand, because nowadays evaluation is an essential component in the formulation of development policies: in economics, education, health, transportation, welfare, protection of the environment or any other significant area. The evaluation of scientific activity is also linked to the study and prediction of the cumulation of information, the so-called "information explosion: a subject close to the heart of many in this audience. Citation analysis is an important tool in the evaluation of both scientific activity and the growth of scientific information.

To be sure, citation analysis has uses beyond the evaluation of science. The publication of research papers is part of the reward system of science and in that system citations are, in some sense, tokens of recognition [1-3]. In consequence, the history and the sociology of science have used citation analysis to study a variety of issues. The best known examples are the

"Matthew effect" [4] and the "Ortega hypothesis" [5] but there are, of course, many others. In this brief presentation, however, I shall confine myself to citation analysis performed with an evaluative objective in mind.

2. Reservations regarding the use of citations in research

Are citations a valid research tool? Reservations have been put forward in this respect and at least some of these need to be dealt with from the outset:

a) **Self-citations.** In general authors tend to cite themselves much more frequently than they cite others. The reason for this is supposed to be human vanity; in consequence, self-citations are assumed to bias comparisons.

The effect of self-citations has been largely exaggerated. Since the research output of a given author is the result of a certain continuity of ideas, very often a paper is the logical sequel of his previous publications and therefore does not constitute an argument against citation analysis.

b) **Non-pertinent citations.** Sometimes a citation seems to serve no useful purpose: it may be **redundant**, in the sense that it makes some point already dealt with by an earlier citation, or **casual** , i.e. mentioning some broadly related work without any comparison or comment [6-7].

In disciplines with perfect replicability, citations are sometimes redundant but this is mostly because competing researchers often work on the same problems and obtain identical results. In disciplines without perfect replicability citations cannot be properly called redundant. Casual citations exist in most disciplines but tend to be relatively rare.

c) **Negational citations.** This kind of citation occurs in most disciplines but is often qualified or modified in the text of the citing paper. In any case, the fact that some result or argument stated in one paper is denied by another does not necessarily detract from its heuristic value.

Several doubts and reservations refer not to the citations themselves but to the data-base from which they are extracted.

d) **Multiple Authorship.** Typically, citations appear under the name of the first author only; unless proper care is taken, this may detract from the share of junior authors, a fact which may be significant in the evaluation of a single author or of collaborative research. One may note here that the "proper" weight to be given to each author in multipleauthored research is still an open question.

e) **Homographs.** that is, names of different authors written in an identical manner, are also a potential source of error.

f) **Incompleteness of the data base.** This is indeed a source of potentially serious bias. Incomplete coverage of "foreign" languages, in particular, tends to be a problem, particularly in the social sciences and the humanities. The omission of significant journals in developing countries from the coverage of citation indices is another aspect of this problem.

Language and country bias are related not only to the bibliographic source. The reluctance of many researchers to consult material that is not written in their mother tongue is also to blame. Whatever its reason, the following example may illustrate the seriousness of the problem: about 2% of the citations in **Journal of the American Society for Information Science** are to documents written in a language other than English. At the same time in the **Nachrichten fur Dokumentation**, a journal covering the same disciplines as JASIS but written in German, almost 29% of the citations are to documents written in a language other than German [8].

On the whole, granting the inevitable amount of error and "noise", and in spite of Cronin's [9] critical analysis of the citation process itself, citations may serve as roughly valid raw material for analysis, provided that language, country bias, and other potential sources of inaccuracy stemming from the sources of information are duly taken in account. There are, however, other questions concerning the proper way to analyze citation data, which should be discussed.

3. Content-related variables and citations

It is common practice to count citations as if they all carried the same weight, regardless of the specific objectives of their analysis. This, however, is doubtful. Citations fulfill different functions in the citing paper and the importance we assign to these functions may have

something to do with our objectives. An example may serve to illustrate this point:
The percent distribution of citations according to their roles, in five journals from the social sciences and related fields, is presented below. The data are reproduced in an abbreviated form from a paper already mentioned [7].

The categories of the role classification are straightforward: "setting the stage" includes the citations to previous work which lead up to the present investigation; "background" cites documents on the study setting (e.g. on the population studied); "methodological" and "comparative" are self-explanatory; "argumental" includes all citations concerning new hypotheses, conjectures, suggestions for further study, etc.; "documentary" refers to the sources of data; "historical" citations retrace the history of the subject and "casual" citations have been mentioned before.

Table 1

Percent distribution of citations, by category in the journals analyzed

	American J. of Sociology	Demo graphy	American J. Educ. Research	American J. of Epidemiology	Library Research
Setting the stage	48.1	49.5	47.0	33.4	36.4
Background info	11.9	11.3	4.7	11.4	5.2
Methodology (design)	6.0	3.8	{25.1	5.5	11.0
Methodology (analysis)	6.8	10.4		3.6	10.4
Argumental	11.4	8.2	9.9	12.6	4.6
Comparative	5.3	8.0	9.2	30.8	19.7
Casual	7.6	3.0	3.1	1.2	1.7
Documentary	2.6	5.8	1.0	1.5	6.9
Historical	0.3	-	-	-	4.0
Total	100.0	100.0	100.0	100.0	100.0

The table shows clearly that the percentage distributions of the various categories differ widely from one journal to another. Differences as large as these are certainly neither random nor capricious. They may reflect the different working habits and traditions in the various disciplines. These habits and traditions, however, may become subjects of evaluation. Thus, one may ask whether the percentage of methodological papers cited in a given discipline or journal, or by a given research team, is not indicative of their methodological sophistication. Whether many citations in the "setting the stage" or the "comparative" categories say something about the cumulative nature of the disciplines; whether a paucity of citations in the argumental groups is due to a reluctance to theorize. Or, leaving the specific example given here, one may ask whether frequent citations from other fields are indicative of the interdisciplinary nature of the discipline. Such questions illustrate a creative use of citations, classified by their roles or by some other content-related characteristic, in clarifying very specific issues relating to evaluation.

The wish to sharpen one's evaluative objectives does not always require a content-related classification of citations. Often a classification of the source papers will suffice. In another paper [10] it was shown that, in sociology, methodological papers are cited more often than theoretical or empirical ones. Now, suppose that one is asked to compare two sociology departments to each other. The two departments are of equal size and exhibit similar numbers of citations but most of department A's citations are of methodological papers while department B is mostly cited for its empirical work.

Now, which of the two departments will be rated higher in this evaluation process? If one thinks that the development of strong methodological tools is essential to the growth of the discipline it will have to be department A. If, on the other hand, one feels that the test of a department's worth should be its contribution to the subject matter of sociology it will have to be department B.

In this particular instance the dilemma faced by the evaluator is of a philosophical nature. However, once the evaluative objectives are formulated in a sufficiently precise manner, the evaluation can be carried out by means of citation analysis in a fairly straightforward fashion. The following example will show that this is not always the case:

We tend to assume that, in some sense, a paper that is more **cited** is also more **important.** But in what sense is this true? Does it mean that a paper which provides the "definitive answer" to a given question tends to be more cited than one that does not do so?

In a recent analysis of clinical trials [11] I found that trials that were well-designed, randomized, carried out by a double-blind procedure, and with a relatively large number of subjects tend to be **less** cited than those that lack these characteristics. How can this happen? What is the explanation of this apparently paradoxical finding? We do not know for sure but one can offer at least a tentative interpretation:

A work tends to be more cited if it offers new ideas, new thoughts, if it suggests a new way of looking at the problem. A study of this kind is said to have a high heuristic value. If, on the other hand, a study provides the definitive treatment for a given condition, there is little reason to cite it, regardless of its intrinsic value. Science (medicine, in this case) simply regards the problem as solved and moves on to other matters.

If this interpretation is correct then early studies, proposing the idea, reporting animal experiments or small, preliminary investigations will be discussed, emulated, verified, contradicted - and consequently cited - in the literature, while definitive papers will be cited only if, by analogy, they inspire the investigation of a different subject.

As I said before, we have no assurance that this interpretation is indeed correct, but, if it is, how shall one evaluate, say, clinical trials? Should one follow the results of citation analysis and give highest marks to originality and creativity at the expense - to some extent - of methodological neatness, or should one give preference to the study whose results are the most solid? The question remains largely unanswered.

4. Reference sets in evaluative citation analysis

The previous section of this paper dealt with the sharpening of a study's evaluative objectives by introducing content-related variables into the analysis. However, even without looking at the contents of either the source papers or the citations there are questions relating to the analysis of citation data which have to be clarified. These questions have to do mostly with the concept of the **reference standard** to which the citations of a given body of source papers will have to be compared. Reference standards are the subject of another paper in this publication (Schubert and Braun) and therefore only considerations not covered in that study will be presented here.

Any comparative analysis has to face the difficulties which stem from the need to take into account at least two related factors which may affect the frequency of citations: the "size" of the research area in question and the size of the potential audience of the cited paper. Clearly, a paper dealing with a field in which there are many important research centers all over the world is likely to be cited more often than a paper in which only a handful of scholars are active - and this regardless of the intrinsic merit of the two papers. Similarly, a paper published in some obscure journal or in a language spoken by few researchers is more likely to be ignored than a paper which appeared in **Science** or **Nature**. Moreover, as has been repeatedly shown,the population of **producers** of research results in some fields is different from the population of their users (and hence their citers). Controlling for these two variables is difficult but important if one wants to compare, even roughly, the citability of different groups of papers.

The size of the potential audience of a paper can be controlled by confining comparisons to a defined set of journals. Thus, one may compare two departments working in more or less in the same field by: a) confining the comparison to a few key journals; b) comparing citation frequencies in the two departments for each journal separately; c) computing some appropriately weighted average between the comparisons of the individual journals. The problem becomes more complex if one wants to control the "size" of the field as well. The issue does not arise if one wants to evaluate small research teams working on a specific problem; all one has to do is to compare "like with like", that is, evaluate one team by comparing it to other teams working on the same or similar problems. In more general situations, however, when the evaluation involves an entire department or institute, which is active in a range of different areas, it is difficult to outline a general solution to the problem. In most cases one does not do too badly if one ignores the issue, but for a truly rigorous treatment one has to go back to a content-related variable: one must identify key fields of activity, both of the unit to be evaluated and of its "reference group", its yardstick for comparison.

5. Concluding remarks

Evaluating the scientific activity of research units by means of citation analysis is certainly worthwhile. Whatever his other motives, in most instances an author cites a paper in order to make a point that is relevant to his own study; therefore, highly cited papers are, generally, papers that were found relevant by many other scholars. The difficulties encountered in citation analysis involve not the worth of the individual citations(although they may involve their respective weight) but rather the canons of sound scientific research: avoiding biased sources and comparing (as far as possible) like with like . Indeed, some citation data sources tend to be incomplete in some well-defined area (language, geographic region) and this must be taken into account. Also, the need to compare scientific outputs in fields of different sizes and with different audiences raises some methodological questions. (Equally important are the problems involving reference standards but these are treated elsewhere).

Useful citation analyses conforming to the basic tenets of the scientific method are performed all the time and have established the legitimacy of the discipline. Nevertheless, in the last analysis, in order to perform a truly rigorous evaluation by citation analysis one has to go back to the main variables defining the contents of the source papers. In doing so one is forced to forego the use of large samples but, instead, one can work with a much more homogeneous body of material and one is offered the privilege of studying issues that are both exciting and meaningful.

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universities have been subjected to little thorough quantitative analysis. This is due in good part to the lack of readily available time series data on these activities.

In this paper we examine in a preliminary manner one of the quantifiable expressions of this activity, i.e. university patenting.

In the process of teaching and conducting academic research across the broad spectrum of scientific disciplines, universities become national repositories of accumulated scientific knowledge and techniques. This knowledge base is embodied in the universities' sophisticated research facilities, their well stocked libraries etc. However, the ultimate personification of this base is the academic staff themselves. In their published research they continually add new bits of information to the ever expanding scientific knowledge base.

In discussing the role of universities in national technological and innovative efforts, it is important to distinguish between those functions and activities which draw from the general pool of scientific knowledge maintained in universities, and their contributions in the generation of specific scientific and technological knowledge of potential commercial value. Probably the major contribution of universities to national technological and innovative efforts is related to the former type of activities. These activities include: the training of generations of students, who go on to man research laboratories in industry; the provision by academic staff of consultative and advisory services to industry; the provision by university departments and institutes of testing, analytical and other technical services; and the provision of specially designed refresher courses for industrial scientists and engineers.

Nonetheless, much of the efforts of national science and technology bodies in establishing research priorities and national programs are made in the hope of developing proprietary knowledge of significant and direct industrial importance in universities, among other research performing sectors. Applied research institutes have also been established in many universities for this purpose. When research reaches a stage where concrete commercial utilization can be envisaged, universities are ill suited to develop them to the stage of marketable products, let alone actually produce them. They may, however, transfer the rights for their exploitation to parties better equipped to complete their development and commercialize them. In such cases universities may desire patent protection for their inventions. Data on the patenting activity of universities, therefore, provide an indication of the level and of the direction of change in the development of novel innovations of potential industrial use by universities.

This paper focusses on the patenting activities of Israeli universities. It is based on a comprehensive study of Israeli patenting activity through 1984 [1] and updated information from published sources through 1987. The objectives of this paper are:

- to describe and analyse the major trends in the patenting activity of Israeli universities in Israel and abroad;
- to explore the policy implications of university patenting activity and possible uses of this data as an indicator of the inventive activities of universities in Israel and perhaps in other countries as well.

The analysis begins in Section 2 with a brief outline of the patenting and commercialization policies and mechanisms of Israeli universities, based on informal interviews held with officials responsible for these functions in five of the six Israeli universities that maintain significant patenting activity (2). This is followed in Section 3 by an overview of trends in the overall patenting activity of Israel and a more detailed analysis of university patenting activity including a comparison with the patenting activities of universities in the United States and Canada. In the final section the findings of the study are discussed and conclusions, albeit preliminary are presented.

2. Patent and Commercialization Policies and Mechanisms of Israeli Universities

By the late 1970's, all seven of Israel's major universities had established mechanisms for the promotion of relations with industry and the transfer of university research an inventions to the productive sector. In five of the universities separate know-how marketing companies were set up, while in the other two (Bar-Ilan University and the Technion - Israel Institute of

Technology) the above objectives were included among the primary responsibilities of the research authorities. No national organization for the exploitation of university inventions, such as the National Research and Development Corporation in the U.K. (now part of the British Technology Group) or Canadian Patents and Development Limited, a Federal Crown corporation in Canada, exist in Israel. In addition, private outside companies are generally not enlisted to assist in the marketing of inventions in Israel or abroad, as is the common practice of many U.S. universities, who market all or some of their inventions through such companies as The Research Corporation [3, p. 5].

The Patents Law of 1967 specifies that "service inventions", i.e. inventions of an employee arrived at in consequence of his service and during the period of his service are, as a rule, the property of the employer. This law has been embellished by each of the universities in the form of detailed rules and regulations regarding the rights and obligations of faculty employed by the universities in cases of the development of inventions of potential commercial value. These rules enjoy a high degree of compliance on the part of university staff, according to the officials we interviewed. All inventions developed by university staff while employed by the university are the property of the university, unless it relinquishes its rights to it. In general, the universities retain the rights to any invention resulting from research funded by outside entities, whether in the form of grants or contracts, with the exception of research funded by the Israeli Government. Various arrangements exist with the different governmental funding agencies, ranging from the outright transfer of the rights to the invention to the government, to limitations on the use of the invention, such as the establishment of a patent licensing agreement with a foreign firm, without the prior consent of the funding agency.

Royalties obtained from the licensing of the patents are split between the inventor and the university, with the inventor receiving between a third to 40% depending on the university. Generally, part of the royalties accruing to the university are allocated to the research funds of the inventor or his department, or to a general university research fund, for the advancement of research projects of commercial potential.

The patent policy of the universities with regard to which inventions to patent, at what stage in their development and in which countries is determined by special committees established by the universities, in close cooperation with the marketing company or research authority. Members of these committees generally include, among others, the vice-president of the university in charge of research and development and a representative of the marketing company or research authority. If and when a decision is made to patent, the priority patent will, as a rule, be filed in Israel. Criteria used in the initial decision to patent include the novelty and inventiveness of the invention, its commercial potential and the stage of its present development. Some universities seek concrete signs of interest on the part of industry prior to the decision to patent, while others view proof of proprietary rights to the invention as a necessary precondition to serious contacts with industrial and entrepreneurial entities. They therefore maintain a more liberal patenting policy with regard to the priority patent in Israel.

As a domestic patent provides protection for an invention only in Israel, patent applications may be filed abroad as well. In such cases applications are usually filed close to but within a year of the date of the domestic application in order to benefit from the provisions of the International (Paris) Convention, from the priority date of the initial application. As foreign patenting can easily run into expenditures of $10,000 and more as compared with the cost of approximately $1,000 to $1,500, for a domestic patent, far greater selectivity is applied in the decision to patent abroad. In the year subsequent to the local filing, attempts are made to seriously assess the potential value of the invention and to interest local and foreign firms in it. If an interested party is found, a patent licensing agreement is concluded and foreign patent protection is sought in conjunction with, and normally at the expense of, the licensee. This agreement generally stipulates the provision of research funds by the licensee for the continued development of the invention by the university, in addition to the royalty fees and other conditions under which the invention can be utilized. The rights to patents themselves are, as a rule, not assigned. If no interested party is found within a year, a number of options are open to the university. If the details of the invention have not been disclosed in a scientific publication or other manner and the invention does not appear to have been patented by someone else, the university may decide to abandon the original application and refile the patent application in Israel, thereby relinquishing its previous priority date and allowing it an additional year to search for a licensee before coming to a decision regarding foreign patenting. If the option to refile is not applicable and the invention is deemed to be of significant value, foreign patent protection may be sought at university expense. Patent protection abroad when decided upon is generally sought in the United States, Canada, Western Europe, Japan and in other countries as well depending on the specific circumstances of each invention.

In certain cases universities have entered joint ventures with local and foreign industrial and entrepreneurial concerns for the establishment of local hi-tech firms to develop and commercialize specific university inventions.

While the marketing of a university invention as a trade secret without attempting to obtain patent protection at any stage of the commercialization process was a distinct possibility, most of the officials interviewed stated that this approach was followed only on rare occasions.

Patent and commercialization policy can and does change over time and these changes can affect the level of patenting activity in a significant manner independent of changes in the number of patentable inventions developed on the campus. Most of the officials interviewed stated that major changes had not taken place in their patent policies in recent years and that their patenting activity in the 1980's reflected the level of inventive activity on campus. However, Yissum Research Development Company of the Hebrew University liberalized its patent policy in the mid-1980's and this was an important factor, although not the only one, in the recent sharp rise in its domestic patenting activity. Ramot, the marketing arm of Tel-Aviv university has become more selective in the last year, but this policy change is too recent to have affected the figures on patenting presented in the next section.

All of the officials interviewed stated that their efforts to market their inventions were not limited to local industry. Foreign firms are selected and approached simultaneously to their efforts with local firms. In addition representatives of foreign firms regularly scan the Israeli campuses for research work of relevance to their interests.

Finally, at this stage in our research, details of successful transfers of university technology were not requested. It was clear though that only a small number of the inventions resulted in significant royalty income. Most of the royalty income emanated from patent licensing agreements with foreign firms. Far greater success has been attained in attracting research contracts from industry as part of patent licensing agreements. All of the officials stated that industry had become a significant source of funds for university research. Once again a large fraction of these funds are from foreign firms.

3. Trends in the Patenting Activity of Israeli Universities

Before analysing university patenting in detail shall prove instructive to take a brief look at the total patenting activity of Israeli residents. Figure 1 represents the trends over the 1970's and 1980's in various measures of Israel's overall patenting activity. With the exception of domestic patent grants, all of these measures show remarkable growth. Generally, local patent protection is sought initially on inventions. Domestic patent applications of Israelis rose by over 350% between 1969 and 1987, from 231 in 1969 to 823 in 1987.

These applications undergo a substantive examination by a patent examiner for novelty, inventiveness and utility. Approximately 56% of domestic patent applications submitted by Israelis in the 1970's were eventually granted patents. During this period three and a half to four years elapsed on average between the filing date of a patent application and the date of the grant. The rise in domestic patent **applications** from the early 1970's began to find expression in the increasing number of domestic patent **grants** from the mid-1970's, continuing through 1982. After 1982 the number of domestic patent grants dropped in spite of the increasing number of applications submitted annually. This was the result of administrative constraints in the Patent Office which have caused an ever-increasing backlog of unexamined patent applications. Since 1982 then, the number of domestic patents granted ceased to be a sensitive and meaningful measure of changes in the level of patenting activity in Israel.

University Patenting Activity - The Case of Israel

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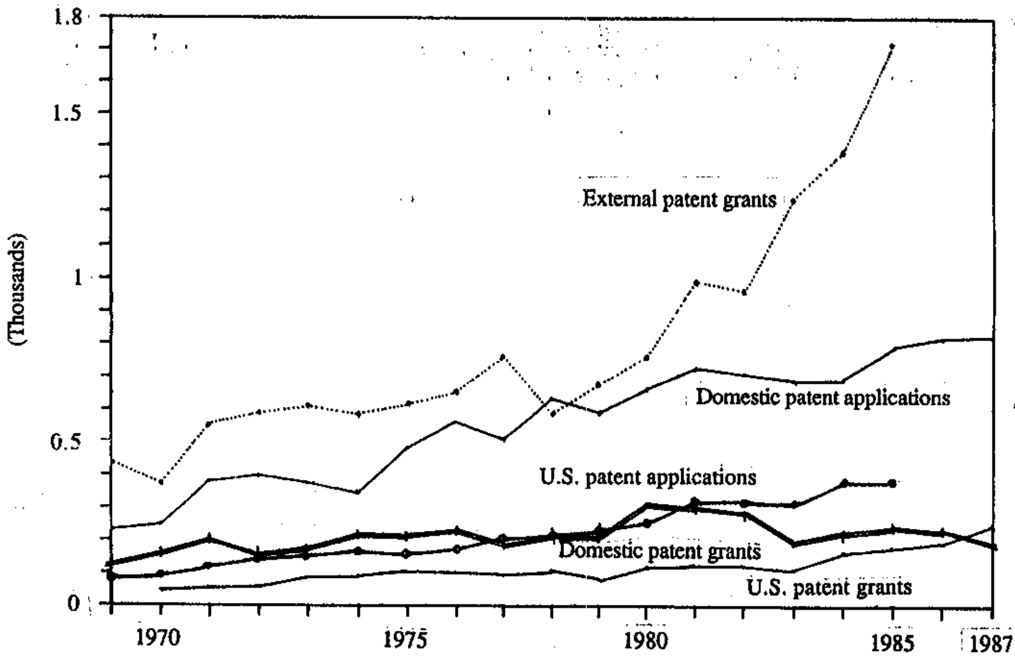
1. Introduction

In the research system of Israel, as in those of most developed western countries, universities are the traditional standard bearers of research activity of an international character, whose results are communicated to the world scientific community freely and openly primarily through publications appearing in scientific journals and books. The tools of scientometrics have been developed to study and evaluate this type of university activity in a quantitative, objective manner.

However, the activities of universities in Israel as elsewhere have never been limited to academic science. Indeed, in recent years, many universities in the western world have attempted to expand the scope of their activities and play a more dynamic, direct and immediate role in the technical and innovative efforts of their country in general, and of the region in which the are situated in particular. In addition, the enhancement and strengthening of the university/industry interface has for decades been a central tenet of national science and technology policy statements of the governments of developed western countries. Although it is a topic of numerous publications, the technological and innovative efforts of

Figure 1
Various measures of Israeli patenting activity 1969-1987



Sources: WIPO - World Industrial Property Organisation, **Industrial Property Statistics**, Israel Patent Office, and U.S. Patent and Trademark Office -**TAF -Technological Assessment and Forecast Geographical Profile Report - Israel** (July 1988).

Note: From 1978 the data on external patent applications include European Patent applications. In the period 1978-1984 each European Patent application was given a value of six external patent applications. See (1, pp. 21-22). In 1985 WIPO began to publish data on European Patent applications according to designatory country and country of origin. The figure appearing above for 1985 is based on this data.

A domestic patent provides protection only in the territorial confines of the State of Israel. Israeli residents seeking more extensive protection will therefore file abroad in those countries of importance to their strategy for the commercial utilization of the patented invention. As mentioned above such applications are usually filed in other countries close to but within a year of the domestic application. Patenting abroad, or external patenting as we refer to it here, is considered a better gauge of commercially relevant inventive activity than domestic patenting because it tends to weed out the less significant inventions of hobbyists and amateur inventors that are part and parcel of the domestic patenting activity of every country. The cost and effort incurred in applying for, securing and maintaining a patent abroad are considered to be generally prohibitive for those inventions with little serious economic potential [3, p.13]. Between 1969 and 1985 (the last year for which data is available to us) Israel's external patenting activity grew fourfold, from 430 in 1969 to 1,718 in 1985. It's external patenting activity grew quickly in the period prior to the advent of the European Patent Convention in 1978, but there can be no doubt of the stimulating effect of this innovative administrative mechanism on the patenting activity of Israel in the 1980's. By 1985 the European Patent had become the most frequently used channel for securing patent protection in Western Europe by Israeli residents and residents of most other countries as well.

The importance of the United States as the principal market for new technology and the major center of innovative activity in the world makes it an obvious target of the external patenting of most countries including Israel. One out of every three Israeli external patent applications in the late 1970's and early 1980's was filed in the United States. In 1985 this share dropped to slightly over a fifth, due primarily to the increased patenting activity of Israelis in European countries participating in the European Patent Convention. As much of the observed external patenting activity is the result of the multiple counting of the same invention being patented in numerous countries, a better indication of the growing importance of U.S. patenting to Israelis can be noted by comparing the number of U.S. patent applications of Israelis in a year with the number of domestic patent applications one year earlier. By 1984 and 1985 this share had reached 54% as compared with 41% in the early 1970's. Over the 1969-1985 period U.S. patent applications by Israeli residents grew by over 430%, while U.S. patents granted to Israelis between 1970 and 1987 grew by over 530%. In 1987 more patents were granted to Israelis in the U.S. than in Israel.

Among the developed OECD countries, only Japan registered growth rates in any of the various measures of patenting activity comparable to those of Israel, while no other OECD country even approached Israel's relative growth performance (see Table 1).

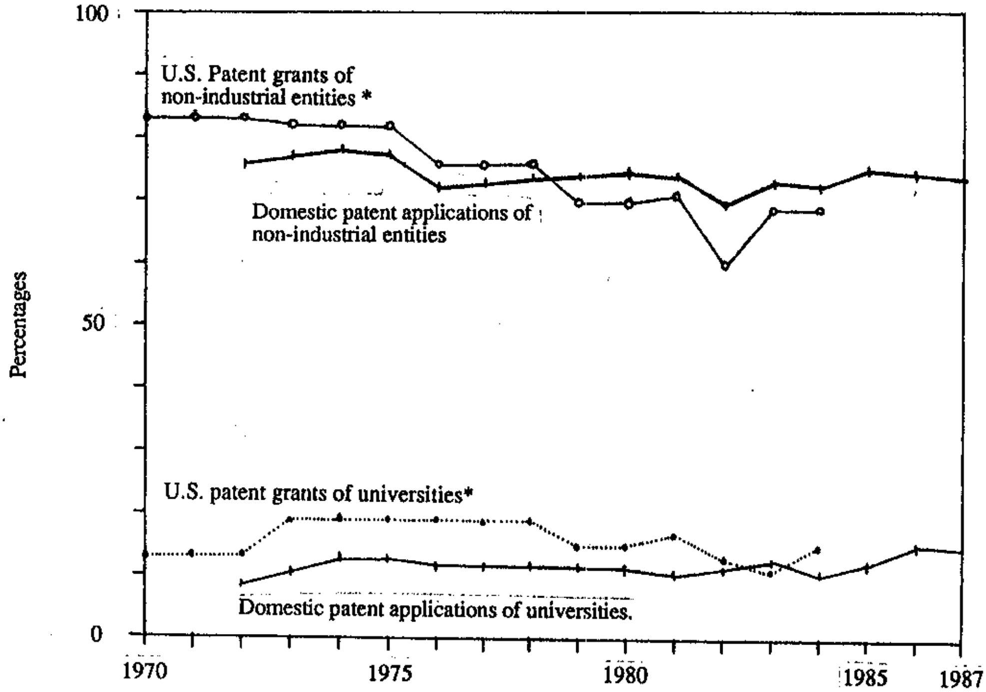
The interpretation that one can give to the above findings is dependent in great part on who is responsible for Israel's increased patenting activity both at home and abroad. Figure 2 reveals the rather surprising fact that Israeli industry, whose R&D expenditures grew more than elevenfold in real terms between 1969 and 1985, has played in the past and continues to play in the present a subordinate role to non-industrial entities in Israel's patent activity both in Israel and the United States. Three quarters of domestic patent applications in Israel in 1972 were filed by non-industrial entities and this share has remained relatively stable through 1987. The

Table 1
Measures of Overall Patenting Activity in Selected OECD Countries and Israel - 1972, 1985

	Domestic patent applications			External patent applications			External patent applications in the U.S.		
Country	1972	74,398	170.8	25,760	74,447	189.0	6,831	22,103	223.6
U.K.	24,337	22,044	-9.4	33,330	37,530	12.6	4,811	4,376	-9.0
France	14,807	13,512	-8.7	27,887	36,545	31.0	3,122	3,954	26.6
West Germany	33,381	39,625	18.7	62,544	93,640	49.7	7,782	11,330	45.2
Netherlands	2,283	2,886	26.4	11,390	13,503	18.5	916	1,281	39.8
Sweden	4,484	4,562	1.7	8,715	13,757	57.9	1,078	1,740	61.4
Switzerland	6,139	4,615	-24.8	25,493	24,728	-3.0	1,963	2,152	9.6
Belgium	1,342	1,023	-23.8	4,353	4,951	13.7	404	477	18.1
Canada	1,872	2,092	11.8	5,401	6,337	17.3	1,966	2,270	15.5
U.S.A.	65,943	63,874	-3.1	119,984	149,917	24.9	-	-	-
Israel	394	790	100.5	590	1,718	191.2	143	377	163.6

Source: WIPO, Industrial Property Statistics.

Figure 2
Patenting activity of universities and other non-industrial entities as a percentage of Israel's domesting and U.S. patenting activity 1970-1987



Sources: The data was assembled from the monthly editions of the Patents and Designs Journal of the Israel Patent Office and from the U.S. Patent and Trademark Office, TAF Organizational Profile Report - Israel - 1/1966-12/1983 and TAF Geographical Profile Report - Israel (July 1988).
According to date of application.

Note: From 1978 the data on external patent applications include European Patent applications. In the period 1978-1984 each European Patent application was given a value of six external patent applications. See (1, pp. 21-22). In 1985 WIPO began to publish data on European Patent applications according to designatory country and country of origin. The figure appearing above for 1985 is based on this data.

dominant ownership class of domestic patent applications in Israel is individual inventors. Their share of patent applications has dropped somewhat in recent years from 61% in the mid-1970's to 56% in 1987, but remains very high. Industrial firms, with about a quarter of all patent applications, are a poor second to individuals. The only other significant ownership class of domestic patent applications in Israel is universities, which have maintained a stable share of applications of between 10.5% and 12.7% since the mid-1970's, rising to about 15% since 1986.

Israeli patenting in the U.S. exhibited a similar pattern. The share of patents owned by Israeli industrial firms rose over the years from 17% of the total in the early 1970's to 31% in 1984. However, non-industrial entities remained throughout the dominant factor in Israel's patenting activity. Over 40% of the patents granted in the U.S. to Israelis during the 1970's belonged to individuals. This share dropped somewhat over time and amounted to 36% in 1984. The share of U.S. patents received annually owned by Israeli universities declined somewhat as well in recent years from its peak of 19% in the latter half of the 1970's to 15% in 1984. However, the rise in the share of domestic applications going to universities in 1986 and 1987 probably presages a resurgence in their share of U.S. patent grants in the late 1980's.

We do not have a breakdown according to ownership class for all of Israel's external patenting activity. However, detailed data of Israeli patenting in Canada from 1978 through May 1984 show that over 20% of Israeli patents were owned by universities [1, pp. 77-81]. A partial check of a few large European countries also clearly indicates that universities account for an important share of Israel's patenting in the United Kingdom

Table 2
Israel's Ten Leading Patentees* in Israel and the U.S. 1969-1987

Name	Sector	Domestic Patent acceptances 1970-87		Domestic Patent applications 1980-87		U.S. Patent grants 1969-1987	
		Number	Rank	Number	Rank	Number	Rank
Yeda (Weizmann Inst.)	Univ.	258	1	301	1	177	1
Ben-Gurion	Univ.	90	2	69	4	22	8
Yissum (Hebrew Univ.)	Univ.	89	3	166	2	37	4
Technion R&D Found.	Univ.	69	4	64	6	53	3
Drori M.	Individual	50	5	62	7	28 **	6
Tadiran	Company	45	6	26	N	10	N
Ramot (Tel-Aviv Univ.)	Univ.	43	7	87	3	31	5
TAMI	Govt/Comp~	37	8	5	N	19	N
Abic	Company	35	9	16	N	18	N
Elscint	Company	30	10	68	5	55	2
Israel Aircraft Ind.	Company	30	10	45	8	21	9
Bar-Ilan R&D Auth.	Univ.	9	N	30	10	3	N
Rosenberg P.& A.	Individual	25	N	38	9	20 **	10
Solmat Systems	Company	11	N	10	N	23	7

Source: The data was assembled from various published and unpublished sources of the Israel Patent Office and from the U.S. Patent and Trademark Office. TAF Organizational Profile Report - Israel - 1/1969-12/12983 and TAF Geographical Profile Report - Israel (July 1988).

* Not including the Government of Israel.
** Figures on individual patentees are for the years 1975-1983 only.
N Not in Top 10.
~ TAMI was a government research institute until its sale to Israel Chemicals Ltd. in the mid-1970's.

and France and probably in other countries as well. This impression is strengthened by the foreign patent policies of Israeli universities discussed in the previous section.

Table 2 provides additional evidence of the central position of Israeli universities in Israel's patenting activity. All of the four leading owners of domestic patent acceptances in Israel over the 197-1987 period were university know-how marketing organizations and research authorities and an additional university know-how marketing organization - Ramot - was ranked 7th. In the 1980's a few industrial firms significantly increased their domestic patenting activity, especially Elscint and Israel Aircraft Industries. Nonetheless the top four spots in domestic patenting applications remained in the hands of Israeli universities and six of the top ten. Bar-Ilan university, which had been somewhat inactive as far as patenting was concerned through the mid-1980's picked up its activity significantly in 1986 and 1987 and managed to enter the 10th slot in domestic patent applications. With regard to the U.S. patent grants as well, four out of the top five Israeli patentees were universities and, with Ben-Gurion University of the Negev in the eighth slot, half of the top 10 Israeli patentees in the U.S. were universities.

Table 3
Published Domestic Patent Applications of Universities According to Technological Field 1985-1987

Technological Field **	Total - All Patentees		Universities		
	Number	Percent*	Number	Percent*	Intensity-index~
Total	2,483	100.0%	349	100.0%	1.00
Agriculture and irrigation	159	6.4	12	3.4	0.54
Food	49	2.0	11	3.2	1.60
Personal and domestic articles	171	6.9	3	0.9	0.12
Medical instruments	201	8.1	26	7.4	0.92
Toys and games	77	3.1	-	-	-
Physical and chemical processes	116	4.7	17	4.9	1.04
Material treatment and handling	176	7.1	-	-	-
Printing	32	1.3	-	-	-
Transportation	148	6.0	2	0.6	0.10
Chemistry and drugs	383	15.4	197	56.4	3.66
Textiles and paper	36	1.4	2	0.6	0.40
Building	204	8.2	6	1.7	0.21
Engineering and machinery	115	4.6	3	0.9	0.19
Non-conventional energy	44	1.8	-	-	-
Lighting and heating	63	2.5	-	-	-
Weapons and ammunition	46	1.9	2	0.6	0.31
Instruments and controls	272	11.0	48	13.8	1.26
Electronics and electricity	149	6.0	14	4.0	0.67
Optics and lasers	42	1.7	6	1.7	1.02

Source: The data was assembled from the monthly editions of the Patents and Designs Journal of the Israel Patent Office.

* Sums may not equal totals due to rounding.

** The concordance between International Patent Classification and technological field can be found in [1, p. 122].

The Intensity Index (II) is calculated as follows: $IIj = \frac{auj}{aj} / \frac{\sum auj}{\sum aj}$

where a = number of applications, u = universities, and j = technological field.

Table 3 provides a comparative breakdown of total domestic patent applications with domestic applications of Israeli universities during the period 1985-1987 according to technological field. This breakdown is based on a simplistic classification scheme, coupling each international patent classification (IPC) class to one of 19 technological fields (for details see (1), p. 122). The table shows that the domestic patenting activity of universities is highly concentrated in the field of chemistry and drugs. Over 56% of all university patents fell in this field. Universities filed over half of all total domestic applications in this field while their share of total applications in all fields was only 14% in this period. This high concentration of chemical and drugs patents filed by universities finds expression in the Intensity Index appearing in the final column of the table. The "Intensity Index" in a specific technological field is defined as the share of total domestic patent applications in that field owned by universities divided by the university share of total domestic patent applications. An intensity index greater than 1.0 indicates that the patent activity of universities is strong in that field relative to the total performance, while an intensity index below 1.0 shows a relative weakness of university activity. The intensity index of chemistry and drugs (3.66) far exceeds the intensity index in any other field. A more detailed analysis of the field of chemistry and drugs revealed that the vast majority (77%) of university patents in this field were classified in IPC classes related to drugs and biotechnology, accounting for over 61% of domestic applications in these areas (intensity index equal to 4.35). In the final section of this paper we discuss the implications of the dominance of universities in the patenting activities in these fields.

From an international perspective, it would appear that Israeli universities have a high propensity to patent and are responsible for an unusually high share of the country's patenting activity. This can be seen from table 4 where we compare the domestic patenting activity of universities in the United States and Canada (the only countries outside of Israel for which we had data at our disposal) with the domestic and U.S. Patenting activity of Israeli universities. The table shows that in 1984 universities accounted for only a very marginal share of U.S. and Canadian domestic patenting activity, while 14% of domestic Israeli patent acceptances were owned by universities. Furthermore, the table shows that per million dollars of expenditure on university R&D, Israeli universities had a propensity to receive 2.25 and 9 times more domestic patents than American and Canadian universities respectively. In absolute terms as well Israeli universities actually outpatented Canadian universities, in spite of the considerable difference in the size of their respective university sectors. It is pertinent to note that the gap in the propensity to patent between Israeli and U.S. and Canadian universities would have been even larger were it not for the administratively caused decline in domestic Israeli patent grants since 1982, that we discussed above. The relative propensity of Israeli universities to patent remains high compared to their U.S. and Canadian counterparts even when comparing patents granted to Israeli universities in the U.S. with the domestic patenting of U.S. and Canadian universities. This latter finding is especially revealing if we recall from Section 2 that Israeli universities patent in the U.S. only in cases where patent licensing agreements have been signed or are in an advanced stage of negotiation, or when the invention is deemed to be of especially high commercial potential.

Table 4
A Comparison of University Patenting Activity in the U.S., Canada and Israel in 1984

	U.S. Universities	Canadian Universities	Israeli Universities
Domestic patents granted **	520 34	* ^	21
Domestic patents granted in U.S.	-- 23		NA
Domestic patents granted to universities as a percentage of total domestic patents granted	1.4%	1.0%	14.7%
Domestic patents granted per million $ expenditure on R&D in universities in 1981	0.08~	0.02	0.1
External patents granted in U.S. per million $ expenditure on R&D in universities in 1981 0.12	---	NA	

Source: U.S. Patent and Trademark Office, TAF Report, All Universities 1/1969-12/1984, (April, 1985); Statistics Canada, Science and Technology Indicators 1987, Ottawa, 1988, p. 155; Israel Patent Office, Patents & Designs Journal; National Science Board, Science and Engineering Indicators - 1987, Washington D.C. 1987, p. 238; OECD Selected S&T Indicators - Recent Results - 1981 - 1987, Paris, 1987, table 27; and Israel National Council for Research Development, Ministry of Science and Technology.

* Includes patents granted to the Research Corporation and University Patents Inc.

** Includes patents granted to Canadian Patents and Development Limited.

\- Not including R&D expenditures in Federally Funded Research and Development Centers (FFRDC's). Their inclusion would lower the ratio from 0.08 to 0.06.

^ The figure refers to published patent acceptances, which automatically become granted patents if no opposition is filed within three months of their publication.

Further evidence of the intensity of Israeli university patenting activity vis-a-vis U.S. universities can be ascertained by examining the number of universities patenting in each country. Slightly over 100 U.S. universities were granted at least one domestic patent in 1984 (5), while over 500 U.S. universities were actively engaged in R&D in the early 1980's. In Canada as well only 4 of the 48 universities and colleges identified as performing R&D in 1984 maintained more than sporadic domestic patenting activity in the 1980's [6]. In Israel, five of its seven major universities maintained constant patent activity throughout the 1980's and in recent years Bar-Ilan University has joined their ranks bringing up to six the number of active patenting universities in Israel. At present, the University of Haifa, which does not engage in research in the natural and engineering sciences of relevance to industry, is the only university in Israel not active in patenting.

In considering the very large gap in the intensity of patenting activity between Israeli and US universities, it is important to note the following:

- U.S. university patenting activity has risen quickly in recent years. Patents granted in 1986 totalled 636 as compared with 378 in 1980 and 520 in 1984 [7, p. 108].
- According to the U.S. National Science Board, the patenting activity of U.S. universities "does not reflect all of the inventive activity that takes place at universities. Although university staff and faculty may assign their patent rights to their institutions, they also may sometimes retain the rights as individuals or assign them to small companies with which they are associated" (ibid). Unfortunately, no hard figures are provided on the extent of these activities. These and other alternate routes for the exploitation of inventions by university staff exist in Israel as well (1, pp. 82, 84). However, according to the university officials we

interviewed their use was never great and is on the decline.

4. Discussions and Conclusions

The data presented in the previous section show that the patenting activity of Israeli universities:

- accounts for a consistently important fraction of total Israeli domestic and external patenting activity;
- is highly concentrated in the fields of chemicals and drugs with regard to domestic patenting and most likely with regard to external patenting as well;
- has grown significantly in absolute and relative terms over time;
- is far more intensive relative to university R&D expenditures and a more common and widespread practice than in universities in the U.S. and Canada.

In the discussion that follows, the meaning of these findings is analysed in a preliminary manner in terms of what they tell us about the inventive and innovative activities of Israeli universities and the impact of these activities on Israel's technological development.

1. Patenting and Inventive Activity in Israeli Universities

Let us begin with the relationship between patenting and inventive activity. In addition to the supply of inventions of commercial potential generated by university research. the level of university patenting activity is dependent on a considerable chain of intervening factors, which include:

- The awareness of university researchers to, and personal interest in the commercial exploitation of their research;

- The legal relationship between the university and its staff on the one hand, and the university and external funding organizations on the other hand, concerning the ownership of inventions generated by university research;
- The degree to which universities enforce these legal arrangements and university staff comply with them;
- The degree to which universities are interested in pursuing the commercial exploitation of their inventions and organize accordingly;
- The patentability of these inventions;
- University policy with respect to the commercialization of inventions as trade secrets as opposed to obtaining patent protection;
- The degree of selectivity of universities in their patenting policy.

All these possible leakages in the process of transforming a university generated invention of commercial potential into a university filed patent application were addressed in section 2 above. From that discussion it appears that the patenting activity of Israeli universities do reflect in a reasonable fashion the level of inventive activities in universities. Although changes in patenting policy and other changes effecting the level of patenting have occurred over time, the manyfold rise in patenting activity in Israel and abroad since the 1970's does appear to manifest a significant rise in the number of university inventions, in addition to the aggressive efforts of the management of Israeli universities to commercialize them.

This interpretation of the findings is supported by the trend in industrial funding of university research in Israel. Concommitant to the rise in university patents in Israel there has been a remarkable rise in the funding of university research by industry. Between 1972/73 and 1984/85 the expenditures of industry grew almost sevenfold, from approximately $1.0 million in 1972/73 to approximately $6.7 million in 1984/85 in constant 1984/85 prices. The share of these funds from total specially funded research expenditures of universities rose from 3.0% in 1972/73 to 9.5% in 1984/85 [8]. No separate figures are available from this survey on funding from foreign industry. On the basis of the information we received during the interviews with university officials, the addition of funds from foreign industry to the funds from local industry would raise the share of industrial funding of R&D in Israeli universities in the mid-1980's to approximately 20% of all research grants and contracts. In the U.S. the comparable figure for the share of U.S. industrial funding of university research was 6.0% in 1987 [7, p. 243], while Canadian business enterprises in 1987 funded approximately 6.6% of research grants and contracts in Canadian universities [6a, p. 57]. Foreign industrial funding of university research in Canada and the U.S. is apparently quite small relative to total university R&D expenditures [ibid, and 9]. From our discussion in section 2, it would appear that these two indicators are related to one another, as university marketing organizations and research authorities use existing patents to lure industrial funds for the further development of the invention. Similar remarks were made by officials of U.S. universities [3, p. 2]. Combining the data from patenting and industrial funding it appears that universities in Israel have a pronounced industrial and commercial orientation, especially in recent years.

We can gain some deeper insight into the relationship between inventive activity on the campus and university patenting by examining the breakdown of patenting activity according to university. Table 2 above shows that Yeda, associated with the Weizmann Institute of Science has been Israel's premier patenting organization both domestically and in the U.S. since the latter half of the 1960's (domestic patents granted in 1970 were applied for in the latter half of the 1960's). The Weizmann Institute of Science is at first glance an unlikely candidate for this position, as it is best known for its excellence in basic research in the natural sciences. On the other hand, the Technion, Israel's leading institute of technology and its major producer of engineers, ranked 4th among the universities in terms of domestic patent acceptances since 1970, fifth in patent applications in the 1980's and a distant second to Yeda in U.S. patent grants since 1970. One would expect a greater level of patent activity on their part.

One possible explanation for this apparent puzzle is the high concentration of research in the Weizmann Institute of Science in the fields of chemistry and the life sciences, particularly in biomedical research. In these fields basic research can lead to the discovery of new compounds, which are clearly patentable, and for which patent protection is warranted and readily enforceable. Research at the Technion, on the other hand, is concentrated in engineering sciences, where basic research is less likely to lead to patentable inventions. According to the officials interviewed from the Technion R&D Foundation, inventions arrived at are often process inventions which are easily circumvented and notoriously difficult to enforce as patents. On occasion inventions of this sort have been marketed as trade secrets by the Technion. This may explain the conservative (for Israel) patent policy pursued by the Technion of seeking signs of interest on the part of industry prior to filing a patent, and in general delaying the filing of a patent for as long as possible. Furthermore, over the years the Technion has consistently been the dominant performer of research funded by the Ministry of Defense in the university sector. The legal arrangements under which this research is performed and the nature of defense R&D may also prevent the filing of patents on inventions resulting from this research.

In Table 5 we examined the hypothesis that the level of research activity in the fields of chemistry and the life sciences may be important determinants of the patenting activity of the universities. The table indicates a very high degree of similarity in the ranking and relative share of individual universities in the breakdown of their domestic patent applications in 1984 and 1985 as compared to the breakdown of their R&D expenditures in the field of chemistry and the life sciences in 1984/85.

It appears then that the scientific fields in which a university in Israel is active are an important factor in explaining its patenting activity. However, other factors more intrinsic to the working environment in the different universities may have some explanatory power as well. With regard to the Weizmann Institute of Science it must be noted that it has played a pioneering and innovative role in strengthening university/industry relations. It was the first academic institution in Israel (1959) to establish a know-how marketing organization to commercially exploit its research. It was also the first institute in Israel to set up a science based industrial park adjoining the campus in the late 1960's and to set up science-based industries based on its own inventions in Israel in joint ownership with leading foreign firms. A recent study of university academic staff by Shye et al. [10] provides some provocative findings concerning this point, which must, however, be viewed at this stage as merely suggestive due to the small size of the sample on which they are based. The data from this study show that the share of researchers at the Weizmann Institute of Science that had maintained contacts with industrial concerns was higher than for any other university. This was especially true with regard to contacts with foreign firms. This is a topic that warrants further research.

2. University Patenting and the University/Industry Interface

Table 3 above showed the high concentration of university patenting activity in the fields of chemicals and drugs and their dominance of total Israeli domestic patenting activity in these fields, especially in the areas of drugs and biotechnology. Foreign pharmaceutical firms tend to patent heavily. The dominance of Israeli patenting activity in the drugs field by Israeli universities and the lack of significant patenting by local industry in this area is indicative of the structural imbalance existing in Israel's research system in this field. Similarly a previous study of ours [11, pp. 72,78] showed that unlike large foreign pharmaceutical firms. Israeli drug firms publish little or no research in scientific journals. A strong, broad based and relatively large university biomedical research community in Israel is interfaced with an extremely small (by international standards) local drug industry. The result of this situation, according to the officials we interviewed, is that many of the university discoveries of commercial potential in this field are licensed to foreign firms either because local industry is not involved in that particular speciality or because the development of the discovery has not reached the stage at which local industry can efficiently absorb it and bring it to the market.

3. The Commercialization of University Inventions

Universities are generally unable to undertake the actual commercial production of their inventions. The commercialization of these inventions requires the disclosure and transfer of the technical details of the invention to interested financial, entrepreneurial or industrial parties. There is no doubt that patent protection plays a crucial role in this transfer process. Without this protection, the university would be unwilling to divulge the details of its inventions. Even if it were willing to do so, outside parties might be hesitant to invest the time and money required to seriously investigate the technical features and commercial potential of the invention without the assurance of patent protection.

Results of a recent study [10], seem to imply a link connecting inventions of university staff, university patenting and industrial commercialization. In this study a representative sample of senior academic staff (lecturer and above) in Israeli universities were requested to provide information on various aspects of their research activities over their career, including details of the outputs and of the outcomes of their activities in their major area of research . Approximately one sixth of the researchers in the sample in the natural sciences, engineering and health sciences were the inventors of at least one patented invention. Specially produced cross-tabulations from this study show that researchers holding a patent had a far greater likelihood to have maintained, at some time during their career, concrete ties with an industrial firm for the application of their research than researchers that did not hold a patent. Ties included here range from researchers whose contact with an industrial firm did not go beyond the stage of negotiations to cases of complete commercialization of the research. Approximately 60% of researchers holding a patent had maintained such ties with a local firm and a similar share with a foreign firm. For researchers who did not hold a patent the comparable figures were 30% and 24% respectively. However, this assessment is far from

Table 5

A Comparison of domestic patent applications of Universities in Israel, and their expenditures on R&D according to University (Percentages)

	Domestic patent applications 1984-1985	R&D expenditures in the natural and engineering sciences 1984/85	R&D expenditures in chemistry and the life sciences* 1984/85
Total	100.0	100.0	100.0
Weizmann Institute of Science	43.9	34.9	45.9
Hebrew University	26.9	23.7	25.4
Tel Aviv University	8.5	12.8	12.9
Technion	11.1	18.3	7.6
Ben-Gurion University of the Negev	5.8	7.1	4.5
Bar-Ilan University	3.7	3.3	3.7

Source: Israel Patent Office, published and unpublished data, and Israel Central Bureau of Statistics, R&D Inputs in Universities 1980/81-1984/85, 1989 Jerusalem.

* Includes life and health sciences.

conclusive, as researchers in their replies to the questionnaire may have referred to advisory services provided to industry, in which their expertise in a specific area is enlisted in the development of new industrial products, rather than the transfer to industry of a specific technology developed by the researcher.

There is no doubt that the patenting activity of Israeli universities at home and especially abroad indicates a serious interest on their part to transfer their inventions. However, in order to make a case that patented university inventions have had an effect on Israel's technological development, one would have to show that such transfers actually took place and that the inventions were actually used in the production of goods and services in Israel. The patent data presented here provide little or no concrete information on either of these events. The problems involved in transferring inventions developed in a non-industrial environment to an industrial environment are numerous. Studies performed in the U.S. and United Kingdom have shown that patents granted to industry are worked to a far greater extent than patents invented outside of industry (12). As exemplified by the case of the drug industry mentioned above, these problems are likely to be especially acute in a small country like Israel, where the spectrum of scientific specialities dealt with in the universities is far broader than the spectrum of technologies used by local industry. This state of affairs can lead to situations where patent licensing agreements are entered into with foreign firms, that may not be in the best long term interests of the technological development of the country. The above analysis applies to individual and other non-industrial inventors as well. The large and increasing number of patents emanating from universities and other non-industrial sources in Israel raises the question of the technological and commercial impact of these patents and the possible need of science and technology policymakers at the national level to consider means, in adition to patent protection, to effect the transfer of these inventions to Israel's productive sector. A study by Noam of the outcomes of all domestic patent applications filed in Israel in 1975, addresses these issues. [13]

4. University Patenting as an International S&T Indicator

There appears to be a dearth of material on the patenting activity of universities in other countries. We, at any rate, were able to obtain time series data only for the U.S. and Canada. Whereas university patenting seems to be a good indicator of inventive activity in Israeli universities, the same cannot be said for university patenting activity in the U.S. and Canada. The large number of universities inactive in patenting betrays more likely a lack of proper organization on the part of university management to commercialize inventions than the absence of such inventions. In addition, significant legal changes of direct relevance to university patenting activity have been enacted recently in the U.S. The U.S. Patent Law of 1980 which provides that universities and other small businesses retain title to inventions resulting from government funded research may have encouraged university patenting activity after 1980, in contrast to the situation prior to 1980 under which the federal government held title to inventions resulting from research it funded. It is as yet unclear what impact, if any, this change of Law has had on university patenting in the U.S. However, it does appear to have increased the awareness to the need of patent protection and brought about changes in the patent policy of many universities [3, p. 14].

Clearly in-depth studies of university patenting activity in other developed countries could be beneficial to our understanding of the inventive activities of universities and the effective transfer of these inventions to the productive sector. In this regard it is important to examine the situation in countries of varying sizes and research systems, as the roles of universities in the technological development of their respective countries may change accordingly.

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3. U.S. General Accounting Office, *University Research Efforts Under Public Law 96-517*, GAO/RCED 86-93, Washington D.C. 1986.

4. National Science Board, *Science Indicators 1982,* National Science Foundation, Washington D.C. 1982.

5. U.S. Patent and Trademark Office. *TAF Custom Report All Universities 1/1969-12/1984*. Washington D.C. April 1985. The figure does not include universities which marketed their patents through patent management companies such as the The Research Corp. and University Patents Inc. Approximately one third of the universities granted patents in 1984 were granted only one patent.

6. Statistics Canada, *Science and Technology Indicators 1987*. Ottawa. 1988, p. 155; and *Estimation of Research and Development Expenditures in the Higher Education Sector, 1984-85*. Ottawa, 1986, pp. 7-8. Some universities in Canada may patent exclusively through Canadian Patents and Development Ltd. However, their number cannot be large as the total number of patents awarded to the company averaged 9 per year in the 1980's.

7. National Science Board, *Science and Engineering Indicators - 1987*, National Science Foundation, Washington D.C., 1987.

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