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The evaluation of national performance in selected priority areas using scientometric methods

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Abstract

How effectively can 'emerging' science-based technologies be coupled to national R&D systems? Dutch and Canadian priority programs in biotechnology and advanced materials are analyzed in terms of differential increases in scientific output by using scientometric indicators and mappings. Methodological issues about using scientometric methods for science policy evaluations in the case of interdisciplinary and rapidly changing areas of 'techno-science' are discussed. The major finding of the paper is that Canadian researchers seem to have used the priority programs as an alternative source of funding, while their Dutch colleagues were able to use these programs to help their specialties grow above the national average, and in accordance with selected priorities. Thus, the results suggest that the national dimension has been more important for explaining differences in performance than the substantive specificity of the two priority areas.

1. Introduction

In reaction to the second oil crisis (1979), governments in the advanced industrial world came under pressure to develop policies with respect to competitive advantages in science-based technologies (OECD, 1980). Innovations in areas like 'advanced materials' and 'biotechnology', for example, were expected to shape future markets of potential substitutes for 'natural' products and 'raw' materials. These areas, therefore, were considered as offering strategic opportunities for international economic competition between the highly industrialized part of the world and the so-called 'low wage' countries. [1] A strengthening of the respective national knowledge infrastructures, however, was considered a prerequisite to meeting these challenges (OECD, 1990).

Policy initiatives varied among OECD countries, but typically included the stimulation of university/industry relations and the formulation of cooperative national priority programs. Initially, it was a matter of some concern that the various OECD countries confronted with problems of competition at the level of the world market tended to make similar choices with respect to the noted priority areas. At the national level, however, the specificities of the science policy systems, the strengths and weaknesses of the national economic and R&D systems, and delays in implementation introduced variations in the effectiveness of the stated objectives (OECD, 1988; Nelson, 1993).

In this study, we compare Canada with the Netherlands in terms of how these two systems met

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[1] For the market impact of substitution by technological change, see, e.g. Fisher and Pry (1971).

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the challenges in the emerging areas of biotechnology and advanced materials during the 1980s. Particularly, we focus on the selective stimulation of the science base in these two countries. From the perspective of hindsight (i.e. using 1993 data), we delineate a set of core journals which can be identified as specific indicators of the developments in and among the disciplines under study. This part of the study is based on factor analysis of aggregated journal–journal citation matrices (Leydesdorff, 1986; Leydesdorff and Cozzens, 1993). By using the corporate addresses of authors publishing in the relevant journals, one can backtrack from the journal structure to the national performance data for Canada and the Netherlands, respectively. The attribution of this data to the previously distinguished disciplinary affiliations of the journals provides us with information about the effectiveness of science policies in relation to existing relevant disciplines, new developments, and the emerging (interdisciplinary) areas.

More generally, the cross-tabling of Canada and the Netherlands versus biotechnology and advanced materials provides us with a model for studying the relations between worldwide technological developments and national (i.e. institutional) R&D systems (Nelson, 1994; cf. Nelson, 1993). This coupling, however, is only one part of a national system of innovation, since the latter also includes university/industry relations, industrial strengths and weaknesses, etc. The model system presented here, in principle, can be extended along both dimensions, and with patent data. We return to these issues in the discussion section. By taking Canadian and Dutch science policies as the frame of reference, we are able to obtain information which we can then appreciate in terms of its relevance for national policies in view of our background knowledge of these systems.

2. The science policy context

Canada and the Netherlands are comparable in a number of respects. First, both countries are OECD member states with elaborate science policies and established R&D systems. Second, the two systems are highly dependent on the international environment. Furthermore, during the 1970s the Dutch science policy system developed its own model of 'concerted action' with reference to the Canadian science policy model (Second Chamber of Parliament, 1974). Thus, well-developed channels of communication between the two countries have existed both bilaterally and at the international level.

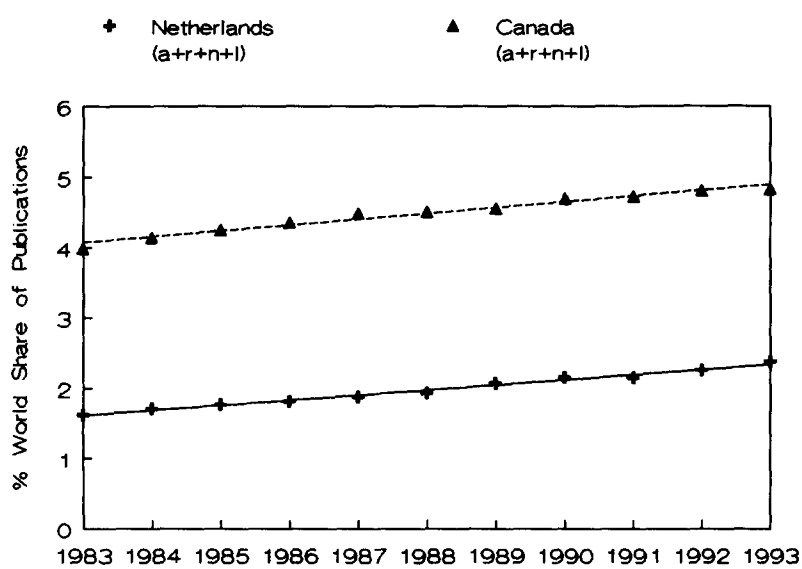

Fig. 1. Percentage world share of the Netherlands and Canada.

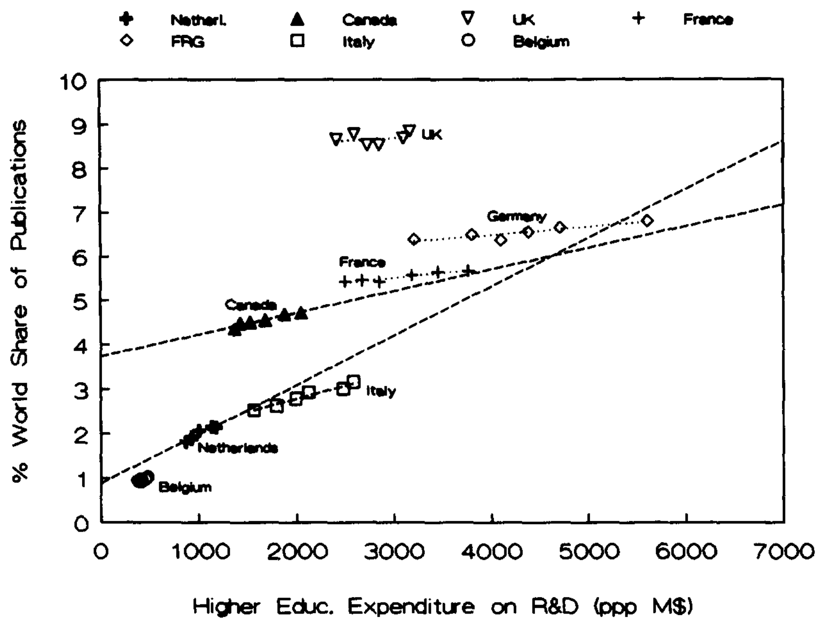

Fig. 2. Input–output statistics for national R&D systems, 1986–1991.

The R&D systems of both countries are in good shape. Fig. 1 shows performance at the aggregate level in terms of percentage of world share of publications for Canada and the Netherlands, in a format which is similar to the one which we shall use in later sections (see below). [2] Such R&D systems challenge policymakers as strategic resources which can be used for the creation of economic wealth if they manage to improve performance selectively and in accordance with industrial needs (e.g. Van den Daele et al., 1976).

An important difference between the two systems is made visible in Fig. 2, by relating the output data given in Fig. 1 to OECD statistics about expenditure on R&D for the two national systems (OECD, 1993, 1994a). [3] Data for various countries have been added in a similar format in order to highlight the point which we wish to make, i.e. that countries differ considerably in their output/input ratios, and thus in terms of the effectiveness of the overall system. Part of the problem of science policy in countries like Canada and the UK may be that these R&D systems are relatively efficient, and thus have difficulty increasing their respective marginal returns. Scientists from non-English speaking countries, such as the Netherlands, publish a considerable number of articles or reports in languages other than English and in serials which are not covered by the *Science Citation Index* (*SCI*). The possibility of a change in publication habits provides these systems with an additional degree of freedom.

2.1. The Dutch case

The Dutch government launched a series of so-called 'innovation-oriented research programs' in selected priority areas in response to a national debate on 'reindustrialization' in 1980 (WRR, 1980). 'Biotechnology' was one of the selected priority areas right from the beginning, because of (1) strengths and weaknesses in the Dutch knowledge infrastructure (Programmacommissie Biotechnologie, 1982;

[2] Throughout this article, regression lines are drawn if they fit above the 99% level; broken lines indicate a fit above the 95% level. Otherwise, lines are dotted for the convenience of the reader.

[3] Since output was measured in terms of percentage of world share of publications, higher education expenditure on R&D seems the appropriate input indicator. However, the differences between Canada and the Netherlands become even more pronounced if statistics about general expenditure on R&D are used instead.

Rip and Nederhof, 1986; OECD, 1988) and (2) the relevance of biotechnology research for various sectors of the Dutch economy (e.g. agriculture, specialty chemistry, and pharmaceutics) (Second Chamber of Parliament, 1984; Nederhof, 1988).

These national 'innovation-oriented research programs' were primarily meant to stimulate strategic thinking among the relevant actors involved in organizing the knowledge infrastructure in the selected areas. Additionally, the respective program committees were provided with means both in terms of finance and in terms of authority to influence ongoing developments in academia and at the university/industry interface. In the case of the biotechnology program, the additional funding amounted to approximately \$20m per year (OECD, 1988). Given a higher education expenditure on R&D of the order of \$1000m, this is not a negligible stimulus. [4]

Dutch policy efforts in the area of advanced materials were shaped only from 1986/1987 onwards (Second Chamber of Parliament, 1985). Efforts have focused mainly on the chemical side of the priority area, i.e. on polymers and composites (Zeldenrust, 1989; OECD, 1990). Until recently, metals and alloys have not been made the subject of major national science policy efforts (Adviesgroep Materialen, 1991; Overlegcommissie Verkenningen, 1992). In a recent policy review, Gathier and Broesterhuizen (1992, p. 97) concluded that "quite a number of initiatives were taken in materials S&T, but here it seemed difficult to come to a comprehensive and coherent policy."

In summary, the Dutch innovation program in biotechnology was structured early in the 1980s. The program committee could build on a strong existing research portfolio in relevant fields like biochemistry, molecular biology, microbiology, and process technology. Given the structure of Dutch industry, biotechnology and new chemical materials were considered highly relevant as potential sources of innovation.

[4] In 1991, The OECD (1994b) listed the higher education expenditure on R&D for the Netherlands at M\$1175 PPA; the gross domestic expenditure on R&D was M\$4750 PPA.

2.2. *The Canadian case*

The Canadian government has put great emphasis on 'advanced materials' as a strategic priority area. Canada has traditionally been highly dependent on the use and export of (raw) materials. Although the Canadian strategy in the field of biotechnology was developed somewhat earlier, the funding for research in advanced materials was more substantive, and the policy effort was organized more strategically than in the biotechnology area.

Recently, Isnor (1993) evaluated the federal biotechnology policy in Canada. Although he argued that a targeted policy approach is more necessary in the case of Canada than in other nations, and that in general spending has not lagged behind, his policy analysis provides us with a picture of a focus on biotechnological industry and on university–industry relations with planning efforts directed less to the substance of the research than in the case of the Netherlands (cf. Canada National Biotechnology Advisory Committee, 1991). A survey of the OECD from 1988 about national biotechnology programs mentions the Netherlands among the countries that have endeavored to achieve vertical and/or lateral coordination of R&D policies and programs in biotechnology, while Canada is mentioned in a second row of countries that "have established coordinating committees, but have not yet achieved or sought to achieve the extent or degree of integration sought by those countries mentioned above" (OECD, 1988). For example, it is noted – with reference to a report of the Science Council of Canada (1985) – that the general situation in plant biotechnology research in Canada can be "characterised by high quality but small and isolated research groups" (OECD, 1988, p. 31).

In a survey by this same organization about advanced materials (OECD, 1990), one notices a strong coordination in this field on the Canadian side. Strategic research in advanced industrial materials and processes has been the area most highly funded by the Natural Sciences and Engineering Research Council during the last decade. A total of 40 universities received grants in advanced materials research in 1987/1988; 6 centers received the equivalent of more than a million US dollars. In 1990, 27 of the country's 82 universities offered undergraduate

Table 1
Expected results of the analysis

	biotechnology	advanced materials
The Netherlands	+	∓
Canada	−	+

and/or postgraduate (Master's/Ph.D.) specialized courses in materials.

The advanced materials program has been perhaps as strategically important for Canadian policies as the biotechnology program has been in the Dutch context (Van Ruskenveld, 1988). The Canadian program in biotechnology developed slowly during the 1980s; given its focus on the applied side and on institutional rearrangements (Isnor, 1993), there are no reasons to expect a significant impact on the R&D system (Leydesdorff and Van der Schaar, 1987).

2.3. Conclusions from the policy analysis

Table 1 summarizes our expectations on the basis of this (limited) policy analysis. First, one expects to find effects of the Dutch policy efforts in biotechnology and of the Canadian efforts in advanced materials. Both programs were directly aimed at influencing higher-education related R&D, and therefore these effects should be measurable in terms of publications.

The effects of Canadian science policy in the area of biotechnology and of Dutch science policy in advanced materials are expected to be significantly lower than in the other two boxes of Table 1. In the Dutch advanced materials case a possible effect is more specifically expected on the chemical side, but at a later date than in the case of biotechnology.

3. Methods

One problem for the scientometric evaluation of priority areas has been the need to account for change both at the level of relevant scientific fields and at the level of performance within these fields. What counts as 'biotechnology' or 'new materials' is expected to vary from place to place (Bud, 1988, 1994; Nederhof, 1988), and the relevant delineations change not least because these fields are subject to interventionist policies. [5] Additionally, the various types of change may feed back to one another (Leydesdorff and Van der Schaar, 1987).

Changes at the field level can be analytically separated from changes in national (or institutional) performance in terms of scientometric operationalizations (Leydesdorff et al., 1994). Thus, we shall proceed in two steps: first, we study the developments at the field level, and then we focus on publication performance, given changes in the structure of the field and given different policy efforts. The (second) evaluation *with hindsight* is central to our argument, and our conclusions therefore will largely be based on the configurations among the relevant disciplines and interdisciplinary areas as analyzed using data for 1993. However, the study of developments at the field level is necessary for legitimating the attribution of publications to disciplinary affiliations.

Developments at the field level can be studied by using a variety of methods. We shall use methods for dynamic journal mapping based on aggregated journal–journal citations. One advantage of these methods is that they have been extensively studied and corroborated by a variety of research groups (e.g. Carpenter and Narin, 1973; Doreian and Fararo, 1985; Leydesdorff, 1986; Tijssen et al., 1987; Cozzens and Leydesdorff, 1992; Leydesdorff and Cozzens, 1993). It is possible to delineate specialties in terms of relevant journals because of the skewness in the distributions of aggregate journal–journal citations (Leydesdorff, 1994). Journal–journal citation matrices are sparse; citation traffic is concentrated among specialist journals (Leydesdorff and Cozzens, 1993).

[5] Nederhof (1988 p. 476) noted that "the European definition of biotechnology stresses the technological or engineering aspects, whereas in the US the new applications of molecular biology are emphasized." The relative absence of venture capital in Europe makes the committal of industries with existing capacities in fermentation technologies prevalent.

A disadvantage of journal-based methods is that articles in interdisciplinary journals like *Science* and *Nature* cannot be attributed unambiguously to the groupings (Carpenter and Narin, 1973), although the impact of these articles may be significant. However, these hierarchically higher-level journals have a different flavor in different environments, and journal–journal methods that focus on substance (as opposed to hierarchy) tend to attribute their citation patterns to a cluster relative to the specific focus of the study. For example, *Nature* will be attributed below to the 'molecular biology' cluster in the context of 'biotechnology', while it has a different function in the citation environment of 'advanced materials' journals. The factor analysis focuses on latent functions, and not on apparent hierarchies.

Recently, scholars have used keyword and/or classification techniques to sort articles in these journals separately (Lewison and Cunningham, 1991; Moed et al., 1992). Note that these techniques take the article as the unit of analysis while we wish to distinguish between journal groups for the indicative attribution of articles to specialties. Second, one of us has shown elsewhere (Leydesdorff, 1989) that words and classifications are an order of magnitude less specific than citations as a scientometric indicator at each moment in time. Furthermore, words and co-words may change over time both in terms of numbers of occurrences and in meaning (Leydesdorff, 1991). The more formal approach of citation analysis allows for appreciation with hindsight, while an index or a thesaurus usually subsumes the data under ex ante categories. In other words, citations allow us to base the evaluation on the current (1993) understanding of the relevant scientific fields. For analogous reasons, the evaluation should not be based on an ex ante fixed journal set (Narin, 1976).

In this study, we have used data from the CD-ROM version of the *SCI* for the first quarter of 1993 for the mapping of the relevant fields. In fact, we have reconstructed the *Journal Citation Report* of the *SCI* by using this data, and have then applied our previously developed methods for dynamic journal mapping (Leydesdorff, 1994). These factor analytical procedures are deliberately designed so that comparisons among results for various years are made possible (Leydesdorff and Cozzens, 1993). We focus the discussion of the indicator on the comparison between the maps for 1984 and 1993. However, we shall use results from in-between years to shed further light on our argument where appropriate. [6]

Guided both by analysis of the relevant scientometric distributions (Leydesdorff et al., 1994) and by expert advice, we chose *Biotechnology and Bioengineering* as the core journal for analysis in the case of biotechnology, and the *Journal of Materials Science* in the case of advanced materials. *Biotechnology and Bioengineering* has existed as a journal under this title since 1962. It is a continuation of the *Journal of Biochemical and Microbiological Technology and Engineering*, which was founded in 1959. The *Journal of Materials Science* was founded in 1966. Both journals are considered as leading in their respective fields. Independently of its previous history, *Biotechnology and Bioengineering* has emerged over the last ten years as the most pronounced representative of a 'biotechnology' factor that can be distinguished from 'molecular biology'. [7]

In short, we included all journals in the analysis which cite or are cited by the aforementioned core journals to the extent of more than 1% of their total citing or being cited rates, respectively. The so-constructed aggregated journal–journal citation matrices were factor analyzed in both the cited and the citing dimensions. The various factors indicated groups of journals, which were then further analyzed in order to assess how the represented groups related to the respective core journal set. Factor representations were stabilized in successive iterations until the set of journals drawn into the analysis by the specific choice of an entrance journal could not be further improved (Leydesdorff and Cozzens, 1993).

[6] The 1984, 1986, and 1988 data have been made available in the context of research supported by NSF-grant SRS-8810197 (Cozzens and Leydesdorff, 1992; Leydesdorff and Cozzens, 1993). The authors are grateful to the ISI for permission to use the data in the context of this study.

[7] In terms of our previous analyses (Leydesdorff and Cozzens, 1993; Leydesdorff et al., 1994), *Biotechnology and Bioengineering* was not yet the journal with highest factor loading on the biotechnology factor in 1988 – it was second only after *Applied Biochemistry and Bioengineering*–but it reached this position in 1993. To the *Journal of Materials Science* can be attributed this ('central tendency') property in all the years analyzed in this study.

The factor analytic results are used to depict the structure of the field in a scientometric map using a multidimensional scaling program. (A multidimensional scaling program essentially creates a map from a distance table. In this case, we use the relative citation frequency as a proximity index.) Below, we shall discuss these maps for the core sets, and for the years 1984 and 1993, respectively. The results of the further analysis of the other factors provides us with answers to questions like whether the biotechnology set is also a relevant factor in the environment of the molecular biology cluster. As noted, we limit the discussion to developments which are visible in the mappings for 1984 and 1993. Furthermore, we focus the discussion on the citing patterns, since this dimension represents the action side in a specific year, while the whole archive of a journal may be cited (Leydesdorff, 1992b).

After a discussion of developments at the field level, we proceed with the performance measurements. As noted, these assessments are based on the delineations of the relevant journal sets in 1993. For the performance measurement, we used the on-line installation of the *Science Citation Index* at the Deutsches Institut für Medizinische Dokumentation und Information (DIMDI) in Düsseldorf. The query

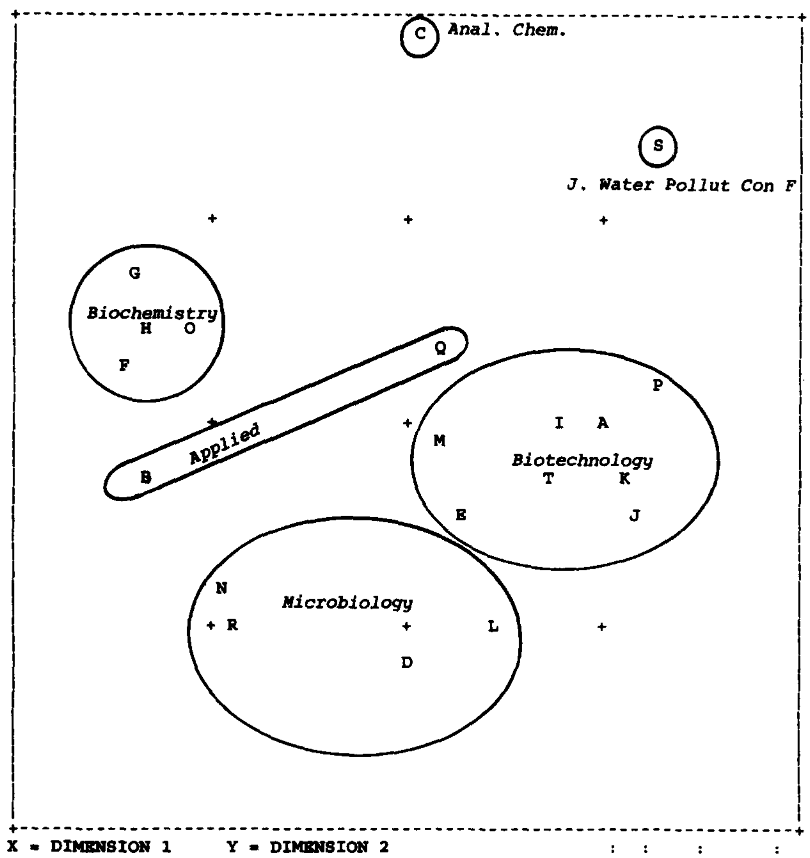

Fig. 3. Multidimensional scaling for *Biotechnology and Bioengineering* citing patterns (1984; threshold = 1%). Abbreviation/journal name: A: *Acta Biotechnol*; B: *Agr. Biol. Chem. Tokyo*; C: *Anal. Chem.*; D: *Appl. Environ. Microbiol*; E: *Appl. Microbiol. Biotechnol.*; F: *Biochem. J.*; G: *Biochemistry USA*; H: *Biochim. Biophys. Acta*; I: *Biotechnol. Bioeng*; J: *Biotechnol. Lett.*; K: *CRC Crit. R. Biotech*; L: *Dev. Ind. Microbiol.*; M: *Enzyme Microb. Technol.*; N: *J. Bacteriol*; O: *J. Biol. Chem.*; P: *J. Chem. Technol. Biotechnol.*; Q: *J. Ferment. Technol.*; R: *J. Gen. Microbiol*; S: *J. Water Pollut. Con. F.*; T: *Process Biochem.*

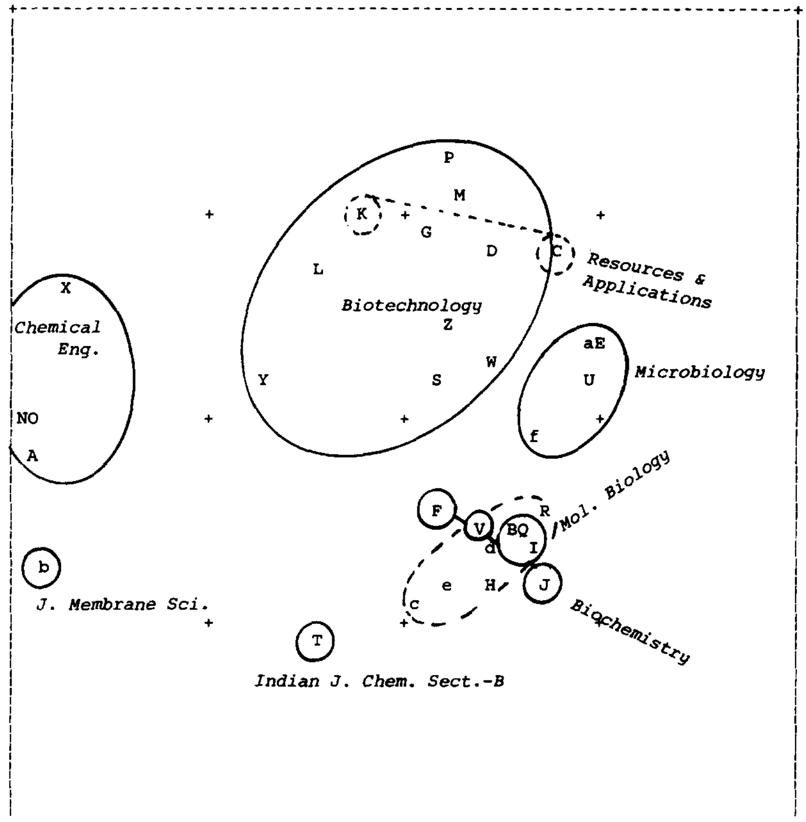

Fig. 4. Multidimensional scaling for *Biotechnology and Bioengineering* citing patterns (1993; threshold = 1%). Abbreviation/journal name: A: *Aiche. J*; B: *Ann. N.Y. Acad. Sci*; C: *Appl. Environ Microbiol.*; D: *Appl. Microbiol. Biotechnol,*; E: *Arch. Microbiol.*; F: *Acs. Symp. Ser.*; G: *Appl. Biochem. Biotech.*; H: *Bio-technology*; I: *Biochim. Biophys. Acta*; J: *Biochemistry USA*; K: *Bioresource technol.*; L: *Biotechnol. Bioeng.*; M: *Biotechnol. Lett.*; N: *Chem. Eng. Sci.*; O: *Chem. Eng.*; P: *Enzyme Microb. Technol.*; Q: *Eur. J. Biochem.*; R: *Gene*; S: *Enzyme*; T: *Indian J. Chem. sect. B.*; U: *J. Bacteriol.*; V: *J. Biol. Chem.*; W: *J. Biotechnol.*; X: *J. Chem. Eng. Jpn.*; Y: *J. Chem. Technol. Biotechnol.*; Z: *J. Ferment. Bioeng.*; a: *J. Gen. Microbiol.*; b: *J. Membrane Sci.*; c: *Nature*; d: *Proc. Nat. Acad. Sci. USA*; e: *Science*; f: *Trends Biotech.*

was formulated as 'Corporate country = Netherlands' or 'Canada', respectively, and given calendar limitations of the relevant tape. [8]

In accordance with standard scientometric practice, we limit the discussion to research articles, reviews, notes, and letters. Although some uncertainty about the inclusion of 'letters' as a category in performance measurement has remained (e.g. Braun et al., 1989; Martin, 1991), we have included this category in the analysis since the UK and Commonwealth countries publish more in the form of letters than do other countries (Schubert et al., 1990). We did not wish to disadvantage Canada in this comparison on a priori grounds. [9]

There has been a debate in the scientometric literature about the question of how to attribute credit for internationally co-authored papers (Ander-

[8] Publication years for journals are determined by publishing houses and editorial policies, and may therefore be delayed (Braun et al., 1989; Martin, 1991).

[9] However, we would not expect a major effect from including or excluding letters in the analysis, since variations in the different categories are strongly coupled in national publication systems (Leydesdorff, 1990).

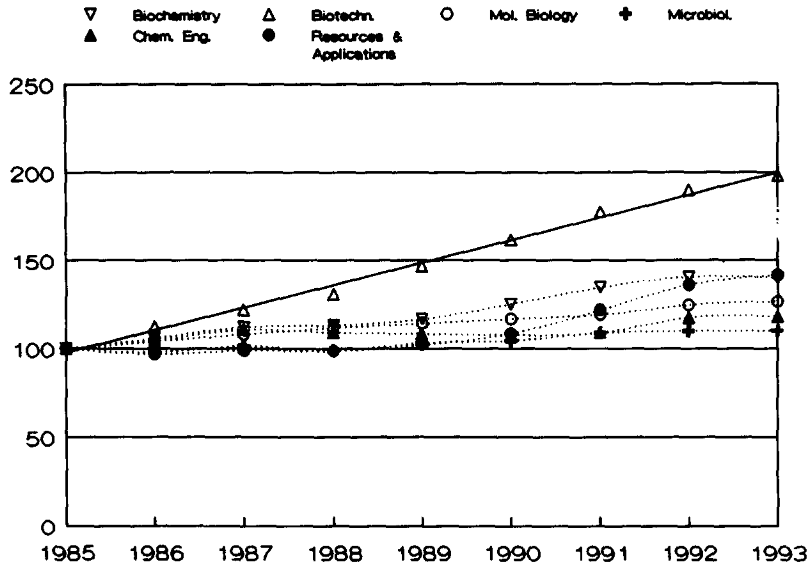

Fig. 5. Publication volume (1985 = 100).

son et al., 1988; Leydesdorff, 1988, 1992a; Martin, 1994). In this study, we have given a full point to any paper with at least one address in the Netherlands or Canada. In our opinion, research questions about increases in international collaboration merit separate analysis (Schubert and Braun, 1990; Lewison and Cunningham, 1991; Narin et al., 1991; Schott, 1991; Leclerc, 1992; Leydesdorff, 1992a; Luukkonen et al., 1992).

In summary, the analysis is based on the use of various versions of the *Science Citation Index*. We analyzed aggregated journal–journal citation data in 1984 and 1993, respectively, in terms of scientometric mappings. Publications were counted as full

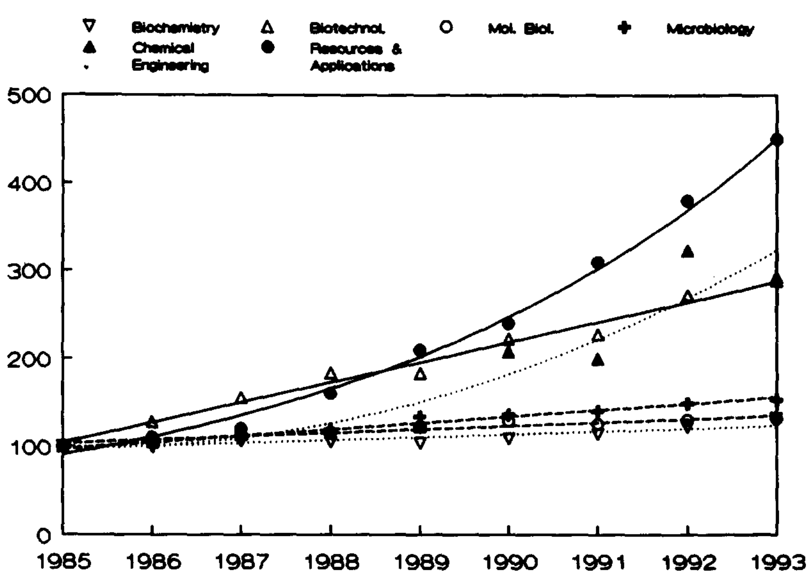

Fig. 6. Publications with an address in the Netherlands (1985 = 100).

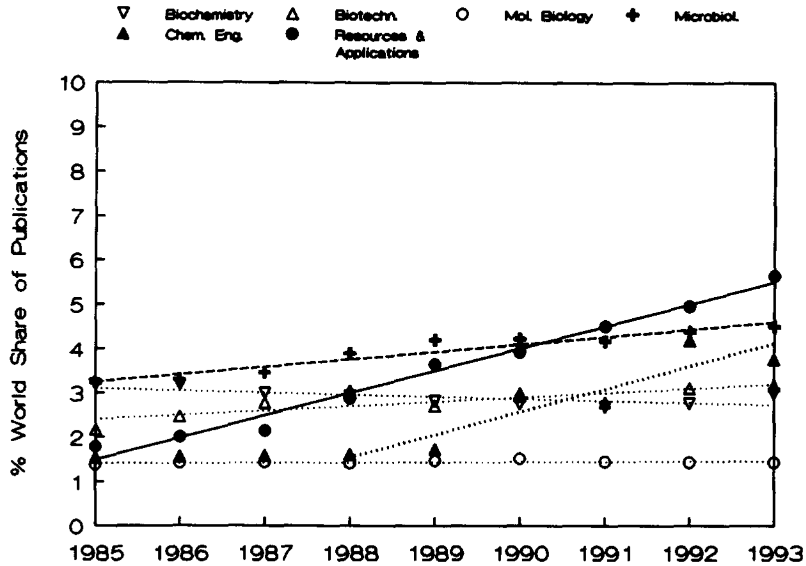

Fig. 7. Percentage world share, the Netherlands.

points, for the years 1983 to 1993. Given the sometimes small numbers for this performance data, the time series have been smoothed by replacing the raw data with three-year moving averages for articles, reviews, notes, and letters.

4. Results

4.1. Biotechnology

4.1.1. Journal maps

Figs. 3 and 4 show the journal mappings for 1984 and 1993 in the case of biotechnology. The major difference between the two pictures is the absence of a 'chemical engineering' cluster in 1984. Additionally, the relevant journals in biochemistry and molecular biology are clearly separable in the environment of *Biotechnology and Bioengineering* in 1993, while only the biochemistry cluster was visible in 1984. However, the relation with core journals of molecular biology like *Molecular and Cellular Biology* and *EMBO Journal* is still mediated by programmatic journals like *Gene* and *Bio-Technology* [10] on the one hand, and general science journals like *Proc. Nat. Acad. Sci. USA*, *Science*, and *Nature* on the other.

[10] Bud (1988) noted that the title of this journal has been chosen programmatically in order to claim biotechnology as merely an application of molecular biology.

Table 2
Three-year moving averages of the number of journal articles in specialties relevant to the development of biotechnology (1985 and 1993; specified for Dutch and Canadian addresses)

	1985	1993
Biochemistry	7559	10590
Dutch	240	317
Canadian	333	557
Biotechnology	828	1639
Dutch	18	52
Canadian	66	91
Mol. Biology	4808	6086
Dutch	66	87
Canadian	160	240
Microbiology	1453	1601
Dutch	47	72
Canadian	61	98
Chemical Engineering	852	1007
Dutch	13	38
Canadian	36	50
Resources and Appl.	563	797
Dutch	10	45
Canadian	43	56

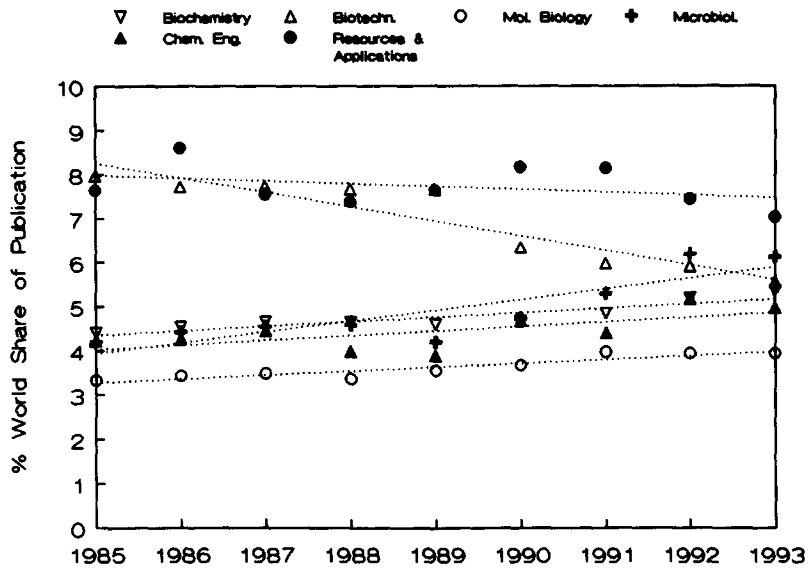

Fig. 8. Percentage world share, Canada.

Otherwise, stability prevails: the core biotechnology cluster consisted in 1984 of eight journals, of which three disappeared from the database, while the other five remained in the same cluster in 1993. Four new journals were added to this cluster. The clusters of biochemistry and of microbiology also exhibit change at the journal level, but as clusters they have remained stable factors in this environment.

Fig. 5 exhibits the volume of publications (i.e. articles, reviews, notes, and letters) in the clusters of journals as grouped in Fig. 4 for 1993. The publication data are normalized for each group by setting

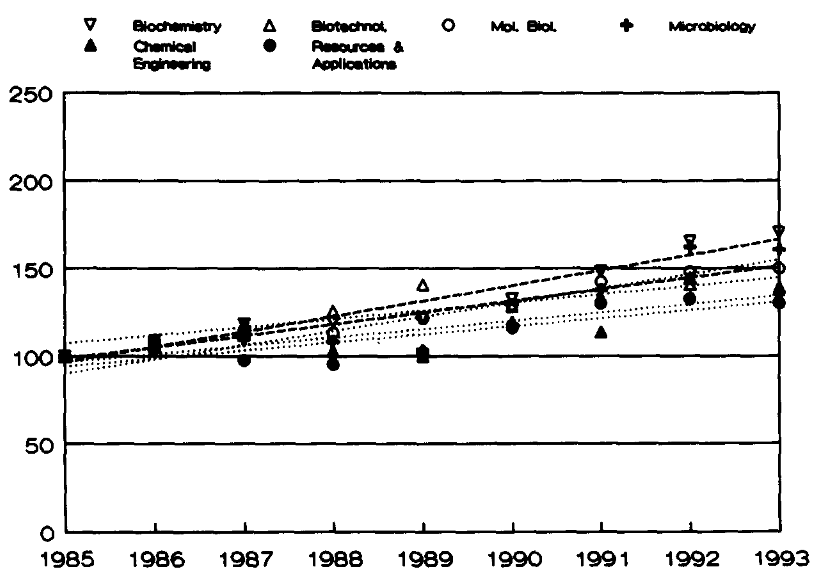

Fig. 9. Publications with an address in Canada (1985 = 100).

the three-year moving average in 1985 equal to 100. (See Table 2 for non-normalized three-year moving averages in 1985 and 1993, respectively.) All the clusters have grown, but growth in the biotechnology cluster has been significantly greater than in the other clusters. Note that the relevant journal groups both on the applied side and on the fundamental side exhibit moderate growth patterns.

When the various fields indicated in 1993 are analyzed in more detail, the biotechnology journals remain visible when the analysis focuses on applied fields like membrane sciences or chemical engineering. However, the biotechnology journals disappear from the relevant citation environment if one zooms in on the more fundamental side, i.e. on biochemistry or molecular biology.

By focusing on the journal *Applied and Environmental Microbiology* one can distinguish a sub-cluster in the microbiology group that is separately related to the biotechnology group mainly in the cited dimension. (Since the other journal belonging to this cluster is called *Bioresource Technology*, we shall use the designation ‘resources and applications’ to indicate this group.) The more fundamental microbiology group itself exhibits a citation pattern like the clusters of biochemistry and molecular biology. A

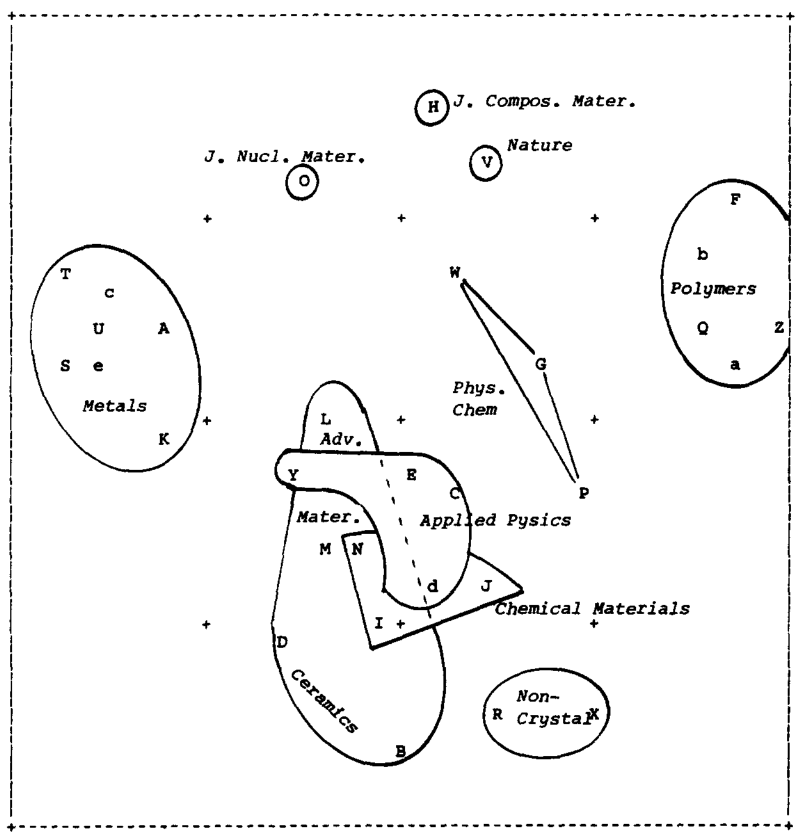

Fig. 10. Scientometric map of the citation environment of the *Journal of Materials Science*; citing patterns, 1984; threshold 1%. Abbreviation/journal name: A: *Acta Metall.*; B: *Am. Ceram. Soc. Bull.*; C: *Appl. Phys. Lett.*; D: *J. Am. Ceram. Soc.*; E: *J. Appl. Phys.*; F: *J. Appl. Polym. Sci.*; G: *J. Chem. Phys.*; H: *J. Compos. Mater.*; I: *J. Cryst. Growth*; J: *J. Electrochem. Soc.*; K: *J. Jpn. I. Met.*; L: *J. Mater. Sci.*; M: *J. Mater. Sci. Lett.*; N: *J. Non-cryst. Solids*; O: *J. Nucl. Mater.*; P: *J. Phys. Chem. Solids*; Q: *J. Polym. Sci. Pol. Phys.*; R: *Mater. Res. Bull.*; S: *Mater. Sci. Eng.*; T: *Met. Sci.*; U: *Metall. Trans. A.*; V: *Nature*; W: *P. Roy. Soc. Lond. A. Mat.*; X: *Phys. Chem. Glasses*; Y: *Phys. Status Solidi A.*; Z: *Polym. Eng. Sci.*; a: *Polymer*; b: *Rubber Chem. Technol.*; c: *Scripta Metall.*; d: *Thin Solid Films*; e: *Z. Metallkd.*.

similar pattern can be discerned in the chemical engineering part of the map, but in this case the central journal *Biotechnology and Bioengineering* always remains visible in the relevant environment.

In summary, biotechnology as a cluster has become twice as big over this period (1985–1993) in terms of the worldwide number of publications in these journals, and it has notably strengthened its relations on the applied side of the spectrum of relevant disciplines. The more fundamental clusters are relevant from the perspective of biotechnology, but the citation relation with journals in the biotechnology cluster is not important to these journals themselves.

4.1.2. Dutch publication performance in biotechnology

Who profits from a priority program? Are researchers in the fundamental sciences flexible in relabeling their efforts so that they can use funds for disciplinary developments, or is the additional funding used for the further stimulation of new and interdisciplinary developments? It has been suggested that the former option is usually what happens

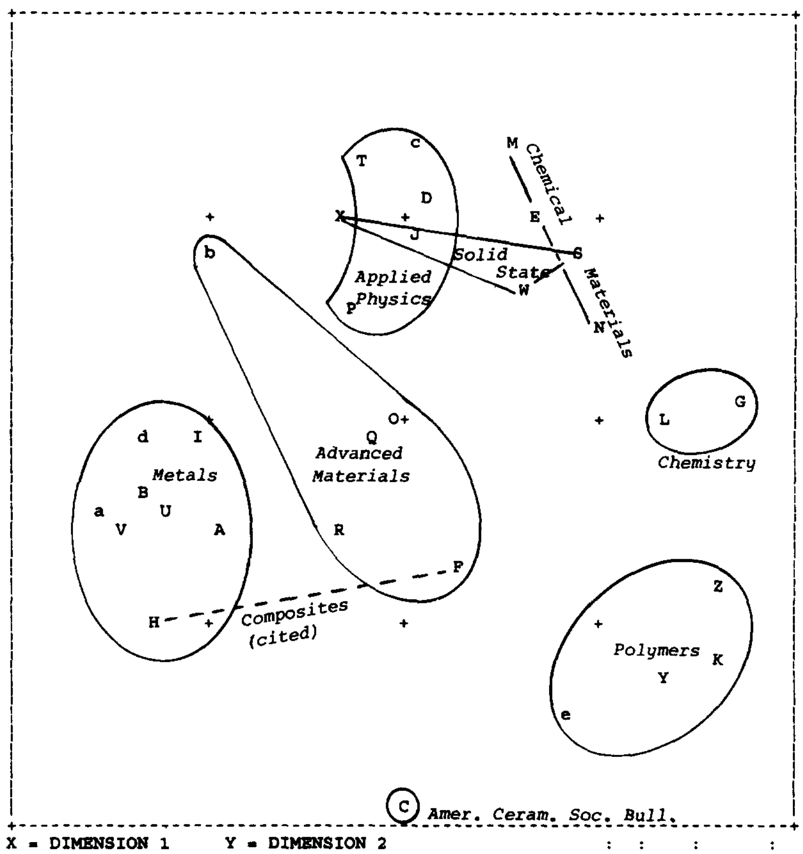

Fig. 11. Scientometric map of the citation environment of the *Journal of Materials Science*; citing patterns, 1993; threshold 1%. Abbreviation/journal name: A: *Acta Mech.*; B: *Acta. Metall. Mater.*; C: *Amer. Ceram. Soc. Bull.*; D: *Appl. Phys. Lett.*; E: *Chem. Mater.*; F: *Composites Sci. Technol.*; G: *Carbon*; H: *Composites*; I: *Int. Mater. Rev.*; J: *J. Appl. Phys.*; K: *J. Appl. Polym. Sci.*; L: *J. Chem. Phys.*; M: *J. Electrochem. Soc.*; N: *J. Mater. Chem.*; O: *J. Mater. Sci. Lett.*; P: *J. Mater. Res.*; Q: *J. Mater. Sci.*; R: *J. Microsc. Oxford*; S: *J. Non-Cryst. Solids*; T: *J. Cryst. Growth*; U: *Mater. Sci. Eng. A. Struct. Mater.*; V: *Met. Trans. A. Phys. Met. Mater. Sc.*; W: *Phys. Rev. B. Condensed. Matter.*; X: *Phys. Status Solidi A. Appl. Res.*; Y: *Polym. Eng. Sci.*; Z: *Polymer*; a: *Scr. Metall. Mater.*; b: *Surf. Coat. Tech.*; c: *Thin Solid Films*; d: *Z. Metallk.*; e: *Vysokomol. Soedin. Ser. A.*.

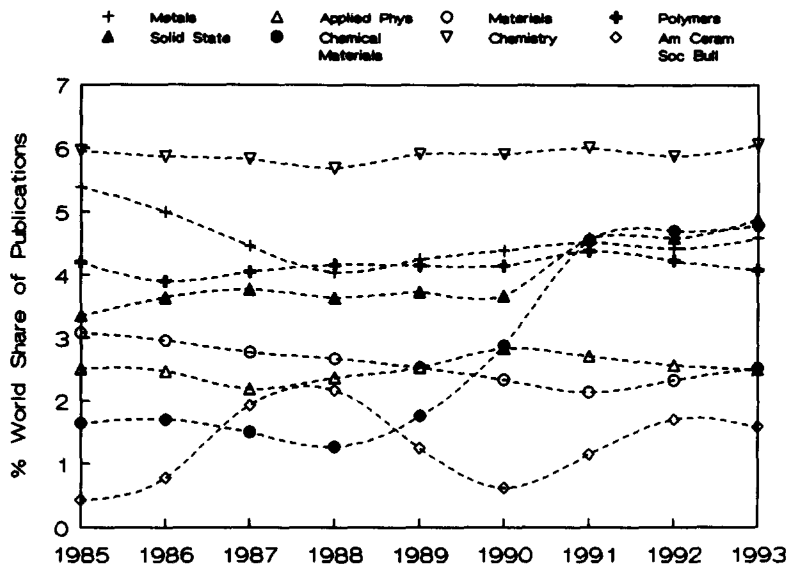

Fig. 12. Percentage world share, Canada.

in fact, while from a normative perspective one hopes for the latter to occur (e.g. Van den Daele et al., 1976; Jagtenberg, 1983; Van den Besselaar and Leydesdorff, 1993).

In the context of this debate, the picture exhibited in Fig. 6 offers a pleasant surprise to the policy-maker. It shows that in the case of the Netherlands, the scientists and engineers on the applied side were able to improve their publication performance so that the regression line fits a pattern of exponential growth. Second, the increase in the number of papers with a Dutch address in biotechnology journals has been larger than the increase of the publication volume in this field as exhibited in Fig. 5 above. Third,

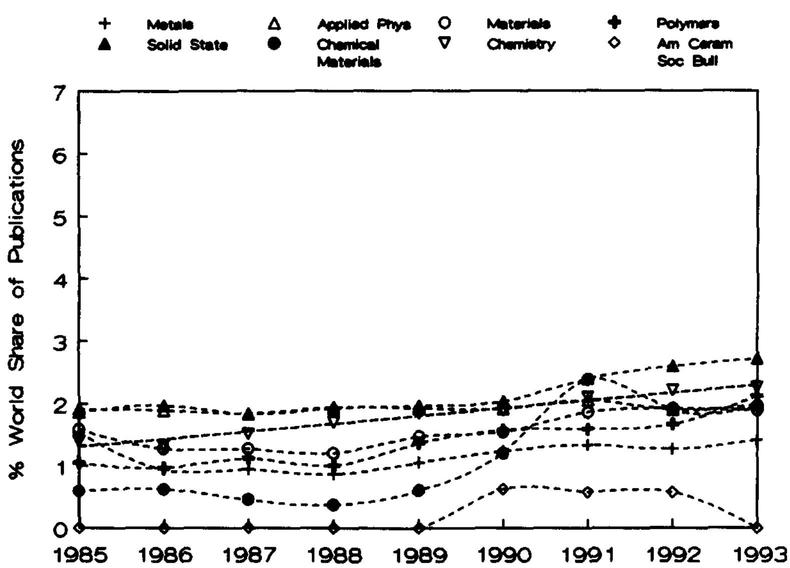

Fig. 13. Percentage world share, the Netherlands.

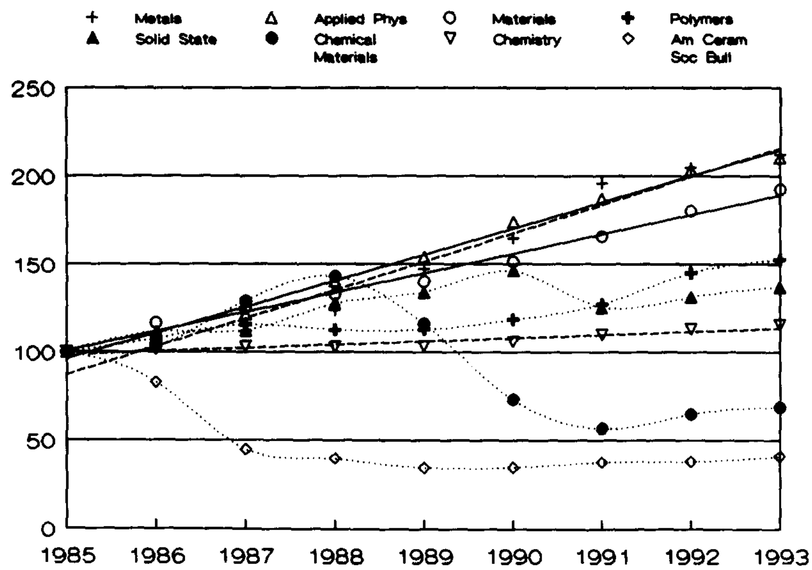

Fig. 14. Publication volume (1985 = 100).

from 1988 onwards the increase of Dutch performance in the relevant chemical engineering journals has also been rather spectacular.

Fig. 7 exhibits the same data, but now normalized as a percentage share of the corresponding categories in the *Science Citation Index*. One can observe an increase on the applied side, while the clusters in the fundamental areas remain more stable (molecular biology) or even exhibit a slight decline (biochemistry). Note that one is not allowed to infer from this data that Dutch performance in biochemistry or molecular biology would not have profited from the priority program, since it remains possible that biochemists (etc.) used the additional funds to prepare

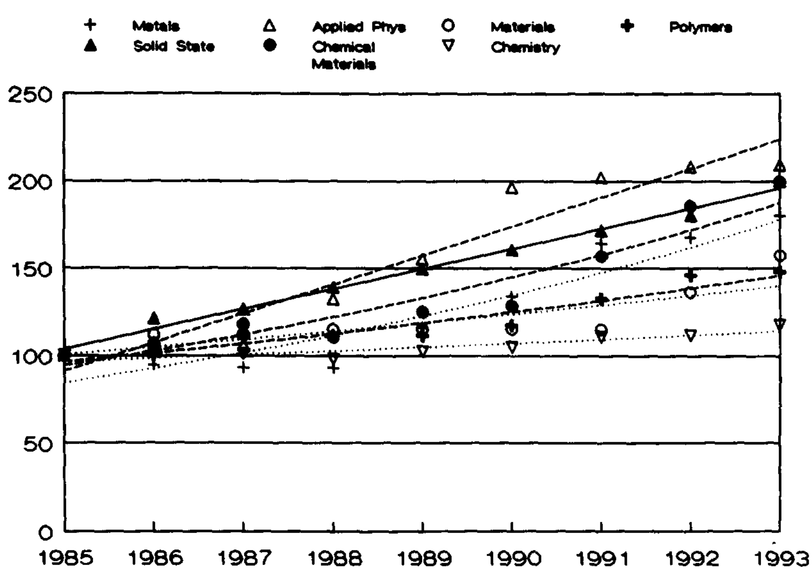

Fig. 15. Publications with an address in Canada (1985 = 100).

publications in journals which belong to the core of their field, but which are not visible from this specific (biotechnological) perspective.

However, one may conclude that the Dutch biotechnology efforts have been successful in stimulating a differential increase among the most relevant parts of these fields, with an emphasis on the applied side. One should keep in mind that the noted effects are significant, including a more than doubling of output in terms of scientific papers over a period of not quite a decade.

4.1.3. Canadian publication performance in biotechnology

Fig. 8 exhibits the percentage share of Canadian publications in these same sets of journals. The percentage world share in the core set of biotechnology journals is decreasing, perhaps because of the noted increase of the publication volume in this area. The other areas generally exhibit stability. Note the relatively high percentage share of Canadian authors in the cluster indicated as 'resources and applications'. Obviously, Canada had a better position in this area than the Netherlands before the start of the biotechnology programs.

Fig. 9 exhibits the same figures but normalized by taking the number for 1985 as equal to 100. In our opinion, this picture shows a significant pattern: the various disciplinary journal groups participate in the ongoing rise of performance in terms of numbers of publications exhibited by the Canadian R & D system (see Fig. 1), but – as one expects – to a somewhat different degree. In contrast to the corresponding figures for the Netherlands (Fig. 6; cf. Table 2), no additional differentiation in growth patterns among the relevant disciplines can be observed.

4.2. Advanced materials

4.2.1. Journal maps

Figs. 10 and 11 exhibit the journal maps of advanced materials for 1984 and 1993, respectively. As in the case of biotechnology, the analysis suggests stability in citation patterns in terms of relevant groups of journals. However, we witness a further differentiation in the core areas: of two ceramics journals belonging to the core of the advanced materials group in 1984, only one (the *American Ceramics Society Bulletin*) is still relevant in this citation environment in 1993, and this journal has become an isolate in this representation. The chemical materials group has also grown further apart, while the advanced materials group itself seems to have remained anchored on the applied physics and metals side of the map. The latter group is notably relevant for the study of alloys.

This metals group dominates the citation patterns as a first factor in both years, in the position that was clearly assumed by biochemistry journals in the case of biotechnology. Thus, on the scale of applied versus fundamental science, the advanced materials field has been more closely oriented towards the applied side than has the biotechnology field. Groups

Table 3
Three-year moving averages of the number of journal articles in specialties relevant to the development of advanced materials (1985 and 1993; specified for Dutch and Canadian addresses)

	1985	1993
Metals	1038	2203
Dutch	16	31
Canadian	56	101
Applied Physics	3306	6957
Dutch	63	138
Canadian	83	174
Materials	1070	2060
Dutch	17	39
Canadian	33	52
Polymers	1237	1889
Dutch	13	40
Canadian	52	77
Solid State Physics	3497	4793
Dutch	65	130
Canadian	117	234
Chemical Materials	1708	1172
Dutch	10	23
Canadian	28	56
Chemistry	1997	2310
Dutch	28	52
Canadian	119	140
Am-Ceram. Soc. Bull.	462	190
Dutch	0	0
Canadian	2	3

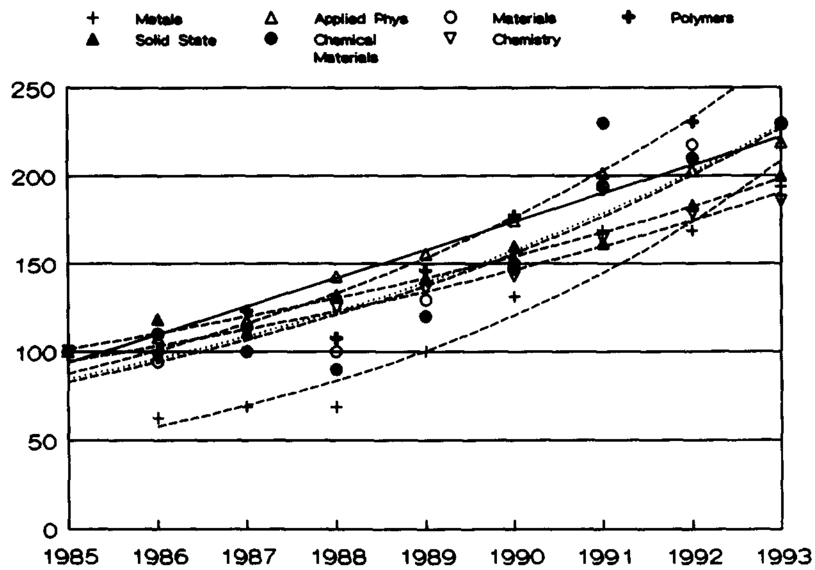

Fig. 16. Publications with an address in the Netherlands (1985 = 100).

of journals which can be classified as solid state physics and more fundamental chemistry journals contribute only as minor factors.

Applied factors from the chemistry side like composites and polymers constitute separate densities of citation traffic. General chemistry journals remain within the perspective when one focuses on these latter densities, but the advanced materials and metals factors tend to disappear from the citation environment. In other words, the advanced materials field is more closely oriented towards the physics and metals side than to the chemistry and polymers side of its citation environment. With hindsight, the noted choice of composites and polymers in Dutch science policy has thus been aimed less at the heart of the emerging field than were the Canadian science policy efforts.

4.2.2. Canadian and Dutch publication performance in advanced materials

Figs. 12 and 13 provide us with depictions of the world shares of publications for Canada and the Netherlands, respectively, when analyzed as in the previous case. These pictures, however, are far from clear. The chemical materials group exhibits a spectacular growth in the case of both countries, but this increase may be spuriously dependent on the decline in publication volume in this area (see Fig. 14). Indeed, the latter figure exhibits increases in publication volumes (in terms of numbers of publications) that are comparable with those for the biotechnology cluster in the previous case, but solely for the factors metals, applied physics, and advanced materials. (Table 3 exhibits three-year moving averages for 1985 and 1993, in a format comparable to that of Table 2 above.)

Both Canadian and Dutch scientists have been able to keep up with these growth rates, but the increase in performance seems to have been somewhat stronger in the case of the Netherlands than in the case of Canada; particularly if one focuses on the period after 1988. [11] The gradual difference between the two countries can be illustrated more clearly by using Figs. 15 and 16, which are normalized using a similar format to that in Figs. 6 and 9 above. Both countries exhibit overall growth in all relevant areas, but the pattern is somewhat bent upward for the case of the Netherlands. Technically, this allows in some

[11] Note how unstable performance figures are when they are based on a single journal (as in the case of the *American Ceramics Society Bulletin*), and not on an analytically informed grouping of journals.

cases for a moderate (i.e. > 95%) fit with an exponential curve. This fit suggests that the indicators are not following a general upward trend, but that additional growth above average is being realized.

Noteworthy is the performance pattern of the Dutch polymer science community, which has tripled its number of publications over this period. However, both this growth pattern and the one for studies about metals pick up momentum only after 1988. Recall that in the case of biotechnology, the growth in chemical engineering publications with a Dutch address began in this same year.

In summary, we find an effect of the Dutch stimulation programs above the general upward trend which both countries have in common. This effect is notable in terms of this indicator particularly after 1988. As expected, the effects are weaker and later than in the above case of biotechnology, and especially pronounced for polymers as a sub-field. Canadian researchers in the field of advanced materials have been able to maintain their world share of publications in the central areas to a larger extent than their colleagues in the biotechnology area.

5. Discussion

The major finding of this paper is that Canadian researchers seem to have used the priority programs as an alternative source of funding, while their Dutch colleagues were able to use these programs to help their specialties grow above the national average, and in accordance with selected priorities. In this final section, we wish to reflect on the question of how one might try to explain these differences.

As we have indicated above, the R&D systems of Canada and the Netherlands are different in size, but they can also be compared in many respects. We pointed to similar overall growth patterns, similarities in international orientation, and communications about science policy instruments. The two countries are well-embedded in the international system of advanced industrial countries; they are both vulnerable in having their economies strategically linked to major neighboring countries, and therefore these national governments are under economic pressure to improve their respective knowledge infrastructures strategically.

Given these similarities in the environment, it seems unlikely that the significant differences which we found in the effectiveness of the various science policy priority programs could be explained in terms of differences in policy pressures. In our opinion, the explanation should focus rather on differences which are culturally rooted in the respective R&D systems themselves, in their organization at the national level, and in the aspirations of the members of the respective scientific communities (Skolnikoff, 1993). The Canadian R&D system is considerably larger and more decentralized than its Dutch counterpart: it is traditionally embedded in the international and Anglo-Saxon system, and the researchers are more accustomed to applying for funds from various sources than are their Dutch colleagues. The mechanisms for response to government intervention in such an internationally oriented system might be different from those in a system that can change its degree of coupling with the international R&D system selectively.

A national priority in a small but highly integrated R&D system like the Dutch one is likely to have effects even if the total amount of seed money spent is limited. In addition to supplying the researchers concerned with additional funds, it legitimates the scientists working in a selected priority area in the competition for institutional resources, for example at the local level. Furthermore, the new funding sources stimulate scientists and engineers in applied fields, who tended previously to publish in local media of communication (e.g. in the national language or in technical reports), to think of their own work more systematically as publishable in international journals in accordance with the science policy objectives of the national research program. In our opinion, the Dutch R&D system contains more organizational slack (e.g. traditional or lump-sum financing) than the Canadian one, and therefore parts of this system may be highly sensitive to selective stimulation.

Thus, one can raise further questions with respect to comparisons along the national dimension of R&D systems. Additionally, one may wish to extend the analysis to national innovation systems by using patent data and statistics about business expenditure. By publishing this data for our two countries, we hope to provide interested colleagues with a design and a yardstick for measuring comparable performance data for other national systems, and perhaps also for other technologies (Van den Besselaar and Leydesdorff, 1993).

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