HAS PRICE'S DREAM COME TRUE: IS SCIENTOMETRICS A HARD SCIENCE?

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At the occasion of the completion of the 25th volume of *Scientometrics*, we present a combined bibliometric and social network analysis of this journal. In more than one respect, *Scientometrics* displays the characteristics of a social science journal. Its Price Index amounts to 43.0 percent, and is remarkably stable over time. The majority of the published items in *Scientometrics* has been written by a single author. Moreover, the network of co-authorships is highly fragmented: most authors cooperate with no more than one or two colleagues. Both the citation networks of the authors and the network of title words indicate that the field is nonetheless highly cohesive. In this sense, a specific identity seems to have developed, indeed. Some indications concerning the character of this identity are discussed.

Introduction

In 1978, the journal *Scientometrics* was launched as a new medium to stimulate the development of scientometrics, the quantitative study of science. According to one of the editors, it would be "a journal for the publication of meaningful and valuable contributions to this new field of science" (Beck 1978). Derek de Solla Price, one of the editors-in-chief of *Scientometrics*, and commonly seen as one of the founding fathers of the specialty, described the development of scientometrics as the emergence of a "relatively hard" social science. "For many years now", he wrote, "we have been guest editors in the journals of other neighboring fields and the special bibliographies in bibliometrics and science of science testify to the rapid cumulation of a coherent literature. (...) I use this word to imply that the growth is coherent, with the new advances being laid down on the basis of rather fresh preceding foundations for the new growth. Thus, the relatively hard sciences are distinguished from those that are relatively soft" (Price 1978). It was Price's goal to develop scientometrics as a "hard social science": "I have to believe that if the little green alien people came from a distant planet and communicated with us all else about them might be alien but they would know in some fashion or other such things as Planck's Constant, the

velocity of light and the Wave Equation. I believe they might also find reasonable points of correspondence with our scientometrics even if their social arrangements were utterly different from our own." (*Price* 1978).

On the occasion of the completion of the 25th volume of the journal *Scientometrics*, we wish to answer the question of whether the journal has stood up to these ambitions, by using the quantitative methods of scientometrics. The general assumption of this paper is that the journal *Scientometrics* can be analyzed, at least to some extent, as representative of this interdisciplinary field (cf. *Moed* et al. 1985). The characteristics of the publications in this journal, and the patterns of the bibliometric relations among them, may therefore indicate the type and extent of the cognitive and social integration of the various disciplinary backgrounds into scientometrics as a field.

Research questions and methods

The question, in other words, is how "hard" scientometrics is, and how strongly its knowledge is codified. These properties can be measured in terms of:

- a) the relative age of the cited literature, the so-called "Price Index",
- b) the relations among the authors of articles published in *Scientometrics*; and
- c) the pattern of words in the titles of these articles.

a: The Price Index

According to Price's theory of knowledge growth (*Price* 1965), science distinguishes itself from other fields of study by the way scientists refer to their literature (*Price* 1970). The existence of "research fronts" in science supposedly leads to an "immediacy effect", which can be measured in terms of the so-called "Price Index". The Price Index is defined as "the proportion of the references that are to the last five years of literature" (*Price* 1970). Price estimated that this index would vary between 22 and 39 percent if no immediacy effect were present.¹ A field that was all research front and with no general archive might have a Price Index of 75 to 80 percent. From his analysis of 162 journals, *Price* (1970) concluded: "Perhaps the most important finding I have to offer is that the hierarchy of Price's Index seems to correspond very well with what we intuit as hard science, soft science, and nonscience as we descend the scale." Biochemistry and physics are at the top, with indexes of 60 to 70 percent, the social sciences cluster around 42 percent, and the humanities fall in the range of 10 to 30 percent.

Cozzens (1985) corroborated *Price* in his observations. *Marton* (1985) also supported *Price*'s immediacy factor. *Moed* (1989) found that the overall picture may be a bit more complicated than *Price* thought: within the natural sciences, significant differences in the Price Index may occur. He suggested that high Price Indices correlate with high citation scores.

Price determined the Price Index by taking all references in a given year and counting the number of references to literature published in the last five years. *Moed* (1989) proposed to use the Price Index of the references of every citing article as a basis for computing the Index for a journal (or a specialty) as a whole. *Moed*'s method has the citing article as the unit of analysis, enabling the analysis of the distribution of the Price Index over the set of articles. We analyzed the Price Index in both ways.²

b: Relations among the authors

Scientific specialties can also be characterized in terms of patterns in the relationships among the authors of scientific texts. Science is, on the whole, practised in tightly knit communities in which the authors address one another (*Crane* 1972). First, we wish to know whether this is also the case in scientometrics. Second, we are interested in the relations among the authors with respect to their various disciplinary backgrounds. In other words, are these disciplinary differences maintained in the relations among the authors or has a more or less complete process of integration taken place?

We analyzed both co-authorships and citations. Co-authorship relations can be considered as indicators of co-operation.³ The meaning of citation relations is less clear, given the ongoing citation debate (*MacRoberts* and *MacRoberts* 1989; *Cozzens* 1989; *Luukkonen* 1990; *Leydesdorff* and *Amsterdamska* 1990; *Woolgar* 1991). But whatever the precise meanings of citations may be, citations can be considered as sociometric data, and the resulting network can accordingly be analyzed (cf. *Shrum* and *Mullins* 1988).

From the file with all authors, we extracted those authors who published more than one article in *Scientometrics* since 1978. Since we are only interested in the structure of scientometrics, we discarded the "transient" authors (*Price* and *Gürsey* 1976). With this data both a square co-author matrix and an among-authors citation matrix was produced. The co-author matrix contains by definition symmetric relationships ($cell_{ij}$ is identical to $cell_{ji}$); the citation matrix contains asymmetric

relations. Self-citations were excluded. This procedure results in matrices with mostly empty cells.

We analyzed the extent to which the authors are connected to one another, i.e. the *cohesiveness* of the network, as well as the pattern displayed by each author in relation to all other authors, i.e. the *position* of authors in the network. Authors who do not have direct relations with one another can still be quite similar in their pattern of relations, and consequently hold similar positions in the network. We also analyzed the similarities among authors in both these dimensions of the matrices, i.e. we clustered strongly connected authors as well as authors in similar positions. Direct as well as indirect linkages between the authors are involved in this analysis. A direct relation between author i and j exists whenever $cell_{ij}$ has a value of one. An indirect relation exists if two authors are related via a third one with whom they have direct relations. For example, in the citation matrix author i will have a direct link with author j if, and only if, i is cited by j . If i is not cited by j , i can still have an indirect link with author j if i is cited by an author who is cited by author j .⁴

We used Burt's program STRUCTURE⁵ to analyze these matrices (Burt 1982). The basic feature of this program is its ability to analyze matrices with respect to both the relations among the authors (as in graph analysis) and to their position in the network, defined as the pattern of their relations with all other authors in the network. Moreover, the network indices of STRUCTURE are not based on the assumption of a normal distribution of the variables.

For every cell in the matrix, a network index z_{ij} can have one of the following values:

$z_{ij} = 0$ if there are no direct or indirect links between i and j ;

$z_{ij} = 1$ if $i = j$;

$z_{ij} = 1 - f_{ij}/n_i$ in all other cases. In this formula, n_i is the total number of authors linked to i , whether directly or indirectly. f_{ij} is the number of all authors linked to i by a number of steps equal to or less than the minimal number of steps needed to link j with i .

The measure z_{ij} varies from 0 to 1.

This network measure provides a basis to analyze differences as distances between the authors in the network. The *relational distance* between i and j , dr_{ij} is computed as:

$$dr_{ij} = 1 - \text{minimum}(z_{ij}, z_{ji}).$$

This measure has a maximum value of 1 if i and j are disconnected; it is a measure of "closeness". Second, we measured the *patterns of relations* within the network, in other words, the position of the authors in the network. The formula of the *positional distance* between i and j is in this case⁶:

$$d^p_{ij} = [\sum_q (z_{jq} - z_{iq})^2 + \sum_q (z_{qj} - z_{qi})^2]^{1/2}.$$

In this formula, the summation is across all authors in the network. This distance measure approaches zero to the extent that author i and author j have similar relationships with the other authors in the network. The more their patterns of relations differ, the more d^p_{ij} increases; it is a measure of "likeness".

We computed both distance measures for the citation and co-authorship matrices. We then clustered the authors using the subroutine subgroup in STRUCTURE. This clustering can be based on two features: the type of relation analyzed (relational versus positional) and the strictness of the cluster criterion (strong versus weak). In this way, we can identify strong (relational) cliques, weak (relational) cliques, strong positional or so-called structural equivalence clusters, and weak structural equivalence clusters.

Strong cliques are sets of authors connected by relations in such a way that all members of the clique are connected to one another, and anyone for whom this holds is included in the clique. The inclusion criterion is less strong for weak cliques, in which all *pairs* within the clique must have relationships with all other pairs, and anyone with a relation to or from a member of the clique is included. Strong structural equivalence clusters are sets of authors with completely identical positions in the network (the distance d^p between them is zero). Weak structural clusters are sets of authors with a significant similarity in their patterns of relations (the distance d^p is small).

In order to assess the similarity in weak structural clusters, estimations have to be made with respect to the composition of the weak structural equivalence clusters, i.e. the sets of authors with similar positions. These estimates can subsequently be used for the analysis of covariance matrices for every cluster. Moreover, they can be submitted to factor analysis to test these cluster solutions.⁷ We admitted only clusters with a loading on one factor of 80 percent or higher. To prevent taking a sub-optimal solution for an optimal one, we applied an iterative procedure. First, the net was cast as widely as possible to capture all possible members of a cluster. Then all members with a reliability below 0.9 were discarded and the covariance matrices analyzed

anew.⁸ (Members of strong component clusters have, by definition, a reliability coefficient of 1). This was repeated until a stable solution was reached for every weak structural equivalence cluster of every matrix analyzed.

c: Epistemic networks

As noted, we wished to know whether a structurally codified semantics of scientometrics exists or whether, on the contrary, the articles in *Scientometrics* use the different terminologies of the various disciplines surrounding scientometrics. If the latter is the case, one would expect distinct sets of words to be used with few or no connections between them. Given the functions of titles of articles, the words in these titles can be considered as indicators of the cognitive message of the publication (Rip and Courtial 1984; Leydesdorff 1989a). The co-occurrence of words in titles can be considered as an indication of the existence or non-existence of relations between these words (Callon et al. 1983). Consequently, the co-occurrence data can be analyzed as sociometric choice data and subjected to network analysis, as above.

From the file, we extracted all titles and title words for the period as a whole and for every three year period (1992–1990, 1990–1988, 1988–1986, 1986–1984, 1984–1982, 1982–1980, 1980–1978).⁹ Word versus title matrices were computed, in which $\text{cell}_{ij} = 1$ if word j occurs at least once in title i . From this matrix a square word-word matrix is obtained where $\text{cell}_{ij} = 1$ if words i and j occur in the same title at least once. We subsequently subjected this matrix to the network analysis referred to above, producing strong cliques, weak cliques, strong structural equivalence clusters and weak structural equivalence clusters. In separate runs, the direct relationships among the words in these matrices were additionally analyzed (by filtering out all indirect links).

Data

We downloaded the complete bibliographic description of all articles and notes in the first 25 volumes of *Scientometrics* (1978–1992) from SCISEARCH/DIALOG, and organized this data in relational database files. The bibliographic description includes the names and addresses of every author, the year of publication, the title, volume number and page numbers of the publication, and the number of references

and for every reference the name of the first author, the journal title, the volume number, the year and the page numbers of the journal cited.

Since 1978, 779 items have been published in *Scientometrics*. They contain 12,341 references to the scientific literature.¹⁰ The number of publications per year in the journal increases in a linear way (Fig. 1).¹¹ After a steep growth during the first three years, the number increases by 3.5 publications per year. The number of references per year shows a comparable pattern, although somewhat more irregular. Every publication contains on average 15.8 references (cf. Yitzhaki 1991). Since 1986, this number has become stable at an average of 15 references per publication (Fig. 2).

The distribution of the number of references per publication over all publications (Fig. 3) seems to be the result of the superposition of two different types of distributions. A more or less normal distribution around 10 references per publication is combined with a large number citing only one reference and a somewhat smaller, but still considerable, number of publications citing no references at all. Note that Price (1965) found a similar superposition of distributions.

Fig. 1. Number of articles per year

Fig. 2. Average number of references/article

Fig. 3. Distribution of references over articles. Articles with more than 50 references not shown

The publications in *Scientometrics* were written by 669 different authors. On average, every author published 1.8 times and every paper was written by 1.6 authors. Nearly three-fourth of the authors (488 or 73 percent) published only once in *Scientometrics*. The distribution of productivity among the authors is a Lotka distribution (Fig. 4).

Fig. 4. Distribution productivity

Results

a: The Price Index

The average Price Index of *Scientometrics* is 43.0 percent. Computed according to Moed (1989) it is 51.4 percent. The Price Index varies between 34.0 and 51.4 percent (Fig. 5). The regression line is not significant.¹² Apparently, the index displays neither rise nor fall since 1978.

Fig. 5. Price Index per year

Recently, *Schubert* and *Maczelka* (1993) concluded from an analysis of *Scientometrics* in 1980–81 and 1990–91 that the journal has moved slightly from the "soft" (social) towards the "harder" (natural) sciences. They drew this conclusion from the rise of the Price Index from 35 percent to 42 percent between these measurement points. This observation is, however, based on only two measurements. Because of the statistical fluctuations in the value of the Price Index over time, any conclusion can be drawn regarding the development of the Price Index if one restricts oneself to only two measurement points.

As noted, measuring the Price Index according to *Moed* makes it possible to analyze the distribution of the index over the articles. This shows the existence of three different sets of articles in *Scientometrics*. A normal distribution around 50 percent overlaps with two subpopulations, one with an index of 0 percent and another with an index of 100 percent. We therefore computed the Price Index anew for every year while excluding these two subpopulations. The curve thus obtained (Fig. 6) underlines the time-independence of *Scientometrics*'s Price Index.

The subpopulation with a Price Index of 0 percent fluctuates around 5 percent of all articles. The subpopulation of articles with a Price Index of 100 percent shows a slow but steady decline. We could not detect any statistically significant specific

properties of these two subpopulations, with one exception. The articles with a Price Index of 100 percent tend to have a small number of references per article. The average number of references per article in this set of documents is only 3.

Fig. 6. Corrected Price Index per year

In accordance with Price's theory, the number of references to literature of a specific age rises until the cited literature is two years older than the citing literature, and then falls off (Fig. 7). Note that this decline is gradual. Apparently, only a small "immediacy effect" is visible in scientometrics. A strong immediacy effect would give a sharp bump in this graph.¹³

How does our value of the Price Index compare with neighbouring journals? *Spiegel-Rösing* (1977) found that the Price Index of *Science Studies* (vol. 1-4) is 41 percent. To get a more comprehensive picture, we compared the Price Index of *Scientometrics*, *Social Studies of Science* and the *Journal of the American Society for Information Science* with one another from 1979 up to and including 1992.¹⁴ *JASIS*'s average Price Index is 45.8, *Social Studies of Science* has an average index of 36.8. On a Tukey Test the differences between *Social Studies of Science* on the one hand and *JASIS* and *Scientometrics* on the other are significant at the 5 percent level. The difference between *Scientometrics* and *JASIS* is not significant. These values, however, are all within the range Price indicated for the social sciences in general.

Our findings are consistent with *Moed* (1989) who found significant differences between Price Indices of subfields from the same discipline.

Fig. 7. Distribution relative age references

b1: The relations among authors: co-authorships

Of the 669 different authors in *Scientometrics* 73 percent (488) published only once. These transient authors are responsible for around 40 percent¹⁵ of the scientific production in *Scientometrics*. This share is stable over time. Thus, by focussing on the 181 authors responsible for the remaining 60 percent of the scientific production in our dataset, we do not introduce distortions when comparing one year with another.

A general phenomenon in science is the growth of the number of co-authored scientific articles, relative to the total scientific production (*Luukkonen et al. 1992; Abt 1992*). This growth is field specific. *Meadows* (1974) reported that papers by a single author comprised only between 17 and 23 percent in chemistry, biology and physics, whereas in history 96 percent of papers were single-authored. In *Scientometrics*, however, 61 percent of the articles have been written by a single author. This share is stable over time. Apparently, scientometrics, unlike the experimental sciences, is still predominantly a solitary affair. This is underlined by

the large minority of authors who have not co-authored any paper in *Scientometrics*. Overall, this share is 31 percent, and of the 181 authors who published more than one article in *Scientometrics*, 28 percent published exclusively single authored papers.

The network of co-authorships is highly fragmented. The number of realized dyadic links among the authors is only a small percentage (5.6%) of the number of possible dyadic links. The distribution of realized relations is highly skewed, most being either direct relations (i.e. co-authorships) or indirect relations at a distance of one step (i.e. authors who do not co-author with one another but do so with the same third author).

With the exception of three subgroups, most co-authors cooperate with no more than one or two colleagues. The clique analysis reveals 16 (strong) cliques of 2 authors, six of 3 and three bigger cliques of respectively 16, 8 and 9 authors (Table 1). Moreover, members of a clique co-author only with members of the same clique. Neither direct nor indirect relations exist among the cliques.

Table 1
Co-authorships strong component cliques (cohesion)

Clique 1

BLICKENSTAFF J
BRAUN T
GLANZEL W
GOMEZ I
GRIFFITH BC
MACZELKA H
MENDEZ A
MORAVCSIK MJ
MULLINS NC
NAGY JI
SCHUBERT A
SNIZEK WE
TELCS A
TODOROV R
WINTERHAGER M
ZSINDELY S

Clique 2

BURGER WJM
DEBRUIN RE
FRANKFORT JG
MOED HF
NEDERHOF AJ
PETERS HPF
TIJSSEN RJW
VANRAAN AFJ

Clique 3

BAUIN S
CALLON M
COURTIAL JP
JAGODZINSKISIGOGNEAU M
LAW J
MICHELET B
RIP A
TURNER WA
WHITTAKER J

plus 6 cliques of 3 authors and 16 cliques of 2 authors.

Table 2
Co-authorships structural equivalence strong component clusters

<u>Cluster 1</u> LAW J WHITTAKER J	<u>Cluster 12</u> CHATELIN Y ARVANITIS R
<u>Cluster 2</u> MICHELET B JAGODZINSKISIGOGNEAU M	<u>Cluster 13</u> CANO V LIND NC
<u>Cluster 3</u> TURNER WA CALLON M	<u>Cluster 14</u> LIPATOV YS DENISENKO LV
<u>Cluster 4</u> CARPENTER MP IRVINE J MARTIN BR	<u>Cluster 15</u> MIDORIKAWA N YAMAZAKI S
<u>Cluster 5</u> NOMA E MCALLISTER PR FRAME J	<u>Cluster 16</u> ALFENAAR W SPANGENBERG JFA
<u>Cluster 6</u> SWEENEY E GREENLEE E	<u>Cluster 17</u> KRISHNAIAH VSR NAGPAUL PS
<u>Cluster 7</u> PORTER AL STUDER KE	<u>Cluster 18</u> MILLER RB ZUCKERMAN H
<u>Cluster 8</u> DIJKWEL PA LEPAIR C	<u>Cluster 19</u> JIANG GH ZHAO HZ
<u>Cluster 9</u> MANORAMA K GARG KC	<u>Cluster 20</u> BEAVER DD ROSEN R
<u>Cluster 10</u> NIEUWENHUYSEN P EGGHE L	<u>Cluster 21</u> BUDD J HURT CD
<u>Cluster 11</u> BORDONS M BARRIGON S	<u>Cluster 22</u> KUMARI L SENGUPTA IN

Table 2 (continued)

<u>Cluster 23</u> LONG JS MCGINNIS R	<u>Cluster 28</u> HASSANALY P DOU H QUONIAM L
<u>Cluster 24</u> BLAIVAS A KOCHEN M	<u>Cluster 29</u> HUSTOPECKY J VLACHY J
<u>Cluster 25</u> OLUICVUKOVIC V PRAVDIC N	<u>Cluster 30</u> BURGER WJM FRANKFORT JG
<u>Cluster 26</u> RABKIN YM INHABER H	<u>Cluster 31</u> TUSSEN RJW NEDERHOF AJ
<u>Cluster 27</u> DORE JC FRIGOLETTO L MIQUEL JF	<u>Cluster 32</u> GOMEZ I MENDEZ A

The analysis of the position of the authors in the network of co-authorship relations reveals 28 strong structural equivalence clusters of 2 authors and 4 clusters of 3 authors, i.e. clusters in which each member has exactly the same position as every other member (Table 2). The analysis shows 10 weak clusters, i.e. clusters of authors with similar positions in the co-author network (Table 3).

Comparison of the composition of the weak structural equivalence clusters with the relational cliques reveals that two clusters are identical: a group of authors from Leiden (*Van Raan* et al.) and a group of authors with various institutional affiliations, probably best characterized as the "co-word analysis group". So, these two groups have distinct identities, with respect both to their relations and to their positions in the network. On the other hand, clique number 1 (*Braun* et al.) turns out to be composed of three groups of authors with distinct positions (clusters 5, 6 and 7 of the positional analysis). The positional analysis reveals a different pattern compared with the analysis of only the relations among authors. It reveals clusters that would otherwise remain invisible (clusters 2, 3, 8, 9 and 10).

Some clusters seem constituted by the institutional affiliations of the authors. This holds for the Leiden group and for the authors around ISI (cluster 3). In other cases, nationality appears to be the binding force. This holds for the group in Hungary (cluster 5), the Belgian informetricians (cluster 10) and the Spanish scientometricians

(cluster 6). However, cluster 1 can best be characterized by its research program (co-word analysis). Cluster 2 seems to consist of authors from Sussex together with CHI Research Inc. Thus, co-author relations are not only institutionally defined; shared interests and common intellectual goals play a role as well.

Table 3
Co-authorships structural equivalence weak component clusters

<u>Cluster 1</u> BAUIN S CALLON M COURTIAL JP JAGODZINSKISIGOGNEAU M LAW J MICHELET B RIP A TURNER WA WHITTAKER J	<u>Cluster 5</u> BRAUN T GLANZEL W MACZELKA H NAGY JJ SCHUBERT A TELCS A ZSINDELY S
<u>Cluster 2</u> CARPENTER MP FRAME J IRVINE J MARTIN BR MCALLISTER PR NARIN F NOMA E	<u>Cluster 6</u> FERNANDEZ MT GOMEZ I MENDEZ A
<u>Cluster 3</u> GARFIELD E GREENLEE E SMALL H SWEENEY E	<u>Cluster 7</u> BLICKENSTAFF J GRIFFITH BC MORAVCSIK MJ MULLINS NC SNIZEK WE
<u>Cluster 4</u> BURGER WJM DEBRUIN RE FRANKFORT JG MOED HF NEDERHOF AJ PETERS HPF TIJSSEN RJW VANRAAN AFJ	<u>Cluster 8</u> DIJKWEL PA LEPAIR C VANHEERINGEN A
	<u>Cluster 9</u> ARUNACHALAM S GARG KC MANORAMA K
	<u>Cluster 10</u> EGGHE L NIEUWENHUYSEN P ROUSSEAU R

Stokes and Hartley (1989) define a specialty as "socially completely cohesive if each and every member co-authors a document with each and every other". A

specialty is completely differentiated in the social dimension if no author is a co-author with any other. In these terms, scientometrics is neither completely cohesive nor completely differentiated. It consists of a few big groups of co-authoring authors, many small ones and a large minority (28 percent) of single authors. Among these subgroups no co-author relations exist. The only exception is the clustering of three different groups of authors in clique 1 (*Braun* et al.), in which the positional cluster around *Braun* is the central group. This is exhibited by the block diagram in Table 4, which gives the relations at the level of the clusters with structurally similar positions (a 1 indicating the existence of co-author relations between clusters).

Table 4
Block model of relations at subgroup level, defined by positions of co-authorships

	1	2	3	4	5	6	7	8	9	10
1	1	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0
5	0	0	0	0	1	1	1	0	0	0
6	0	0	0	0	1	1	0	0	0	0
7	0	0	0	0	1	0	1	0	0	0
8	0	0	0	0	0	0	0	1	0	0
9	0	0	0	0	0	0	0	0	1	0
10	0	0	0	0	0	0	0	0	0	1

CUTOFF AT ZERO

A 1 indicates the existence of co-authorship relations between the subgroups, a 0 the absence thereof.

To sum up, scientometrics is a fragmentary field of co-authorships. The authors are highly selective in their co-authorship relations with one another. Co-authorships are defined neither exclusively by social nor only by intellectual factors. Both dimensions shape the pattern of co-authorships. With respect to the number of solitary authors and the large number of isolated small clusters, scientometrics exhibits the pattern of a social science.

b2: The relations among authors: citations

Of the 779 articles published in *Scientometrics*, 411 were subsequently cited one or more times in *Scientometrics*. The share of references to *Scientometrics* (as a percentage of all references) has stabilized around an average of 19.4 percent since 1987. Of the 181 authors in the core set, 130 authors cite one another. So, 51 (or 28.2 percent) of the authors publishing more than one article in *Scientometrics* from 1978 till 1993 are neither citing nor cited within this group of authors.

The core set of authors in *Scientometrics* is found to be highly cohesive in terms of their mutual citation relations. All these authors are members of one single weak clique. Moreover, a majority of these authors (88) also belongs to one strong clique (Table 5). The picture is different if we exclude all indirect relations from the analysis. This "fine structure" of the citation matrix is shown in Table 6, where 13 strong cliques and 6 weak cliques are revealed. Most strong cliques seem to coincide with shared institutional affiliations. The exception is clique 9, which indicates the existence of a debate among the members of this clique. The cohesiveness of the citation network of *Scientometrics* is, given the severe condition that only direct relations are analyzed, underscored by the fact that no fewer than 31 authors cluster together (in weak clique 6 in Table 6). This cohesiveness is also apparent from the distribution of realized relations as a percentage of the possible dyadic relations in the citation network: only 4 percent of all possible citing relations is realized, although most authors are connected indirectly to each other at distances of 2, 3 and 4 steps.

If we analyze the *pattern* of citation relations, the mutual citation matrix of *Scientometrics* seems to consist of 8 different sets of authors. If one wishes to know which authors are similar to each other in their "behaviour" of citing and being cited, one must exclude all indirect relations within the matrix from the analysis. The result is shown in Table 7. The majority of authors cluster together on the criterion of their position in the network (cluster 3). So, most scientometricians are similar to one another in terms of their direct citation relations within this group. This is true regardless of the extent to which an author is connected to other authors. Most positional clusters do have citation relations with one another, which indicates an integration of the citation network at the subgroup level.

Table 5

Citation relations strong component clique

ADAMSON I	LEYDESDORFF L
ARUNACHALAM S	LINDSEY D
BALDAUF RB	LUUKKONEN T
BAUIN S	MANORAMA K
BLICKENSTAFF J	MARTIN BR
BONITZ M	MCALLISTER PR
BRAUN T	MENDEZ A
BURGER WJM	MILLER RB
CALLON M	MOED HF
CARPENTER MP	MORAVCSIK MJ
CHUBIN DE	NAGY JI
COHEN JE	NARIN F
COURTIAL JP	NEDERHOF AJ
COZZENS SE	NIEUWENHUYSEN P
DAVIS CH	NOMA E
DEBRUIN RE	OLUICVUKOVIC V
DIAMOND AM	OROMANER M
DIJKWEL PA	PERITZ BC
DOREIAN P	PRAVDIC N
EGGHE L	RABKIN YM
ETO H	RIP A
FERNANDEZ MT	ROUSSEAU R
FRAME J	SCHUBERT A
FRANKFORT JG	SEN SK
GARC KC	SENGUPTA IN
GARFIELD E	SMALL H
GLANZEL W	SMART JC
GOMEZ I	SNIZEK WE
GORDON MD	SWALES J
GRANOVSKY YV	SWEENEY E
GREENLEE E	TAGUE J
HAITUN SD	TIJSSEN RJW
HARGENS LL	TODOROV R
HUSTOPECKY J	TURNER WA
INHABER H	VANRAAN AFJ
IRVINE J	VELHO L
KRETSCHMER H	VINKLER P
KUMARI L	VLACHY J
KUNZ M	WINTERHAGER M
LANCASTER FW	ZSINDELY S
LANGE L	ZUCKERMAN H
LEPAIR C	

Table 6
Citation matrix: cliques using only direct citation relations

Strong component cliques

Cluster 1

HARGENS LL
LINDSEY D

Cluster 2

BONITZ M
KUMARI L
SENGUPTA IN

Cluster 3

DEBRUIN RE
NEDERHOF AJ
TIJSSEN RJW

Cluster 4

GREENLEE E
SMALL H
SWEENEY E

Cluster 5

BAUIN S
CARPENTER MP
IRVINE J
MARTIN BR

Cluster 6

TODOROV R
WINTERHAGER M

Cluster 7

FRAME J
MACALLISTER PR
NARIN F
NOMA E

Cluster 8

BURGER WJM
FRANKFORT JG
MOED HF
VANRAAN AFJ

Cluster 9

CALLON M
COURTIAL JP
LEYDESDORFF L
TURNER WA

Cluster 10

HAITUN SD
KUNZ M

Cluster 11

ARUNACHALAM S
GLANZEL W

Cluster 12

MORAVCSIK MJ
VELHO L

Cluster 13

BRAUN T
SCHUBERT A
ZSINDELY S

Table 6 (continued)

Weak component cliquesCluster 1

HARGENS LL
LINDSEY D

Cluster 2

GREENLEE E
SMALL H
SWEENEY E

Cluster 3

CALLON M
COURTIAL JP
LEYDESDORFF L
RIP A
TURNER WA

Cluster 4

HAITUN SD
KUNZ M

Cluster 5

MORAVCSIK MJ
VELHO L

Cluster 6

ARUNACHALAM S
BAUIN S
BONITZ M
BRAUN T
BURGER WJM
CARPENTER MP
DEBRUIN RE
EGGHE L
FRAME J
FRANKFORT JG
GARG KC
GLANZEL W
IRVINE J
KUMARI L
MACALLISTER PR
MANORAMA K
MARTIN BR
MOED HF
NARIN F
NEDERHOF AJ
NIEUWENHUYSEN P
NOMA E
ROUSSEAU R
SCHUBERT A
SENGUPTA IN
SWALES J
TIJSSEN RJW
TODOROV R
VANRAAN AFJ
WINTERHAGER M
ZSINDELY S

Table 7
Citation matrix analyzed only on the direct relations

Authors with similar positions

Cluster 1

BLAIVAS A
DOREIAN P
KOCHEN M
KRETSCHMER H
LANGE L
SWALES J

Cluster 2

BONITZ M
EGGHE L
NIEUWENHUYSEN P
ROUSSEAU R
TAGUE J

Cluster 3

ADAMSON I
ALFENAAR W
ARUNACHALAM S
ARVANITIS R
BALDAUF RB
BARRIGON S
BAUIN S
BEAVER DD
BLICKENSTAFF J
BORDONS M
BRAUN T
BRUNK GG
BURGER WJM
CALLON M
CANO V
CARPENTER MP
CHATELIN Y
CHU H
CHUBIN DE
COHEN JE
COURTIAL JP
COZZENS SE
DAVIS CH
DEARENAS JL
DEBRUIN RE
DIAMOND AM
DIJKWEL PA
DORE JC
DOU H
EHIKHAMENOR FA
ETO H
FERNANDEZ MT
FRAME J
FRANKFORT JG
FRIGOLETTO L

LANCASTER FW
LAWANI SM
LEMOINE W
LEPAIR C
LIND NC
LINDSEY D
MACALLISTER PR
MACZELKA H
MANORAMA K
MARTIN BR
MCCAIN KW
MENDEZ A
MICHELET B
MILLER RB
MIQUEL JF
MOED HF
MORAVCSIK MJ
NAGY JI
NALIMOV VV
NARIN F
NEDERHOF AJ
NOMA E
NORDSTROM LO
OROMANER M
PAO ML
PERITZ BC
PLOMP R
POURIS A
QUONIAM L
QURASHI MM
RABKIN YM
RICHARDS JM
RIP A
ROCHE M
ROSEN R

Table 7 (continued)

GARFIELD E	RUSHTON JP
GARG KC	RUSSELL JM
GLANZEL W	SEN SK
GOMEZ I	SMALL H
GORDON MD	SMART JC
GRANOVSKY YV	SNIZEK WE
GREENLEE E	SPANGENBERG JFA
GRUPP H	SWEENEY E
GUAY Y	TIJSSEN RJW
GUPTA DK	TODOROV R
HAITUN SD	TROFIMENKO AP
HARGENS LL	TURNER WA
HASSANALY P	VANHEERINGEN A
HURT CD	VELHO L
HUSTOPECKY J	VINKLER P
INHABER H	VLACHY J
IRVINE J	WINTERHAGER M
JAGODZINSKISIGOGNEAU M	YABLONSKY AI
JASCHEK C	YUTHAVONG Y
KORENNOI A	ZSINDELY S
KRAUSKOPF M	ZUCKERMAN H
KRYZHANOVSKY LN	
KUNZ M	

In summary, within the core set of 181 authors in *Scientometrics*, 130 authors cite one another regularly. The majority has strong mutual relationships, being members of one clique. Moreover, the pattern of citation relations of most authors is highly similar. This holds even for the relatively isolated authors. Thus, these results are indicative of a strong integration. In this respect, the field of scientometrics seems indeed to have developed an identity of its own.

c: The epistemic network

The most striking feature of the network of title words of articles published in *Scientometrics* is its cohesiveness. All words cluster together in a single strong component clique (Table 8). If only direct relations are included, all words cluster together in a single weak component clique. This means that all words are either used together in a title or share a common co-word. This strong cohesiveness is underlined by Table 9, which gives the realized word-word relations as a percentage of all possible dyadic relations for the matrix as a whole and for every three year period. Almost all the co-word possibilities are realized in two steps, meaning that the words are at the most one step apart. So, the titles exhibit many overlaps.

Table 8
The overall network of title words

<u>Strong component clique</u>		
ACTIVITIES	EUROPEAN	POLICY
ACTIVITY	EVALUATION	PRICE
ANALYSIS	FIELD	PROBLEM
APPLICATION	GROUP	PRODUCTIVITY
ARTICLE	GROWTH	PROGRAM
ASSESSMENT	IMPACT	PUBLICATION
AUTHORSHIP	INDEX	QUANTITATIVE
BASIC	INDICATOR	RESEARCH
BIBLIOMETRIC	INFORMATION	REVIEW
BRADFORD	INTERNATIONAL	SCIENCE
CASE	JOURNAL	SCIENTIFIC
CHEMISTRY	LAW	SCIENTIST
CITATION	LIFE	SCIENTOMETRIC
CO	LITERATURE	SIZE
COLLABORATION	MEASURE	SOCIAL
COMMENT	MEASUREMENT	STATE
COMMUNICATION	METHOD	STRUCTURE
COMPARATIVE	MODEL	STUDIES
COMPARISON	MULTIPLE	STUDY
COUNTRIES	NATIONAL	SYSTEM
DATA	NETWORK	TECHNOLOGICAL
DEVELOPMENT	OUTPUT	TECHNOLOGY
DISCIPLINE	PAPER	THEORY
DISTRIBUTION	PATTERN	UNITED
ECONOMIC	PERFORMANCE	UNIVERSITY
EFFECT	PHYSICS	USE
		USING
		WORLD

At the same time, the language of scientometrics appears not to be strictly codified. The words display a highly individual pattern in their relations to one another. In contrast to the authors, most words cannot be clustered reliably at all. Even if the threshold of reliability coefficients is lowered to 0.85 (instead of 0.9 as used in the analysis of the author-author matrices), only two small clusters of words with similar positions show up (Table 10). Apparently, the network of title words does not have a clear structure. This may be explained by postulating that there is no clear subdivision of the set of words used in titles in *Scientometrics*. Nor do distinctions between subject-, methodology- and theory-related words show up in the analysis. Since this occurs commonly in the social sciences, scientometrics seems to share not only social, but also epistemic features with the latter.

Table 9

Realized word-word relations as percentage of possible dyadic relations 1978-1992

PATH	PERCENTAGE OF	
DISTANCE	FREQUENCY	ALL RELATIONS

1	2852.	45.13
2	3468.	54.87
3	0.	.00
NO		
CONNECTION:		
	0.	.00

Table 10

Words with similar positions in the epistemic network

Cluster 1
NATIONAL
INTERNATIONAL

Cluster 2
ANALYSIS
INDICATOR
CITATION
SCIENTIFIC
RESEARCH
SCIENCE

Thus, the language of scientometrics is both strongly unified and weakly codified. This strong cohesiveness is a stable characteristic of the titles in *Scientometrics*, from the very start of the journal. Perhaps a distinct discourse already existed before the journal was founded. In any case, it constitutes a textual identity of scientometrics as a field, one probably different from the various mother disciplines. Thus a process of de-differentiation seems to have occurred not only in the patterns of citing (and being cited) but also at the cognitive level.

Summary and conclusions

Has scientometrics as a specialty achieved the characteristics of a 'hard' social science, in other words has Price's dream come true? Does the history of *Scientometrics* exhibit the features one would expect if it had grown into the core journal of a scientific community with a research front?

As noted, the Price Index measures the immediacy of citation impact, and has therefore been used as an indicator of the existence of a "research front". In the case of *Scientometrics* we found values for this index in the range of 40 to 50. These values are common to the social sciences. It made no significant difference whether we normalized for the whole set or used Moed's (1989) proposal to compute this index on an article-by-article basis. We also found a small but significant difference between the Price Indices of *Social Studies of Science* on the one hand, and *Scientometrics* and *JASIS* on the other. This variation is comparable with the results of Moed (1989) in natural science disciplines.

The interpretation of the Price Index is complicated because of these variations within disciplines. If we, nevertheless, take the Price Index preliminary as an indicator of "hardness", scientometrics belongs to the group of relatively hard social sciences. At the same time, it stays unequivocally within the social science range. Taken literally, Price's dream has therefore not come true, since he postulated the emergence of a completely new type of social science with a natural science character. But if we reformulate his goal a posteriori in a more modest way, as the building of a relatively hard social science, it did come true.

The value of the Price Index appears stable over the years. Since a number of other indicators also exhibit stability, this seems to suggest the existence of some scientometric identity. For example, the journal expands at a regular rate, while the percentage of co-authored papers increases only very slowly. The origin of this stability can best be explained by the finding that the community of researchers who have published more than once in *Scientometrics* acts as a tightly knit network. In addition to the co-authorships within various institutes, and partly overlapping with this structures, there are national co-authorship relations, like those among the Belgian informetricians, and programmatic co-authorship relations, like those among the users of the French co-word instrument. In general, co-authorship relations are firmly embedded in existing social structures, both at the national and at the community level. These various strong graphs of co-authors, however, are structurally embedded in the communication structure as indicated by textual indicators. Both in

terms of citation relations and in terms of title-words the network is very cohesive, while the structural dimensions of codification are less clear. Scientometrics apparently is a scientific discourse with the fluid characteristics of a social science discipline. Although it is institutionalized, this institutionalization has led neither to (e.g., semantic) rigidities nor to strong sub-group formation. In summary, the community of authors publishing in *Scientometrics* is well integrated, while there are no indications of an exclusive paradigm or a research front.

Are these results an artefact of using the algorithms of the program STRUCTURE for the analysis? We don't think so. While it is always possible to create a grouping by using a cluster or principal component analysis technique, the programme STRUCTURE allows (provisional) solutions to be tested for their statistical significance. We would not have been able to draw these fine-grained conclusions without this option. Of course, our focus on *Scientometrics* as a journal – on the occasion of completing its twenty-fifth volume – created a bias. The wider social context is not visible if we focus on only one journal.¹⁶ Our research question, however, was whether an increasingly coherent set could be found by focussing on the core journal, since we already knew that the contributing authors were identified with different research communities. We found a cohesive set within this specific domain, indeed, despite differences in disciplinary backgrounds.

In the introductory section we raised the question of whether scientometrics has grown into an interdisciplinary area with a stable cognitive and social core group. We expected as a possible outcome that *Scientometrics* might not have a stable core, but that it would function primarily as a meeting place or a publication outlet for different scholarly communities like library scientists, sociologists of science, and applied mathematicians. Given these differences in disciplinary backgrounds, one would expect to find various structural dimensions reflected in the networks among these authors, and consequently differentiation into various groupings. As noted, the absence of these structural characteristics is significant. In terms of cultural theory (Douglas 1982; Thompson et al. 1990) one could speak of "high group, low grid", and thus one might characterize this community as "a democratic sect".

How can this be explained? Perhaps the authors are so much aware of the differences among one another's work that they counter-act such differentiation. De-differentiation, however, is expected to be successful only in a highly competitive market, one which feeds back on tendencies toward specialization and niche-formation. In our opinion, the metaphor of a competitive market may help us to understand these results. Although there are a few larger groups whose members

regularly co-author among themselves, open competition seems to be the main characteristic of the network. The larger groups have not monopolized the cognitive arena, neither in terms of specialist terminologies nor in terms of co-authorship relations. Probably the fierce competition for funding and institutional legitimization does not encourage highly specialized profiles. We suggest, in other words, that most groups have to survive in a hostile environment, in which they have to be able to utilize (cognitive) relations at the level of the scientific community in their quest for resources. Scientometricians may therefore prefer to maintain a broad profile which relates to the field as a whole.

Notes

1. "Price's Index (as I might call it) will vary from 22 percent for normal growth to 39 percent for most rapid growth for a field that is purely archival, raiding all the literature that has gone before equally, with only a gradual secular decline with aging, and without this special immediacy of an active research front." (*Price* 1970, p. 10).
2. First, we measured the Price Index for every year as follows:

$$PI = (N1/N2) * 100$$

In this formula N1 is, for every year, the number of references with a relative age less than 6 years. N2 is the total number of references. The relative age of a cited article is the difference between the publication year of the citing article and its own publication year. Using the same procedure for every citing article gives Moed's Price Index per article. The overall Price Index is then the sum of the Price Index per article, divided by the total number of articles.

3. Recently, *Lubrano* has used co-authorship data to reveal informal networks in Soviet science (*Lubrano* 1993).
4. The shortest path between two indirectly linked authors is sometimes, informally, called the Erdős Index.
5. *R. S. Burt, Structure* (1987), version 3.2.
6. If self relations are ignored, as in our case, a third term must eliminate the self relations from the distance definition. The formula is:

$$d_{ij}^p = [\sum_q (z_{jq} - z_{iq})^2 + \sum_q (z_{qj} - z_{qi})^2 + (z_{ij} - z_{ji})^2]^{1/2}$$

7. The percentage of variation in distances to structurally equivalent authors that can be described with a single principal component is measured as follows:

$$100 g / \sum_j s_j$$

In this formula summation is across all members *j* of the cluster, *s_j* is the observed variance in distances to *j*, and *g* is the maximum eigenvalue for the cluster matrix of covariances among distances to the members of the cluster. If authors have identical positions, this percentage is 100. This check on the cluster composition is necessary because the distances are a relative measure. *Van Rossum et al.* (1988) seem however to have missed this point.

8. The reliability coefficient measures the degree to which the author involved is similar to the other members of the cluster. To the extent that j 's pattern of relations is identical to the aggregate pattern of the cluster involved, anyone's distance from j will equal the average distance from all other members of the same structural equivalence cluster. Hence the reliability coefficient r_{pj} will equal 1.0:

$$r_{pj} = \sum_q (d_{jq} - d_j)(d_{pq} - d_p) / \{[\sum_q (d_{jq} - d_j)^2][\sum_q (d_{pq} - d_p)^2]\}^{1/2}$$

In this formula summation is across all individuals q in the network, d_{jq} is the Euclidean distance between j and q , d_{pq} is the aggregate Euclidean distance between individual q and all members of the cluster excluding j , and d_j and d_p are the respective means on these variables.

9. Words with a frequency lower than 3 were discarded. For reasons of economy the threshold was set on 11 in the production of the matrix of the complete set of titles, and on 4 to produce the matrix of the period 1992–1990. All conjunctions ('or'), general adjectives, numbers, and one-letter words were discarded as well.
10. Mistakes, like empty fields, were corrected (74 cases), and virtual references to literature before the year 1000 or after the year 1992, were discarded (303 references).
11. $R = 0.95378$; $F = 130.96345$; Signif. $F < 0.00005$; $R^2 = 0.90275$.
12. $R = 0.38962$; $F = 2.32663$; Signif. $F = 0.1511$; $R^2 = 0.08656$.
13. *Abt* (1981) found a peak reference age at 6–8 years in astronomy.
14. Using Price's method of measuring the Price Index.
15. If taken as the summation of every different paper of every author over all authors.
16. See *Leydesdorff* (1989b) for an aggregated journal-journal citation mapping using *Scientometrics* as the entry journal.

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