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Management of technology: themes, concepts and relationships

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Abstract

In this paper, bibliometric (co-citation analysis) and social network analysis techniques are used to investigate the intellectual pillars of the technology management literature as reported in Technovation. Network analysis tools are also used to show that the research agenda of scholars from different parts of the world differ substantially from each other, and it is argued that such differences may have exacerbated the delays experienced in developing technology management as a respected academic discipline.

Keywords: Technology management; Bibliometric techniques; Factor analysis; Co-citation; Citation analysis; Social network analysis

1. Introduction

Over the last two decades technology management (TM) has gradually established itself as an academic discipline. For example, Drejer (1997) identifies four schools of thought as the discipline evolved from R&D Management, through Innovation Management and Technology Planning before developing as Strategic Management of Technology (MOT). Under this classification, MOT is distinct from economics and public policy and is solidly located within the management field. This establishment of a discipline has been a slow process probably as TM researchers prefer to publish their best work in more established journals—such as *ASQ, Management Science, the Academy of Management Journal, Harvard Business Review and Strategic Management Journal*—typically associated with competing fields (Cheng et al., 1999). The importance of publishing in established and respected journals only partially explains why career conscious academics hesitate to submit their ideas to TM-specific journals.

Ambiguity on discipline location and roots relate back to its very early development. For example, Brockhoff (2003) plots the roots of TM back to the philosophical writings of Francis Bacon's 17th century ideas concerning the organization of inquiry and also discusses the significance of the engineering perspective and its associated investigations which followed the establishment of industrial research and development laboratories about a century ago. However, in common with ideas assigned to most other philosophical or physical science perspectives, these view invention as an art with technical progress dependent upon the ingenuity of single persons. Brockhoff continues by discussing the influence of the Schumpeterian view of the innovator as entrepreneur, which represents a perspective often viewed as a contribution form management planning (Solow, 1957). Exploring more recent developments also show a similar contradiction in discipline location for TM. The focus before the mid 1970s was largely in the hands of practitioners and governmental authors (Allen and Sosa, 2004) with business schools taking over in the 1980s when managing technology became considered as a competitive advantage (US National Research Council, 1987) and the management of technology educational programmes finally emerged 'to mainstream business management during the 1990s' (Nambisan and Wilemon, 2003).

As such, the major obstacle to the development of a TM tradition lies in the subject's unusually high degree of interaction with other disciplines. This overlap blurs the boundaries of TM and as a result its distinct theoretical models and analytical tools are unjustly attributed to competing fields. The review by Garcia and Calantone

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(2002) shows this rather graphically in their analysis of innovation terminology. This confusion, we argue, will be further exacerbated if there are substantial differences in interests and approaches by TM scholars in different parts of the globe. Without cross-fertilisation of ideas between authors on both sides of the Atlantic and elsewhere, recognition of what the discipline stands for will be that much more difficult to obtain.

This paper empirically investigates the issues arising from the struggle to establish TM by examining its literature using citation and co-citation data obtained from *Technovation*. A brief review of similar bibliometric studies is presented to introduce the approach, along with a description of the data. The principal investigation was a factor analysis which was performed to determine the latent structure underlying the TM literature. The view of the TM literature which this analysis produces is discussed and a simple non-parametric technique is used to test the geographic dichotomy.

2. Studies of the academic literature

There are a number of techniques that can be used to examine a body of literature. Most frequent is the simple literature review where a highly subjective approach is used to structure the earlier work (Drejer, 1996, 1997). More objective, quantitative techniques are also available and use an analysis of author citations, co-citations (or a combination of the two) and systematic review. Citation analysis is based on the premise that authors cite papers they consider to be important to the development of their research. As a result, heavily cited articles are likely to have exerted a greater influence on the subject than those less frequently cited (Sharplin and Mabry, 1985; Culnan, 1986). As such these analyses represent 'the field's view of itself' (White and Griffith, 1981). There are well defined concerns surrounding citation analysis, including the problem that a study may be heavily referred to due to its poor quality. However, with adequate screening and a sufficiently large sample, citation analysis provides a useful insight into which papers and authors are considered influential. Similarly, co-citation analysis involves analysing the frequency with which two citations appear together in the literature (Small, 1973). The approach is instrumental in identifying groupings of authors, topics, or methods and can help us understand the way in which these clusters relate to each other.

A number of bibliometric analyses have been performed on the literatures of fields adjacent to TM. For example, Culnan (1986) used co-citation analysis to investigate the founding pillars of management information systems and found the subject to have more affinity with information science than organisation studies. Similarly, Karki (1996) examined the sociology of science literature and found that information scientists and sociologists exchange ideas only when they are discussing 'scholarly communication' as a subject. Pilkington and Liston-Heyes (1999) have also examined the sub-fields in operations management. To the best of our knowledge no such study has dealt with the field of TM, with the closest being Cottrill et al's (1989) investigation of the links between 'diffusion theory' and 'technology transfer'. Somewhat surprisingly, they found the use of distinct approaches within each sub-field but that they rarely interacted with each other.

With regards to the second objective of this study—assessing whether scholars from different regions are interested in the same TM issues—we follow in the footsteps of Usdiken and Pasadeos (1995) who tested the literature of Organisational Analysis for a similar geographical division. They found that the field's two major journals, the North American produced *Administrative Science Quarterly*, and the UK edited *Organisation Studies*, almost exclusively published the work of local authors who were similarly parochial in their citation practices. This approach was adapted by Pilkington and Liston-Heyes (1999) and found a noticeable difference between the interests of North American and European scholars and their research traditions in operations management.

3. Methodology

The data used in this study included the contents (article titles, authors, publication dates, and citations) of *Technovation* between 1996 and 2003. *Technovation* was selected on the basis of its prominence in the field, wide geographical coverage, and ease of access because of its inclusion in the on-line version of the Social Science Citation Index (SSCI). This is a somewhat imperfect record of the literature which should ideally include the contents or partial contents of other journals such as *Research Policy, R&D Management, Decision Science, Management Science, IEEE Transactions on Engineering Management,* and *Journal of Engineering and Technology Management (JETM)*. However, it was felt that the wide range of topics covered by the articles in these journals and the differences in readership focus would necessitate a manual and time consuming classification of the articles to identify those relevant to TM. Also, as there were no citation data in the SSCI for *Technovation* before 1996, it was decided to limit the scope of the sample to the articles appearing in *Technovation* from Volume 16, Number 10, 1996 to Volume 23 Number 12, 2003.

One concern with the data selection and recovery phase of the work revolved around some omissions in the SSCI database. Whilst there are records for every issue between these dates, they contain an uneven number of articles, and some entries, such as January and October 1997, list only one article. Therefore, it is evident that the SSCI records are incomplete. However, despite there being no discernable reason as to why some articles were missing, it was thought that this represents a sampling effect rather than any

Table 1
Authors contributing articles to the sample

Author	Number of articles
Watanabe C	21
Carayannis EG	14
Sohal AS	8
Griffy-Brown C	7
Nagamatsu A	5
Gunasekaran A; Ilori MO; Lee J; Perez MP; Sanchez AM; Takayama M; Tomes A	4
Armstrong P; Asgari B; Bessant J; Brown S; Drejer A; Fernandez E; Garavelli AC; Kondo R; Ottosson S; Ouchi N; Sanni SA	3

deliberate bias, and it is felt unlikely that the results of the following analysis have been unduly affected.

The initial extraction of the data from the SSCI resulted in 321 articles by 532 different authors. The discrepancy is due to multiple articles by the same author and because many authors also feature as co-authors with others. Table 1 shows the authors with the most articles published in the *Technovation* sample.

A certain amount of manipulation was required to standardise entries and correct inconsistencies in the SSCI particularly the spelling of author names, affiliations, and journals. For example, at least three different abbreviations were used for the *International Journal of Operations and Production Management* journal: *IJOPM, IJOpProdMan* and *IntJOPM*; and author's names seemed to arbitrarily include one or two initials. The 321 source articles produced a total of 10,176 citations.

4. Results

4.1. Citation analysis

Preliminary analyses of the data produced interesting background statistics, for example the frequency of journal citations, listed in Table 2. Not unsurprisingly given the discussion about TM as a discipline above, general management and strategy specific journals featured prominently alongside the technology management specific journals, with a cluster of operations management focussed titles also evident, whilst economics and marketing are less prominent. This suggests that there is a clear strategy and management emphasis in *Technovation*, showing how the ideas of technology management relate to the firm rather than wider contexts and markets. It also clearly differentiates us from the more inwardly and methodologically concerned economic and public policy traditions.

A standard approach often used in bibliographic analysis is to concentrate on cited authors as a proxy for their ideas, amalgamating all their publications together (Culnan, 1986). This is normal practice as studies start with a few key authors as a seed which is then expanded by searches of citations in the SSCI. In these cases, author name searches offer a massive time advantage over looking at individual publications in data retrieval and are far more accurate. In our case, given the census type approach following the adoption of *Technovation* as our source, we are able to use the more detailed and robust measure of individual papers and texts. Table 3 gives the frequencies with which a particular individual document has been cited.

Table 2
The most frequently cited journals

Journal title	Number of citations
Research Policy	339
Strategic Management Journal	279
Technovation	252
Harvard Business Review	236
Journal of Product Innovation Management	139
R&D management	116
International Journal of Technology Management	110
California Management Review	104
Administrative Science Quarterly	100
Academy of Management Review	96
Management Science	90
Technology Forecasting and Social Change	87
Academy of Management Journal IEEE Transactions of Engineering Management	82
Research and Technology Management Sloan Management Review	80
International Journal Operations and Production Management	78
Organisation Science	72
Journal of Business Venturing	64
Long Range Planning	53
Technology Analysis and Strategic Management	49
Journal of Marketing	47
American Economic Review	42
Journal of Operations Management	36
JET-M	30
Economics Journal J Management OMEGA	29
Journal of International Business Studies	28
Science and Public Policy	26

Although it does not eliminate the bias against younger authors, an article-based ranking places more emphasis on the quality (as opposed to the quantity) of the documents produced by a given author than a ranking of the frequencies with which a particular author has been cited. In addition, Table 3 represents the focus of the main authors in the field and this gives us an indication of the popularity of certain TM topics. Examining the list, one notices the high frequency of what can be termed discipline-forming titles (Rogers, Penrose, and Freeman) which laid the ground work for the understanding of technology management as a distinct process or activity. The list also shows our close ties to strategy, with Porter's texts and the resource based view (RBV)/core competency ideas emerging as highly influential, particularly where they have been applied to the innovation process by the likes of Cohen and Levinthal. Given the age effect on citation frequencies, the newer

Table 3
Article citation frequency

Document	Frequency
Nelson R, Evolutionary Theory (1982)	31
Cohen W, Adm Sci Q (1990)	27
Nonaka I, Knowledge Creating C (1995); Rogers E, Diffusion Innovation (1962)	22
Porter M, Competitive Adv Nati (1990); Prahalad C, Harvard Bus Rev (1990)	19
Porter M, Competitive Strategy (1980); Vonhippel E, Source Innovation (1988)	17
Dosi G, Res Policy (1982)	15
Freeman C, Ec Ind Innovation (1974)	14
Nelson R, Nat Inn Syst (1993); Porter M, Competitive Advantage (1985); Womack J, Machine Changed World (1990)	13
Christensen C, Innovators Dilemma (1997); Senge P, 5 Discipline (1990)	12
Barney J, J Manage (1991); Nonaka I, Harvard Bus Rev (1991); Penrose E, Theory Growth Firm (1959); Utterback J, Mastering Dynamics I (1994); Yin R, Case Study Res Desig (1994)	11
Clark K, Product Dev Performa (1991); Cohen W, Econ J (1989); Griliches Z, J Econ Lit (1990); Leonardbarton D, Wellsprings Knowledg (1995); Lundvall B, Natl Systems Innovat (1992); Polanyi M, Tacit Dimension (1966); Teece D, Res Policy (1986); Tidd J, Managing Innovation (1997); Watanabe C, Technovation (2001); Wheelwright S, Revolutionizing Prod (1992)	10

publications that feature near to the top of the list in Table 3 can be judged to have made an unduly large impact on the discipline, with Nonaka and Christensen's contributions being particularly striking.

We again find evidence for the difficulty in establishing TM as a distinct discipline with the top journal articles showing a heavy bias towards the outlets of other fields, for example, *Administrative Science Quarterly, Harvard Business Review, Academy of Management Review, Organisation Science, California Management Review*, and *Strategic Management Journal*, with only a small showing for *Research Policy* and *Technovation* in this list of most influential articles.

Whilst the tables above give us some insight into the field and represents a fairly standard citation analysis, the method does not give a clear account of the concentration of interests within TM. We address such issues by performing various analyses on the co-citation matrix. As explained above, co-citations are counts of the frequency with which two existing documents are cited *together* in a new document and their analysis enables us to say something about the way ideas support and interact with each other and also to plot the structure of intellectual disciplines (Small, 1973; White and Griffith, 1981).

4.2. Co-citation analysis

Co-citations were tabulated for each of the 321 source documents using the bibliometric analysis package *Bibexcel* from Persson (2003). Many of the documents had very few co-citations and were either unlikely to have had a significant impact on the development of the field and/or were too recent to have had time to impact on the literature. To facilitate the running of our analyses and improve the probability of its success, we made sure that all documents in the final set had at least four citations. This resulted in a 199 by 199 co-citations matrix, an extract of which is presented in Table 4. In doing so, we were essentially following the procedures recommended by White and Griffith (1981), but with the added precision of using the individual work level rather than aggregated author level.

Table 4
Author co-citation matrix (extract)

	Aaker (1989)	Abernathy (1985)	Abernathy (1978)	Allen (1977)	Amit (1993)	Ansoff (1966)	Ansoff (1990)
Aaker (1989)	XXX						
Abernathy (1985)	0	XXX					
Abernathy (1978)	0	1	XXX				
Allen (1977)	0	1	0	XXX			
Amit (1993)	3	0	0	0	XXX		
Ansoff (1966)	2	0	0	0	1	XXX	
Ansoff (1990)	0	0	0	0	0	2	XXX
Archibugi (1992)	0	0	0	0	0	0	0
Argyris (1978)	3	0	0	0	5	0	0
Barney (1991)	4	0	0	0	4	2	0

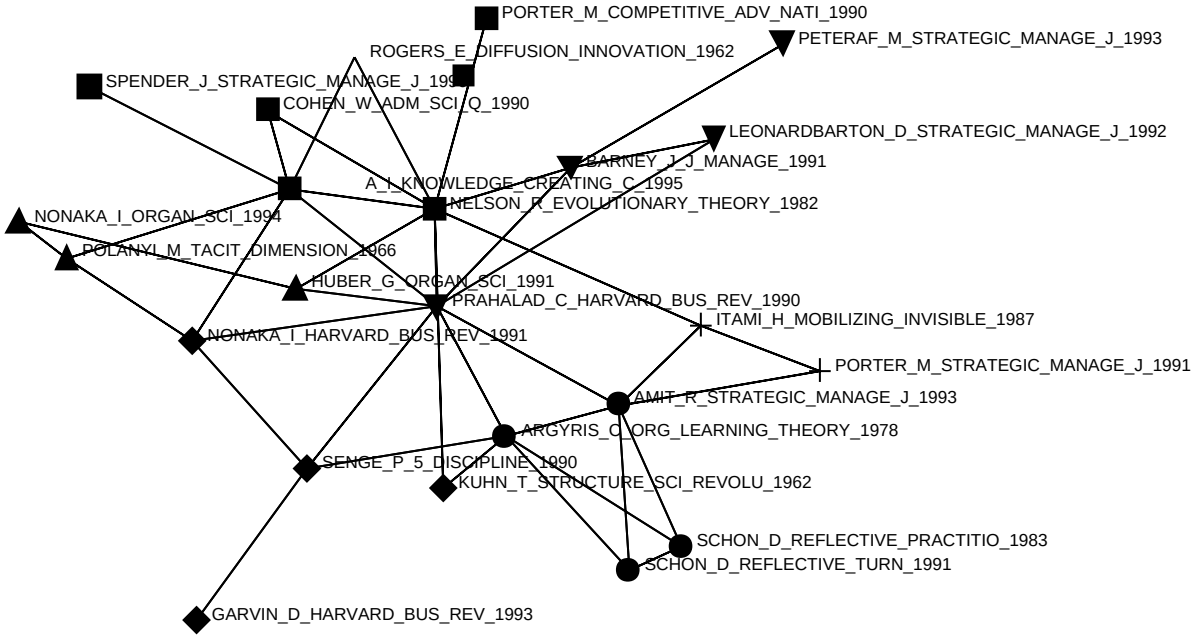

Fig. 1. Core disciplines—co-citation network of ≥ 4.

The relevance of the co-citation matrix in this context is based on the notion that documents which are related to one another will, in general, be repeatedly cited together in subsequent publications, while documents which are rarely or never cited together do not.

Social network analysis tools can be used to graph the relations in the co-citation matrix and identify the strongest links and so the core areas of interest in TM. Fig. 1 shows the core of the co-citations in *Technovation* with links of greater than or equal to four co-citations shown in the network. This was produced using UCINET software (Borgatti et al., 2002) and shows graphically the core areas of interest. The different shapes of the nodes result from performing a faction study of these articles. This method seeks to group elements in a network based on the sharing of common links to each other. These factions can be interpreted as concentrating on the interaction between organisation, knowledge, resources and strategy, with empirical investigation occurring through the medium of patent analysis and case study.

Whilst the diagram in Fig. 1 is very telling and provides a clear picture, its focus is only on the very core area and a limited amount of the data available. By taking the co-citation matrix and grouping the documents using factor analysis of the correlation between the entries determines which documents are grouped together and therefore share a common element. It does so by producing a number of 'factors', each of which captures a common element (i.e. latent) of the documents that are grouped together. It is also capable, by producing numerical indicators of the relevance of the factors (i.e. eigenvalues), to tell us something about the relative importance of these underlying elements.

The raw co-citation matrix was factor analysed using the varimax rotation, a commonly used procedure, which attempts to fit (or load) the maximum number of documents on the minimum number of factors. The diagonals were set at the three highest scores divided by two—following the method of White and Griffith (1981).

Fourteen factors were extracted from the data and together they explain over 60% of the variance in the correlation matrix. Table 5 lists the seven most important factors along with the documents that had a factor loading of at least 0.4. As is usual in this type of analysis, documents with less than a 0.4 loading were dropped from the final results (Hair et al., 1998). We tentatively assigned names to the factors on the basis of our own interpretation of the documents with high associated loadings. Implicitly, our interpretation of the analysis results is that the TM field is composed of at least seven different sub-fields: strategy and technology, national systems and differences, sources of competitive strategies, manufacturing/operations/NPD, knowledge management and inventors, patents, and life-cycles/change/discontinuity. We made no attempts to interpret the remaining factors on account of their relatively small eigenvalues ($<3.2\%$). They have similarly been excluded from Table 5.

It is well established that technology and strategy lie at the heart of TM and so the first three groups resulting from the factor analysis were more or less expected. What the analysis highlights, however, are the three distinct approaches to the study of technology strategy. The first factor is concerned with the wider question of the role of strategy in general. Many papers in this group discuss the need and value of innovation to be part of the strategic focus of firms, without giving too many details about particular

Table 5
Document factor loadings (varimax rotation) at 0.4 or higher

Factor 1: strategy and technology	13.6% Variance	Factor 2: national systems and differences	7.6% Variance	Factor 3: sources of competitive strategies	6.3% Variance	Factor 4: manufacturing/ operations/ NPD	4.3% Variance	Factor 5: knowledge management and inventors	4.1% Variance	Factor 6: patents	3.9% Variance	Factor 7: life-cycles/change/ discontinuity	3.9% Variance
COLE R, STRATEGIES LEARNING, (1989)	0.9630	FREEMAN C, CAMBRIDGE J ECON, (1995)	0.9350	HALL R, STRATEGIC MANAGE J, (1992)	0.9480	BESSANT J, INT J TECHNOL MANAGE, (1993)	0.9010	KOGUT B, ORGAN SCI, (1992)	0.8230	JAFFE A, AM ECON REV, (1986)	0.9590	PAVITT K, J IND ECON, (1987)	0.8340
QUINN J, INTELLIGENT ENTERPRI, (1992)	0.9630	SCHERER F, INT J IND ORGAN, (1983)	0.9190	WERNERFELT B, STRATEGIC MANAGE J, (1984)	0.8380	HAYES R, RESTORING OUR COMPET, (1984)	0.8970	SEATON R, TECHNOVATION, (1993)	0.8190	COHEN W, ECON J, (1989)	0.9500	TUSHMAN M, ADM SCI Q, (1986)	0.8260
SCHON D, REFLECTIVE TURN, (1991)	0.9440	ARCHIBUGI D, SCI PUBL POLICY, (1992)	0.8960	DIERICKX I, MANAGE SCI, (1989)	0.8350	HILL T, MANUFACTURING STRATE, (1994)	0.8800	MOWERY D, STRATEGIC MANAGE J, (1996)	0.7340	GRILICHES Z, R D PATENT PRODUCTIV, (1984)	0.9230	ABERNATHY W, RES POLICY, (1985)	0.7920
SCHON D, REFLECTIVE PRACTITIO, (1983)	0.9420	BASBERG B, RES POLICY, (1987)	0.8890	STALK G, HARVARD BUS REV, (1992)	0.8200	WOMACK J, MACHINE CHANGED WORL, (1990)	0.8430	WEICK K, SOCIAL PSYCHOL ORG, (1979)	0.7280	GRILICHES Z, BELL J ECON, (1979)	0.9080	UTTERBACK J, OMEGA-INT J MANAGE S, (1975)	0.7360
CARAYANNIS E, INCREMENTALISME STRA, (1993)	0.9320	CANTWELL J, TECHNOLOGICAL INNOVA, (1989)	0.8890	GRANT R, CALIF MANAGE REV, (1991)	0.7910	ITAMI H, STRATEGIC MANAGE J, (1992)	0.8140	NONAKA I, ORGAN SCI, (1994)	0.6610	BERNSTEIN J, J IND ECON, (1998)	0.9070	COOPER R, J MARKETING, (1979)	0.7330
MINTZBERG H, LONG RANGE PLANN, (1991)	0.9320	PAVITT K, HDB QUANTITATIVE STU, (1988)	0.8850	ANSOFF H, CORPORATE STRATEGY, (1966)	0.7740	PAVITT K, CALIF MANAGE REV, (1990)	0.8120	GILBERT M, TECHNOVATION, (1996)	0.6570	WATANABE C, RES POLICY, (1999)	0.9040	SCHUMPETER J, THEORY EC DEV, (1934)	0.7330
PORTER M, STRATEGIC MANAGE J, (1991)	0.9120	PAVITT K, SCIENTOMETRICS, (1985)	0.8800	BARNEY J, ACAD MANAGE REV, (1986)	0.7270	CHANDLER A, STRATEGY STRUCTURE, (1962)	0.7920	PIORE M, 2 IND DIVIDE, (1984)	0.6570	WATANABE C, TECHNOVATION, (2001)	0.7940	ANDERSON P, ADM SCI Q, (1990)	0.7120
DAVENI R, HYPERCOMPETITION MAN, (1994)	0.9080	ARCHIBUGI D, TECHNOLOGICAL SPECIA, (1992)	0.8630	PENROSE E, THEORY GROWTH FIRM, (1959)	0.6690	WHEELWRIGHT S, REVOLUTIONIZING PROD, (1992)	0.7910	POLANYI M, PERSONAL KNOWLEDGE, (1962)	0.6190	WATANABE C, TECHNOL FORECAST SOC, (1995)	0.7650	SCHUMPETER J, CAPITALISM SOCIALISM, (1942)	0.6700
AMIT R, STRATEGIC MANAGE J, (1993)	0.9020	DOSI G, TECHNICAL CHANGE EC, (1988)	0.8270	PETERAF M, STRATEGIC MANAGE J, (1993)	0.6660	BEST M, NEW COMPETITION, (1990)	0.7580	POLANYI M, TACIT DIMENSION, (1966)	0.6180	ARROW K, REV ECON STUD, (1962)	0.6970	ABERNATHY W, TECHNOL REV, (1978)	0.6270
HEDBERG B, HDB ORG DESIGN, (1981)	0.8970	NELSON R, NAT INN SYST, (1993)	0.8250	PORTER M, COMPETITIVE STRATEGY, (1980)	0.6430	BESSANT J, MANAGING ADV MANUFAC, (1991)	0.6850	HAMEL G, STRATEGIC MANAGE J, (1991)	0.5890	MEYER P, TECHNOL FORECAST SOC, (1999)	0.6450	FOSTER R, INNOVATION ATTACKERS, (1986)	0.5930

(*continued on next page*)

Table 5 (*continued*)

Factor 1: strategy and technology	13.6% Variance	Factor 2: national systems and differences	7.6% Variance	Factor 3: sources of competitive strategies	6.3% Variance	Factor 4: manufacturing/ operations/ NPD	4.3% Variance	Factor 5: knowledge management and inventors	4.1% Variance	Factor 6: patents	3.9% Variance	Factor 7: life-cycles/change/ discontinuity	3.9% Variance
ARGYRIS C, ORG LEARNING THEORY, (1978)	0.8920	PAVITT K, RES POLICY, (1984)	0.8090	AAKER D, CALIF MANAGE REV, (1989)	0.6320	CLARK K, PRODUCT DEV PERFORMA, (1991)	0.6020	HUBER G, ORGAN SCI, (1991)	0.5550			HENDERSON R, ADM SCI Q, (1990)	0.5750
KUHN T, STRUCTURE SCI REVOLU, (1962)	0.8740	SCHMOOKLER J, INVENTION EC GROWTH, (1966)	0.7980	HAMEL G, HARVARD BUS REV, (1989)	0.6270	HARRIGAN K, STRATEGIC MANAGE J, (1988)	0.5730	NONAKA I, HARVARD BUS REV, (1991)	0.5210			DOSI G, RES POLICY, (1982)	0.4660
ITAMI H, MOBILIZING INVISIBLE, (1987)	0.8720	LUNDVALL B, NATL SYSTEMS INNOVAT, (1992)	0.7810	GOODMAN R, TECHNOLOGY STRATEGY, (1994)	0.6180	PORTER M, COMPETITIVE STRATEGY, (1980)	0.4270	PRAHALAD C, RES TECHNOL MANAGE, (1993)	0.4820			PORTER M, COMPETITIVE ADVANTAG, (1985)	0.4390
CYERT R, BEHAV THEORY FIRM, (1963)	0.8440	JOHNSON B, NATL SYSTEMS INNOVAT, (1992)	0.7750	KOTLER P, MARKETING MANAGEMENT, (1991)	0.6020	WOMACK J, LEAN THINKING, (1996)	0.4070	GRANT R, STRATEGIC MANAGE J, (1996)	0.4730			MOLINA A, TECHNOVATION, (1997)	0.4120
NELSON R, STRATEGIC MANAGE J, (1991)	0.8250	MOWERY D, TECHNOLOGY PURSUIT E, (1989)	0.7730	PORTER M, COMPETITIVE ADVANTAG, (1985)	0.5970			COHEN W, ADM SCI Q, (1990)	0.4720				
TEECE D, STRATEGIC MANAGE J, (1997)	0.8230	FREEMAN C, TECHNICAL CHANGE EC, (1988)	0.7340	ALDRICH H, ORG ENV, (1979)	0.5840								
MARCH J, ORGANIZATIONS, (1958)	0.8160	LUNDVALL B, TECHNICAL CHANGE EC, (1988)	0.7340	LEONARD-BARTON D, STRATEGIC MANAGE J, (1992)	0.5750								
SPENDER J, STRATEGIC MANAGE J, (1996)	0.8020	CHANDLER A, SCALE SCOPE DYNAMICS, (1990)	0.6720	GRANT R, CONT STRATEGIC ANAL, (1991)	0.5630								
CARAYANNIS E, TECHNOVATION, (1998)	0.7600	PORTER M, COMPETITIVE ADV NATI, (1990)	0.6380	HAMEL G, COMPETING FUTURE, (1994)	0.5450								

HUBER G, ORGAN SCI, (1991)	0.7580	GRILICHES Z, J ECON LIT, (1990)	0.5810	BARNEY J, J MANAGE, (1991)	0.5390
SENGE P, 5 DISCIPLINE, (1990)	0.7580	TAYLOR C, EC IMPACT PATENT SYS, (1973)	0.5200	LAWRENCE P, ORG ENV, (1967)	0.5380
CARAYANNIS E, TECHNO-VATION, (1999)	0.7560	DOSI G, RES POLICY, (1982)	0.4770	BELL M, TECHNOL-GOICAL CAPABI, (1984)	0.5210
ROGERS E, DIFFUSION INNOVATION, (1962)	0.7450	FREEMAN C, EC IND INNO-VATION, (1974)	0.4340	LEVIN R, BROOKINGS PAPERS EC, (1987)	0.4280
PRAHALAD C, HARVARD BUS REV, (1990)	0.7110			PRAHALAD C, HARVARD BUS REV, (1990)	0.4130
BARNEY J, J MANAGE, (1991)	0.6900			BURNS T, MANAGE INNOVATION, (1961)	0.4120
LEONARD-BARTON D, STRATEGIC MANAGE J, (1992)	0.6880			WILLIAMSON O, MARKETS HIERAR-CHIES, (1975)	0.4100
PRAHALAD C, RES TECH-NOL MAN-AGE, (1993)	0.6640				
PETERAF M, STRATEGIC MANAGE J, (1993)	0.6580				
AAKER D, CALIF MANAGE REV, (1989)	0.6440				
NONAKA I, KNOWLEDGE CREATING C, (1995)	0.6410				
HAGEDOORN J, STRATEGIC MANAGE J, (1994)	0.6290				

(*continued on next page*)

Table 5 (*continued*)

Factor 1: strategy and technology	13.6% Variance	Factor 2: national systems and differences	7.6% Variance	Factor 3: sources of competitive strategies	6.3% Variance	Factor 4: manufacturing/ operations/ NPD	4.3% Variance	Factor 5: knowledge management and inventors	4.1% Variance	Factor 6: patents	3.9% Variance	Factor 7: life-cycles/change/ discontinuity	3.9% Variance
GRILICHES Z, J ECON LIT, (1990)	0.6220												
NELSON R, EVOLUTIONARY THEORY, (1982)	0.6150												
IANSITI M, RES POLICY, (1995)	0.5810												
FORD D, LONG RANGE PLANN, (1988)	0.5490												
NONAKA I, ORGAN SCI, (1994)	0.5450												
VONHIPPEL E, SOURCE INNOVATION, (1988)	0.5370												
DODGSON M, ORGAN STUD, (1993)	0.5290												
SHANNON C, MATH THEORY COMMUNIC, (1949)	0.5170												
MINTZBERG H, MINTZBERG MANAGEMENT, (1989)	0.5150												
COHEN W, ADM SCI Q, (1990)	0.5130												
CHRISTENSEN C, INNOVATORS DILEMMA, (1997)	0.5110												

SAHAL D, PATTERNS TECHNOLOGIC, (1981)	0.5040
POLANYI M, TACIT DIMENSION, (1966)	0.4820
POLANYI M, PERSONAL KNOWLEDGE, (1962)	0.4760
SIMON H, ADM BEHAV, (1976)	0.4740
WILLIAMSON O, MARKETS HIERARCHIES, (1975)	0.4450
NONAKA I, HARVARD BUS REV, (1991)	0.4320

strategies and how they can be adapted to suit particular environments and are consequently theoretical in nature. The full results cannot be published in the limited space available here, but a sample of the papers in this factor include the classic works by Quinn, Schon, Mintzberg, Porter, Nelson, Cyert, Teece, Rogers and Prahalad.

National differences in technology policy or performance permeate the documents in the second group. These come from a range of disciplines such as economics and organization behavior and use a variety of methods to measure and analyze national systems including cases, patents and pairs of innovations. Sample papers are Freeman, Archibugi, Pavitt, Dosi and Lundvall. The third group are concerned with specific sources of competition and their accompanying strategies and as such are more prescriptive in their nature. Again the articles cover a range of applications with the most closely associated idea being time based competition, but a large number of the articles address the application of resources. Authors whose work features here include Hall, Wernerfelt, Stalk, and Barney.

Specific systems and operational aspects of the technology management cycle dominate the fourth factor group with manufacturing, operations management and new product development featuring strongly. These papers tend to be very practical in their outlook often making use of comparative analyses as a basis for their recommendations. This is typified by Hayes, Hill, Bessant and Womack. The fifth factor takes a different unit of analysis compared to the preceding focus on the organization, as the articles are generally concerned with individuals and resulting views such as knowledge management. Here there is another strong showing for the resource based view, along with social and psychological elements. The difference between the RBV articles identified in the third factor and this are that the former focus on the application of resources and capabilities to generating advantage, whereas here the articles are concerned with the understanding of the role of individuals as the medium of learning and transferring competences. Illustrative authors here are Weick, Nonaka, Piore and Kogut.

The sixth factor is unique in the analysis in that it is not concerned with a clear theoretical perspective of technology management, but one particular way of measurement, namely patents. These studies are methodological in the same way as the patent works featuring in factor 2, but the focus of analysis is competition at the firm level, rather than identifying national differences. Jaffe, Cohen, Griliches and Watanabe are all represented. The common element of the documents associated with factor seven is an interest in lifecycles and associated periods of transition. Here the emerging ideas of discontinuity of Anderson, Pavitt and Tushman appear with the more traditional views of change management such as Schumpeter, Abernathy and Utterback.

The results of the factor analysis above were checked by the use of social network analysis to graph and group the publications using a less statistically driven approach. The results were similar and confirm the groupings above.

Table 6
Geographical differences in TM Interests

North America	Europe	UK	RoW
Dynamic organisations	Alliances and learning	Operation strategy	Diffusion
RBV	Learning organisations	Innovation process	Pull/markets
Technology strategy	RBV	PCs and electronics case studies	Adaptation of innovations
Evolution and diffusion	Knowledge management	R&D returns in uncertainty	National systems and differences
	Patents		
	Measuring R&D networks		

However, there is not sufficient space to discuss the results of this analysis here.

4.3. Geographical research concentrations

Attendance of conferences and a feeling from subscribing to many TM journals suggested to the authors that there might be different research agendas in different parts of the world. If this was indeed the case, it would provide us with an additional explanation as to why TM has had such difficulties establishing itself as a coherent discipline. Differences in research agenda are likely to reflect a contested understanding of what the discipline stands for which would hamper the subject's growth. A simple approach was used to test this geographic division hypothesis. Since we were particularly concerned with geographical differences in research agenda, the *Technovation* database was separated into citations given by North American (1960), continental Europe (3237), UK (2216) and rest of the World (2763) authors (the bracketed figure refers to the number of citations associated with each group). To determine whether geographically different authors exhibit different citation patterns the methods employed above—network analysis, factions and factor analysis—were repeated on each group of citations. The results are not as clear as those above, as a result of the reduced amount of available data, but the tools were generally aligned and confirmatory in their identification of grouping of interests. Table 6 shows a summary of the schools of thought which emerged from this analysis.

The table shows the range of different areas of interests to authors from different geographical locations. In terms of similarities, the Europeans appear to sit between the North American and UK authors, sharing interests in dynamics, organisations and RBV with one group and R&D Management with the other. They are also the main protagonists of patent analysis. The North American's seem to be interested in dynamic and evolutionary change in organisations whilst the UK authors have a more practical bearing with a clear focus on the processes in TM such as operations and innovation and specific industry studies. The RoW authors appear from this analysis to be concerned with extending the more classical areas of TM such as diffusion, the role of market pull, adaptation and national systems.

Whilst this analysis is based upon some considerable subjective input from the authors, it does suggest that there is a readily identifiable difference in the intellectual interests of authors from different regions, and adds weight to this acting as a delay in establishing TM as a distinct discipline in its own right.

5. Conclusion

This paper has investigated technology management using citation and co-citation data published in *Technovation* between 1996 and 2004. A factor analysis of the co-citations suggested that the field is organized along seven different concentrations of interest: strategy and technology, national systems and differences, sources of competitive strategies, manufacturing/operations/NPD, knowledge management and inventors, patents, and life-cycles/change/discontinuity.

We have argued that TM has failed to create its own literature and that this has undermined its reputation as a legitimate academic field. One of the most apparent symptoms of this confidence crisis is the relatively low contribution of TM scholars to the field's own publication outlets—few of the most cited items in our data-set were to TM dedicated journals, with only *Research Policy* making a slight showing in the most cited articles. More concretely, TM researchers submit their best work to general management or other discipline specific journals. Admittedly, academic pressure to publish in established places has much to do with this phenomenon but this is also true of any new discipline. Another contributing factor to his apparent confidence crisis is a lack of consensus regarding the extent of TM and how it differs from other disciplines such as the sub-fields of economics and public policy. Without a clear understanding of the field's intellectual boundaries, it will be difficult for TM to gain recognition.

More evidence of the problems with establishing TM as a discipline came from our investigation whether there were geographical differences in the research agendas of scholars. We argue that such discrepancies may have hindered the establishment of TM as a legitimate discipline by further blurring the boundaries of its literature. A repeat of the tests above indicated that there are significant differences in the intellectual interests of authors from different regions and was interpreted as an indication of underlying differences in

their respective research agendas. Although these issues represent substantial obstacles to overcome, the TM field is still relatively young and our analysis has shown that it does have an emerging structure. Perhaps if we learn more about the factors in this structure, how they relate, and what they stand for, TM conferences and publication outlets will gain the popularity and prestige that is required to establish a serious academic discipline.

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