UiO : University of Oslo

TIK **Centre for technology, innovation and culture**
P.O. BOX 1108 Blindern
N-0317 OSLO
Norway

Eilert Sundts House, 7th floor
Moltke Moesvei 31

Phone: +47 22 84 16 00
Fax: +47 22 84 16 01

http://www.sv.uio.no/tik/
info@tik.uio.no

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Universitetet i Oslo

Science and Technology Studies: Exploring the Knowledge Base

Ben R. Martin*†, Paul Nightingale* and Alfredo Yegros-Yegros‡

* SPRU – Science and Technology Policy Research, University of Sussex, Brighton, BN1 9QE, UK

† Centre for Science and Policy (CSaP), and Centre for Business Research, Judge Business School, University of Cambridge, Cambridge, UK

‡ INGENIO (CSIC-UPV), Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, España

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Abstract

Science and Technology Studies (STS) is one of a number of new research fields to emerge over the last four or five decades. This paper attempts to identify its core academic contributions using the references that are most cited by the authors of chapters in a number of authoritative 'handbooks'. The study then analyses the impact of these contributions by exploring the research fields, journals, and geographical location of the researchers that have cited these core contributions in their own work. Together, these two analyses reveal the various phases in the development of STS and the various aspects of convergence and divergence of the field as the quantitative studies of science and technology gradually separated from the main body of STS. The paper ends with some conclusions about the evolution of STS such as the role of 'institution builders' in developing new research fields and the structures required to hold them together.

Key words: science studies, STS, knowledge base, handbooks, core contributions

1. Introduction

New research fields in the social and natural sciences often originate at the interstices of established disciplines when researchers from neighbouring disciplines, using different disciplinary perspectives, realise they share a common interest. Over time, by working together, they may start to develop their own shared conceptual, methodological and analytical frameworks. This allows them to move from publishing in journals of their 'parent' disciplines to establishing their own journals, professional associations, specialised university departments or units (often with the name of the new field in their title), and PhD programmes to train their own researchers. Eventually, some fields may acquire enough of these characteristics in sufficiently developed form to achieve 'disciplinary' status.

This process of convergence can be seen in the field of Innovation Studies (which previously went by other titles such as 'Science Policy' – see Fagerberg and Verspagen, 2009; Fagerberg et al., this issue) and Entrepreneurship (see Landström et al., this issue). However, as this paper will show, convergence is not the only possible outcome. The field of Science and Technology Studies (STS[1]), the subject of this paper, has shown elements of both convergence and divergence since it emerged as a distinct organised specialty in the 1960s.

From a science policy perspective such convergence and divergence have both positive and negative consequences. The shared assumptions of a discipline increase the coherence and speed of distributed problem-solving (Turro, 1986), but can also lead to group-think and intellectual inbreeding (Rafols, this issue).[2] Disciplines allow researchers to refrain from constantly justifying their implicit assumptions and judgements about research quality standards; they allow standardisation (for example, in terms of methodology); and they generate the scale needed to justify high fixed-cost investments in data collection, instrumentation and career development. However, disciplinary cognitive-framings can also blind researchers to alternative perspectives; disciplinary power structures can adversely influence resource allocation, academic promotions and research evaluation; and cognitive

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1 Somewhat confusingly, STS is also used as an abbreviation for 'Science, Technology and Society'. During the early decades at least, these two terms were used interchangeably (the 1977 STS Handbook uses 'Science, Technology and Society' in its title), although since then some authors have made a distinction between the two.

2 These conflicting interactions are why ground-breaking research is often interdisciplinary, although interdisciplinary research is often not ground-breaking.

infrastructure can embed flawed assumptions in path-dependent research trajectories that are difficult to escape.

The process of moving from a research field of shared interest to disciplinary status is generally punctuated by the publication of a series of connected core contributions that act as models, or paradigm cases, of research that can be imitated, borrowed from, modified and replicated (Turro, 1986). The interconnected hierarchy of explicit and implicit shared assumptions that these core contributions establish and modify, then structures the ongoing theoretical debates in the research field (Nightingale, 2008). Analysis of work on the 'theory of the firm' suggests that researchers need to agree on certain fundamental assumptions before they can disagree on minor points, and that debates about more fundamental assumptions occur rarely if at all (ibid.). Retooling in academia, as in industry, is expensive and happens relatively infrequently (Turro, 1986).

The primary aim of this paper is to identify as far as possible the core contributions made within STS during the last 50 years in order to map out the field and to understand how those contributions helped structure its development. This is done using qualitative and quantitative analysis of the review chapters contained in STS handbooks. Doing this is valuable for a number of reasons. First, STS is inherently interesting in its own right, not least for Innovation Studies scholars seeking insights into the development of their own field.

Secondly, the analysis has implications for understanding the processes by which academic fields and disciplines emerge. This is commonly understood in terms of a shift from having common interests, to recognising and advancing those common interests through shared methods, conferences and journals, and this then being recognised by the outside world (e.g. by funding agencies) in ways that legitimise and formalise the change. Our analysis highlights that this process does not simply unfold, and the components of this putative disciplinary infrastructure may not always fit together nicely. While the interconnected hierarchy of assumptions may help structure the development of research fields, they do not exist in cognitive isolation. Researchers embed their work in physical artefacts and social structures – academic papers help with memory and communication, for example, and conferences assist in building collective identify. Research is often dependent on a high fixed-cost invisible infrastructure that must be built and maintained (Nightingale, 2008). Institution builders play important roles in integrating this infrastructure; when they fail, or the mismatch is too large, disciplines (or proto-disciplines) may come apart.

Thirdly, the internal divergence that is observed provides a methodological warning about bibliometric analysis of this kind. It suggests academic fields, like biological species, do not have an inner 'core' that they are teleologically drawn towards over time. This has implications for choices about the scale of analysis, as the convergence found in studies of Entrepreneurship and Innovation Studies might look like divergence from a common core if analysed from a higher level of aggregation (on their overlap, see Bhupatiraju et al., this issue). Similarly, the divergence from a common origin seen with respect to the quantitative and qualitative studies of science and technology might look like internal convergence at a lower level.[3]

These features make the history of academic fields sensitive to bias, particularly if internal actors are constructing past events in selective ways to justify current or future allocations of power and resources. The methods we use here and our position outside STS as what might be perceived as 'critical friends', go part way to addressing some of these biases, and it is particularly appropriate that a sociological sensitivity to the construction, meaning and reflexivity of numbers and narratives is so relevant to the history of STS.

The structure of the remainder of the paper is as follows. In Section 2, we describe the methodology we have adopted to identify the core STS literature. Section 3 identifies the core contributions to STS, and analyses that central core in terms of both individual and institutional contributors. Section 4 then explores the structure of the knowledge base, using clustering analysis to break down the STS core into a number of identifiable clusters. In Section 5 we analyse the authors citing the STS core literature, in particular in terms of the research fields that draw most prominently on those STS contributions. In Section 6, we interpret the quantitative evidence on those core contributions in the light of various qualitative histories of the subject (e.g. Fuller, 2000; Pestre, 2004; Zammito, 2004; Hackett et al., 2007; Jasanoff, 2010), while finally in Section 7 we summarise the main conclusions to emerge from the study and highlight some of the implications.

[3] To a lesser extent, there has also been some interaction between STS and science policy research (as it was originally known), particularly in the early decades. In due course, science policy research became part of what is now often termed 'science, technology and innovation (STI) studies' or simply 'innovation studies', the subject of the papers by Fagerberg et al. (this issue) and Martin (this issue). Even today, some STS researchers occasionally publish in 'STI' journals (such as *Research Policy*), and vice versa.

2. Identifying the 'core' literature of STS

To ensure comparability of the results, we have employed as far as possible the same methodological approach as Fagerberg et al. (this issue) used for Innovation Studies (where a fuller description of that methodology can be found) and as Landström et al. (this issue) used for Entrepreneurship. Normally, such a review process would focus on scientific articles, but as an emerging field STS has been, and to a considerable extent still is, dominated by books, which complicates both data collection and selection. An approached based on surveying researchers may be biased by the selection of respondents, so we have, as a first step, focussed on leading STS practitioners (in the form of the authors of handbook chapters) and what they have identified as the core contributions to the field.

Thus, we begin by identifying a number of authoritative handbooks comprised of expert reviews of STS. Four central assumptions underpin this methodological approach: first, that the authors chosen to write the handbook chapters are, in general, comparatively prominent in the field[4]; second, that they carry out reasonably systematic reviews that identify the core intellectual contributions in the area they are reviewing; third, that those chapters collectively represent the content of STS in a relatively comprehensive manner; and fourth, that the publication of a handbook marks out a sufficiently coherent field to make analysis meaningful. To a certain extent, the handbook chapters' references are also influenced by social negotiations between authors and handbook editors. As such, these references are taken to reflect collective views about what constitute the fundamental intellectual 'building blocks' of the STS field.

However, the rather fragmented and disputed nature of STS, with the existence (as we shall see) of separate 'schools' with their own perspectives and interests, makes the use of handbooks and the analysis of the references contained in handbook chapters potentially more problematic than in the case of Innovation Studies or Entrepreneurship.[5] In the light of this limitation, we combine our quantitative analysis with a qualitative account of the history of STS.

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4 Evidence in support of this assumption comes from an analysis of the proportion of handbook chapter authors who are on the editorial advisory boards of leading STS journals. In the case of the first STS handbook, nearly half (47%) the authors were members of an editorial board of one or more of the top ten STS journals. For the four other handbooks included in this analysis, the proportion ranged from 39% to 43%.

5 For example, despite the size and prominence of STS within UK sociology, it is not included in a key UK sociology textbook (Giddens, 2006).

The first STS handbook[6] was published in 1977 and was edited by Ina Spiegel-Rösing and Derek de Solla Price. The former was a sociologist of science[7], while the latter was a historian of science who was a pioneer in introducing a more quantitative approach to studies of science and technology. A second edition of the STS Handbook, now under the auspices of the Society for Social Studies of Science, was published 18 years later in 1995. By then, researchers pursuing a more quantitative approach to STS had begun to form a somewhat separate sub-community reflected in the appearance in 1988 of the first 'Handbook of Quantitative Studies of Science and Technology', edited by Antony van Raan, the Director of one of the leading academic groups in the area, CWTS at Leiden University. CWTS Leiden was also central in coordinating the second 'Handbook of Quantitative Science and Technology Research', published in 2004.[8] Finally, a third edition of the STS Handbook was published in 2007.

In total, the five selected handbooks contain 136 chapters, with 211 authors (and editors) involved (see Table 1 below).[9] These handbooks would seem to capture the evolution of the field, with the first STS handbook describing a nascent field borrowing heavily from other disciplines, the second and third an adolescent field slowly establishing its own identity, and the most recent two a more mature field capable of generating ideas and concepts that it may then export to other fields (see Hackett et al., 2007, p.4).

6 Although the term 'Handbook' was not part of its title, it was subsequently regarded as the 'first edition' of the series of three STS handbooks described here.

7 Her habilitation was in sociology of science, although in later years she came to focus more on cultural anthropology.

8 Despite the central role of CWTS Leiden in these two Handbooks, they brought together contributions by leading researchers from round the world. To this extent, they can therefore be seen as reasonably 'representative' of the field of quantitative studies of science and technology.

9 We explored a number of other possible 'handbooks'. We excluded those that merely reprinted 'classic' articles (e.g. MacKenzie and Wajcman, 1985 and 1999; and Scharff and Dusek, 2003), since the chapters had not been written to provide an authoritative overview of the field. For practical reasons, we also had to exclude edited volumes with a combined bibliography at the end of the book rather than after individual chapters (this was the main reason for excluding Bijker et al., 1987, and Bijker and Law, 1992).

Table 1. Reference works (12,354 References)

Name of author/editor	Title	Year of publication	Publisher	Number of chapters (references)
I. Spiegel-Rösing & D. de Solla Price	Science, Technology and Society: A Cross-Disciplinary Perspective	1977	Sage	15 (2361)
A.F.J. Van Raan	Handbook of Quantitative Studies of Science and Technology	1988	Elsevier	21 (864)
S. Jasanoff et al.	Handbook of Science and Technology Studies	1995	Sage	28 (2947)
H.F. Moed et al.	Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems	2004	Kluwer	34 (1326)
E.J. Hackett et al.	Handbook of Science and Technology Studies	2007	MIT Press	38 (4856)

The next step involved collecting all the references in the individual chapters of these five handbooks and entering them into a dedicated database. After 'cleaning' them to remove obvious errors and duplicates, a total of 12,354 references remained, of which about 9,759 are non-identical. Most (94.6%) are cited only once or twice by handbook authors. Simply counting each publication's citations in all the handbook chapters would clearly disadvantage more recent publications that could not have been cited in earlier handbooks. As in the analysis of Innovation Studies, we have therefore constructed and used an age-adjusted J-Index. In this, we first calculate the maximum number of citations (E) that any publication (P) could earn, assuming it was cited in every source chapter published in handbooks appearing one year or more after the publication date of P. If the actual citation total is A, then the formula A*100/E is used to calculate the J-index. We then applied a cut-off in the J-index of 3.3% in order to exclude any publication cited less than once per 30 chapters (for all those chapters that could potentially have cited it – i.e. in handbooks published a year or more after that individual publication). This yielded a list of 155 publications (see Appendix A) that are taken to represent the 'core literature', with their J-index reflecting their relative importance to the authors of 136 handbook chapters (i.e. as viewed by experts *within* the field of STS). To assess the broader impact in other fields and specialties, we analysed the citations to the STS core literature using the Web of Science (WoS) database, and identified a total of 108,000 citations (an average >700 citations per core publication). The results of the latter analysis are discussed in Section 5.

3. The central core

Table 2 lists the 20 most important (i.e. highest J-score) contributions to STS, including the location of authors (at the time of writing), publication title, type and year, J-index and the average number of citations per year in the Web of Science. Among those items on the list, only Narin et al. (No.10) and to a lesser extent de Solla Price (No.6) are based on the use of science indicators. The great majority (about three quarters) are primarily in the sociology of science/knowledge, with just two (Jasanoff and Gibbons et al.) addressing the STS-science policy connection, while Dickson focuses on the politics of science. Three others are primarily concerned with the history of science (Kuhn; Shapin & Schaffer; de Solla Price).

In terms of the national origins of these core contributions, the main country is the United States, which appears in the institutional addresses of 12 of the top 20, followed by the UK (seven), then France (three) and the Netherlands (two). The majority (85%) of these 20 core contributions are books rather than journal articles. If we extend the analysis to the entire set of 155 publications listed in Appendix A, the share of journal articles is only a little higher (21.9%). Possible interpretations for this high preponderance of books are that book-length expositions are needed to set out major new theoretical contributions, perhaps reflecting the relatively early state of the field, or the reluctance of STS practitioners to separate theory and evidence in case studies, thereby making short expositions difficult.[10]

The final column of Table 2 gives the average number of citations (as recorded in the Web of Science in April-May 2010) per year since publication. There is only a partial correlation[11] between the J-Index (which reflects the views of the expert STS authors on each core publication) and the average citation rate (which reflects each publication's overall impact on the wider research community). For example, Kuhn's *The Structure of Scientific Revolutions* has by far the largest average citation rate (over 400 citations per year) but comes only 3rd on J-Index within STS, reflecting its enormous impact across a range of disciplines, while the impact of Latour, and of Latour and Woolgar, although substantial, is evidently narrower.

[10] Similar comments can be made in relation to Innovation Studies, at least in its early decades.

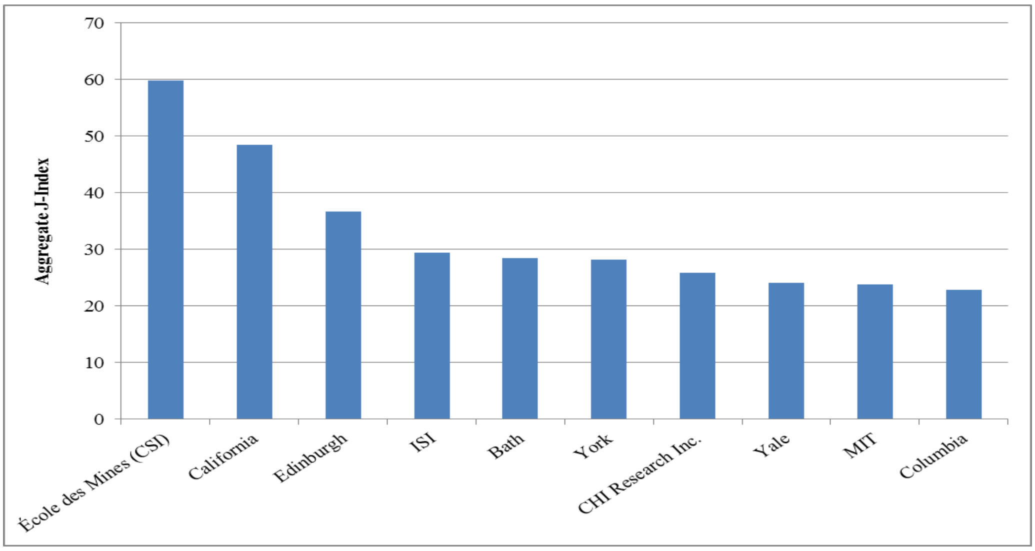
[11] $r=0.515$, $p<0.05$ (two-tailed test) for the first 20 core works (as listed in Table 2).

Also interesting is the comparatively small number of ISI citations to many of these 'top' STS publications, indicating a relatively small or narrow external impact.

3.1 Institutional and individual contributions to the STS core

Which have been the leading institutions contributing to STS? Figure 1 lists the top ten research institutions based on the contributions of their researchers (using the aggregated J-Index for each institution). The figure suggests that CSI at the Ecoles des Mines in Paris, home to Latour and Callon, has been the single most influential institution, followed by the University of California, then Edinburgh University. Interestingly, the top two institutions with regards to quantitative studies of science are both private companies (ISI[12] and CHI Research[13]) rather than universities. This reflects the pioneering role of these two companies in constructing the large databases on publications and citations needed to carry out such quantitative studies, databases that require a level of investment beyond the means of most university departments (CWTS Leiden being one prominent exception here). Of the top ten institutions in Figure 1, a majority (six) are in the US, while the UK has three (Edinburgh, Bath and York) and France one (although it is in top position).

Figure 1. STS: Most prominent institutions (as based on aggregate J-Index)



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12 Now part of Thomson-Reuters.

13 On the retirement of Francis Narin, its founder and director for many years, CHI Research was taken over by another company, and is now known as The Patent Board.

Table 2. STS: Top twenty contributions as identified by handbook authors

No.	Author	Country	Title	Type	Year	J-Index	Citations (ISI/Year)
1	Latour B	France	Science in action: how to follow scientists and engineers through society	Book	1987	24	154
2	Latour B; Woolgar S	France, UK	Laboratory life: the social construction of scientific facts	Book	1979	19	78.9
3	Kuhn T	USA	The structure of scientific revolutions	Book	1962	16.9	402.5
4	Jasanoff S	USA	The fifth branch : science advisers as policymakers	Book	1990	15	27.6
5	Shapin S; Schaffer S	UK	Leviathan and the air-pump: Hobbes, Boyle and the experimental life	Book	1985	14	45.4
6	de Solla Price DJ	USA	Little science, big science	Book	1963	14	28.7
7	Traweek S	USA	Beam-times and lifetimes: the world of high energy physicists	Book	1988	12	21.1
8	Star SL; Griesemer J	USA	Institutional ecology, "translations" and boundary objects: amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907-1939	Journal (SSS)	1989	12	28.2
9	Bloor D	UK	Knowledge and social imagery	Book	1976	11.8	30
10	Narin F; Hamilton KS; Olivastro D	USA	The increasing linkage between us technology and public science	Journal (RP)	1997	11.1	15.5
11	Haraway D	USA	Simians, cyborgs, and women: the reinvention of nature	Book	1991	11	120.5
12	Bijker WE; Hughes TP; Pinch T	Netherlands, USA, UK	The social construction of technological systems: new directions in the sociology and history of technology	Book	1987	10.7	37
13	Gibbons M; Limoges C; Nowotny H; Schwartzman S; Scott P; Trow M	UK, Canada, Austria, Brazil, USA	The new production of knowledge: the dynamics of science and research in contemporary societies	Book	1994	10	81
14	Collins HM	UK	Changing order: replication and induction in scientific practice	Book	1985	9.9	31.5
15	Pickering A	USA	The mangle of practice: time, agency and science	Book	1995	9.7	34.3
16	Knorr K	Germany	Epistemic cultures: how the sciences make knowledge	Book	1999	9.7	45.4
17	Cole JR; Cole S	USA	Social stratification in science	Book	1973	9.6	18.1
18	Dickson D	USA	The new politics of science	Book	1984	9.1	8.1
19	Pinch T; Bijker WE	UK, Netherlands	The social construction of facts and artifacts, or how the sociology of science and the sociology of technology might benefit each other	Journal (SSS)	1984	9.1	7.5
20	Latour B	France	The Pasteurization of France	Book	1988	9.0	30.1

The most influential researchers tend to produce several important publications – most prominently, Latour has three in the top 20. Other authors of the top 20 publications also published items further down the list of 155 core publications. Table 3 aggregates the data by author, adjusting for co-authorship (e.g. an individual is credited 0.5 if there is one other author, 0.33 if there are two others, and so on) and lists the top 20 authors. The "Total J-index" is the sum of the J-indices of an author's works, while a similar calculation is used for "Total ISI citations/year".

Table 3. STS: Top 20 STS contributors (as judged by handbook authors)

Rank	Author	Affiliation(s)	Country	Total J-Index	Total ISI cites/year
1	Latour B	École des Mines de Paris	France	48.3	233.0
2	Collins HM	University of Bath/ Cardiff University	UK	28.5	63.7
3	Knorr K	University of Bielefeld	Germany	21.2	83.2
4	Woolgar S	Brunel University/ University of Oxford	UK	20.8	70.9
5	Price, DJ de Solla	Yale University	USA	20.0	45.0
6	Pickering A	University of Illinois	USA	18.7	70.3
7	Kuhn T	University of California, Berkeley	USA	16.9	402.5
8	Jasanoff S	Harvard University	USA	16.1	29.9
9	Star SL	University of California	USA	16.0	26.8
10	Pinch T	Cornell University	USA	15.9	28.0
11	Fujimura J	Stanford University/Tremont Research Institute	USA	15.8	22.7
12	Winner L	Rensselaer Polytechnic Institute	USA	15.6	37.4
13	Wynne B	Lancaster University	UK	15.2	27.8
14	Small H	Institute for Scientific Information	USA	15.1	20.7
15	Haraway D	University of California, Santa Cruz	USA	15.0	161.0
16	Merton RK	Columbia University	USA	14.6	44.2
17	MacKenzie D	University of Edinburgh	UK	13.4	32.7
18	Narin F	CHI Research Inc.	USA	12.8	16.6
19	Law J	Keele/Lancaster University	UK	12.2	29.4
20	Traweek S	Rice University	USA	12.0	21.1

The table is again headed by Latour, who has a total J-Index of 48.3, well over double that of all the others except for Collins (28.5), suggesting that Latour has been the dominant influence within the field of STS. These two are followed by Knorr, Woolgar and de Solla

Price, each with a J-Index of around 20. The next ten individuals are all clustered fairly closely together in the range 15-19 on the aggregated J-Index. Again, there is only a rather weak correlation[14] between the J-Index and the aggregated citation counts. For the latter indicator, the list is once more headed by Kuhn (402), then Latour (233) and Haraway (161), followed by Knorr (83), Woolgar (71), Pickering (70) and Collins (64).

4. Exploring the structure of the knowledge base

In this section, we examine various characteristics of the field in order to establish whether the 155 core contributions can be broken down into identifiable clusters. Following the cluster analysis methodology developed by Fagerberg et al. (this issue), we focus on three dimensions: the *disciplinary orientation* of those citing the STS core literature; a number of *generation and selection processes* relating to key characteristics of the literature; and the *thematic orientation* of the core literature as reflected in key words appearing in the titles of the core contributions. Let us consider each of these in turn.

In the next section, we show how a large proportion (89%) of those citing the STS core literature can be classified into one of ten main subject areas or groups (see Figure 2). The variable we use here in the cluster analysis is the share of citations from each of those ten subject areas as a proportion of all citations to the particular core contribution.

With regard to the production and selection environments, we use a number of variables that our previous analysis suggests may be important here. In particular, we include a variable 'INSIDER' reflecting whether the orientation of a contribution is towards STS as opposed to the scientific world in general, this variable being defined as the ratio of the J-Index to journal citations per year. Secondly, we include a variable reflecting the quality of the institutional research environment of the author(s) of the core contributions; this variable (EXCELLENCE) is calculated from the sum of the J-indices of all core contributions from that particular institution (having adjusted for co-authorship). Thirdly, three institutions – CSI Paris, UC Berkeley (where Kuhn was based in the early 1960s) and the University of Edinburgh – appear from the earlier analysis to have been particularly central in the development of the field, so these three are included as variables here. Fourthly, it is clear that three journals (*Social Studies of Science*, *Science, Technology & Human Values* and *Scientometrics*) are seen as leading journals by STS researchers (see Table 6 in Section 5

[14] r=0.416, p=0.068 (two-tailed test) for the first 20 core authors (as listed in Table 3).

below), so citations from such sources may reflect work that is of higher quality or greater relevance. The three journal variables here are calculated as the share of citations from articles published in that journal to all citations to the contribution.

Finally, in an effort to characterise the thematic orientation of the core contributions, we analysed key words appearing in their titles, again following the methodology of Fagerberg et al. (this issue) so that similar words (or terms) were grouped under a single heading.[15] We then used the ten most common key words/terms, assigning a value of 1 to that keyword variable if the core contribution contained that keyword/term in its title.

Using the above variables, we then carried out a cluster analysis in an attempt to explore the structure of the STS core contributions and whether these can be broken down into a number of identifiable clusters. Like Fagerberg et al. (this issue), we adopted a two-step cluster method. In the first, the 155 core contributions are aggregated into a large number of small clusters, while in the second step those clusters are then combined into a few larger clusters on the basis of agglomerative hierarchical clustering. Using traditional statistical criteria (see ibid, p.19, footnote 15), the three best cluster solutions are those with two, three and four clusters (see Appendix C for details). Of these, the two-cluster solution was the most 'natural' (in terms of requiring least 'forcing'), so we shall examine this first, the results for which are shown in Table 4 below.

[15] Ideally, one would have preferred to carry out a textual analysis of the abstracts of all the core publications (or better still the entire texts). However, since most of the core literature consists of books, and since books do not have abstracts nor can they generally be accessed electronically, we (like Fagerberg et al., this issue) had instead to base the thematic analysis on the words appearing in titles. This is far from ideal, but the assumption is that titles of books and articles will in most cases reveal important information about the focus of the publication, although this is perhaps less true for STS than for Innovation Studies given that STS authors sometimes make use of rather more 'quixotic' terms in their titles.

Table 4. Clustering the literature – two-cluster solution

Cluster	Cluster 1	Cluster 2
Works (authors)	127(163)	28(57)
Thematic focus (keywords/terms)	Science (51%) Sociology (31%)	Science (54%) Science indicators (50%)
Most central work (J-index)	Latour B 1987	Price, Derek J. de Solla 1963
Most cited work (ISI/year)	Kuhn T 1962	Nelson RR; Winter S 1982
Most important affiliation*	University of California (8.1%)	Institute for Scientific Information (19.6%)
Location of authors	North America (50%) Europe (43.8%)	North America (66.7%) Europe (29.8%)
Most important citing journal	Social Studies of Science	Scientometrics
Largest citing field	Other Social Sciences (17.6%) Management, Business, Economics, Operations Research, & Engineering (13.4%)	Management, Business, Economics, Operations Research, & Engineering (52.0%) Information, Library & Computer Science (24.6%)
Specialisation	Sociology / History & Philosophy Of Science	Information, Library & Computer Science
Location of citers**	North America (51.1%) Europe (38.8%)	Europe (50.6%) North America (36.2%)
Insider (norm-alized mean 0-1)	0.04	0.04
Excellence (norm-alized mean 0-1)	0.29	0.27

*% of authored core articles

**Single-authored papers from 1998 to 2003

The larger cluster (with 127 contributions) consists of the STS 'mainstream' while the smaller one (with 28 contributions) corresponds to quantitative studies of science and technology, as is apparent from the frequent appearance of the term 'science indicators' (or synonyms of this) in their titles. For the latter cluster, the most central work is de Solla Price's 1963 book, *Little Science, Big Science,* while the most important institution is the Institute for Scientific Information (accounting for nearly one fifth of the contributions), and the main journal is *Scientometrics*. In terms of authors of these core contributions, North Americans dominate, accounting for two-thirds of the total, over twice the European share (30%). However, in terms of authors citing the core contributions, Europe (with just over

50%) is some way ahead of North America (36%). Those citing the core contributions are drawn predominantly from two fields, the Management-related cluster[16] (52%) and the aggregated field of Information, Library & Computer Science (just under 25%).

For the larger cluster, in contrast, the key focus is on the sociology of science or of scientific knowledge. Here, the most central work in the view of handbook authors is Latour's *Science in Action*, while Kuhn's book on *The Structure of Scientific Revolutions* earns most citations per year (but with most of these coming from outside STS). No single institution accounts for 10% of the core contributions, the largest being the University of California with just over 8%. The fields of the authors citing the core contributions are likewise spread quite widely, the largest being 'Other Social Sciences' with just under 18%. In terms of the authors of the core contributions, North America (50%) is slightly ahead of Europe (44%), while in terms of those citing the core contributions the gap between these two is a little larger (51% compared with 39%).

What happens if the cluster analysis is modified in an effort to split this large cluster into smaller parts? Table 5 below shows the results of the 3-cluster solution.[17] Here, the cluster in the final column remains unchanged from that in Table 4. However, the previous large cluster is split into a smaller cluster of 38 core contributions and a larger one of 89. For the latter, the characteristics listed in the middle column of Table 5 are virtually the same as those listed for the left hand cluster in Table 4, so they will not be further discussed here. However, the characteristics of the new Cluster 1 are quite different. Here, the key words/terms suggest an emphasis more on technology than science, and on politics, power and governance rather than sociology. This reflected in the fact that the most important contribution is Jasanoff's 1990 book on *The Fifth Branch: Science Advisers as Policymakers*. However, the other characteristics of this cluster are not dissimilar to those for Cluster 2. It is interesting that these two clusters bear some resemblance to Jasanoff's (2010) characterisation as STS as having been formed by the merger of work on the nature and practices of science and technology, on the one hand, and studies of the impact and control of science and technology (or the 'governance' of S&T, as we would now describe it), on the other. The former would appear to correspond to Cluster 2 in Table 5 and the latter to cluster 1.[18]

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[16] This cluster includes the work on innovation studies.

[17] A summary of the four-cluster solution can be found in Table C in Appendix C, while further details are available from the authors.

[18] We are grateful to an anonymous referee for pointing this out.

Table 5. Clustering the literature – 3-cluster solution

Cluster	Cluster 1	Cluster 2	Cluster 3
Works (authors)	38(54)	89(109)	28(57)
Thematic focus (keywords/terms)	Technology (58%) Politics & Power (53%)	Science (55%) Sociology (29%)	Science (54%) Science Indicators (50%)
Most central work (J-index)	Jasanoff S 1990	Latour B 1987	Price, Derek J. de Solla 1963
Most cited work (ISI/year)	Foucault M 1980	Kuhn T 1962	Nelson RR; Winter S 1982
Most important affiliation*	Keele University (8.6%)	University of California (8.5%)	Institute for Scientific Information (19.6%)
Location of authors	North America (54.7%) Europe (39.6%)	North America (47.7%) Europe (45.9%)	North America (66.7%) Europe (29.8%)
Most important citing journal	Social Studies of Science	Social Studies of Science	Scientometrics
Largest citing field	Other Soc Sc's (26.3%) Other Humanities (13.6%) Management, Business, Economics, Operations Res, & Engineering (13.6%)	Other Social Sciences (16%) Management, Business, Economics, Operations Research, & Engineering (13.0%)	Management, Business, Economics, Operations Research, & Engineering (52%) Information, Library & Computer Science (24.6%)
Specialisation	Other Social Sciences	Sociology / History & Philosophy of Science	Information, Library & Computer Science
Location of citers**	North America (50.8%) Europe (37.1%)	North America (51.2%) Europe (39.1%)	Europe (50.6%) North America (36.2%)
Insider (norm-alized mean 0-1)	0.07	0.02	0.04
Excellence (norm-alized mean 0-1)	0.22	0.32	0.27

*% of articles

**Single authored core papers from 1998 to 2003

5. STS: citations to the STS core contributions

This section shifts the focus from the *producers* of the core contributions to STS to analyse those publications and authors citing the STS core contributions – i.e. to the *users* of these core contributions. The analysis focuses on the citations to the core contributions, based on the assumptions that citations reflect the impact on the wider research community, and the journals in which the citing source article was published provide some indication of the research fields in which the core contributions had an impact.

We carried out a systematic search in April-May 2010 of all the citations to the 155 core contributions as recorded in the Web of Science (WoS), which scans several thousand leading international journals and records all the references contained within them.[19] The results show that the 155 core STS contributions have been cited in a total of about 6,000 journals (it is impossible to be precise because of changes in journal titles over time) covering all areas of research. However, most of these journals have cited the core contributions very infrequently (i.e. one citation per year or less) and the impact is highly skewed, with 13.3% of the journals accounted for three-quarters of all the citations. Table 6 lists the 20 most important citing journals, which together account for 15.1% of all citations to the STS core contributions.

[19] However, it does not scan lesser journals or books, so citations in these are not included here.

Table 6. Top twenty journals citing STS core contributions

Rank	Journal	Citing articles	Percent	Cumulative Percent	WoS Subject Categories
1	Social Studies of Science	3238	3.0	3.0	History & Philosophy of Science
2	Scientometrics	1709	1.6	4.5	Computer Science, Interdisciplinary Applications; Information Science & Library Science
3	Science, Technology & Human Values	1644	1.5	6.1	Social Issues
4	Research Policy	1581	1.5	7.5	Management; Planning & Development
5	Studies in History and Philosophy of Science	801	0.7	8.3	History & Philosophy of Science
6	Social Science and Medicine	694	0.6	8.9	Public, Environmental & Occupational Health; Social Sciences, Biomedical
7	Isis	658	0.6	9.5	History & Philosophy of Science
8	Technology and Culture	536	0.5	10.0	History & Philosophy of Science
9	Minerva	509	0.5	10.5	Education & Educational Research; History & Philosophy of Science; Social Sciences, Interdisciplinary
10	Journal of the American Society for Information Science and Technology (JASIST)	492	0.5	10.9	Computer Science, Information Systems; Information Science & Library Science
11	Journal of Research in Science Teaching	481	0.4	11.4	Education & Educational Research
12	Organization Studies	479	0.4	11.8	Management
13	Strategic Management Journal	463	0.4	12.2	Business; Management
14	American Sociological Review	463	0.4	12.6	Sociology
15	Technological Forecasting and Social Change	447	0.4	13.1	Business; Planning & Development
16	Environment and Planning A	446	0.4	13.5	Environmental Studies; Geography
17	Science Education	445	0.4	13.9	Education & Educational Research
18	Social Science Information sur les Sciences Sociales	437	0.4	14.3	Information Science & Library Science; Social Sciences, Interdisciplinary
19	Philosophy of the Social Sciences	432	0.4	14.7	Ethics; Philosophy
20	Technology Analysis & Strategic Management	416	0.4	15.1	Management; Multidisciplinary Sciences

Perhaps not surprisingly, two of the top three positions are filled by *Social Studies of Science*, and *Science, Technology & Human Values*, the two leading journals in the STS field. In second position is *Scientometrics*, the leading journal for quantitative studies of science, with *Journal of the American Society for Information Science and Technology*, the other main journal used by researchers in this subfield (as well as by those in the field of information science), further down the list in tenth position.

Interestingly, in fourth position is *Research Policy*, the leading journal in the neighbouring field of Innovation Studies (see Fagerberg et al., this issue, Table 4), showing that researchers in that field do draw quite extensively on the STS core contributions.[20] Further evidence for this comes from the fact that two other journals among the top 20, *Technological Forecasting and Social Change* and *Technology Analysis & Strategic Management*, are also among the top ten in the field of Innovation Studies (see ibid.).[21]

The journals listed in fifth to ninth position are all recognisably STS journals. They are followed by a number of leading journals in adjacent social science disciplines including *Organization Studies*, *Strategic Management Journal*, and *American Sociological Review*, indicating that STS has had a significant impact on these social sciences. The list also contains two journals (in 11th and 17th position) in the area of educational research. Among the notable omissions from this list, however, are any journals in the fields of economics and psychology, suggesting that the impact of STS in these areas has been less pronounced.[22]

In considering the above findings, one must bear carefully in mind the limitations of this analysis. In particular, the journal classification scheme developed by ISI (and later the Web of Science, WoS) may not accurately reflect the changing nature of fields, especially newer or less mature ones (such as organization studies).[23]

To identify groups of like-minded scholars drawing upon STS core literature, we adopted a two-step approach. First, we brought together a number of clearly related subfields (e.g. merging all the different subgroups within psychology into one group). Then in a second step, we analysed the citation patterns of the 38 biggest subject-areas (those with over 500 citations – together, these accounted for 89% of the total citations to the STS core contributions) in order to establish whether some of these could be grouped into larger clusters. If the citation

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[20] The impact in the other direction (i.e. from Innovation Studies to STS) appears to be much smaller in that there are no STS journals among the top 20 journals citing the Innovation Studies core literature (see Fagerberg et al., this issue, Table 4).

[21] Part of this may also be due to the fact that a few STS researchers choose to publish some of their work in STI journals such as *Research Policy* and *Technology Analysis & Strategic Management*.

[22] See, Nightingale (2008) for an explanation.

[23] It seems somewhat strange, for example, to note that SSS and ST&HV, both central STS journals, are classified by WoS as being in two rather different fields (History & Philosophy of Science, and Social Issues, respectively). Moreover, applying these field categories to relatively small datasets may lead to problems.

preferences of two subject-areas with regard to the STS core literature are strongly correlated, this was taken as an argument for merging the two.[24] Conversely, if the citation patterns for two subject areas are rather different, this was seen as a reason for keeping those two fields separate.

The results of this analysis are given in Appendix B. This shows that while some fields have relatively distinct citation patterns, others are quite closely related (for example, Geography and Environmental Studies; and Information, Library and Computer Science). There is also a larger cluster consisting of Economics, Management, Business, Planning and Development, Operations Research & Management, and (perhaps somewhat surprisingly) Engineering.

Figure 2 shows the ten largest clusters of fields, which collectively account for 89% of the total citations in the Web of Science to the STS core literature.

Figure 2. Disciplinary orientation of publications citing STS core contributions (top 10 subject-areas)

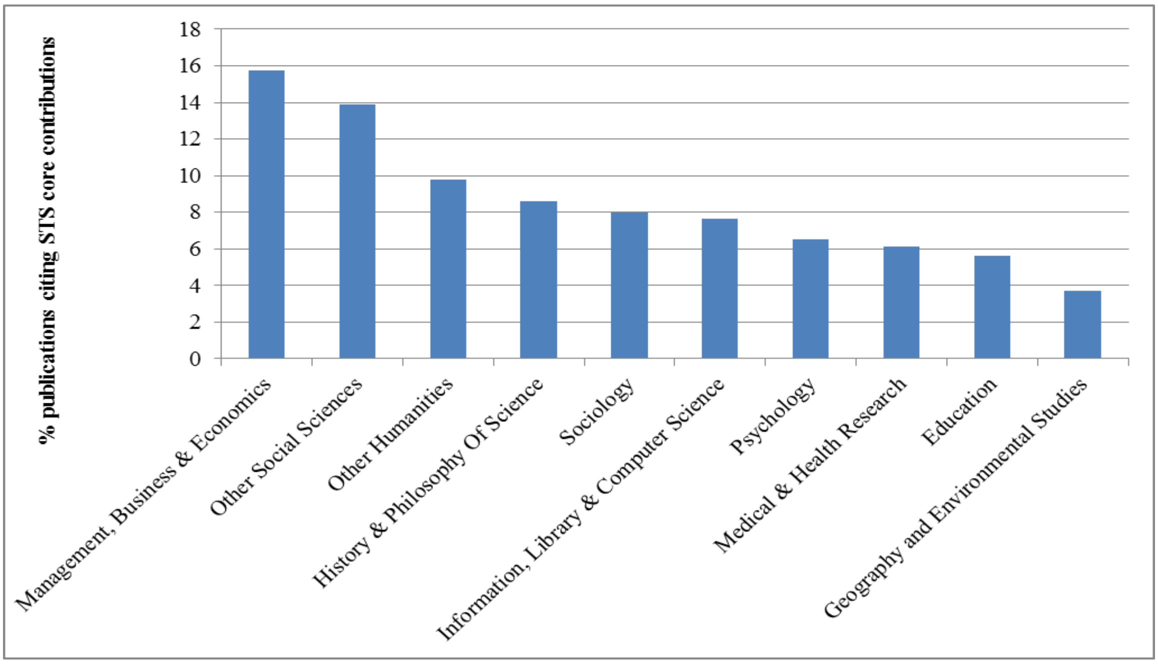

Figure 2 takes no account of the different sizes of the various fields listed. In order to normalise for field size, we follow the procedure outlined in Fagerberg et al. (this issue) of dividing the shares shown in Figure 2 by the shares of the same subject areas in terms of all

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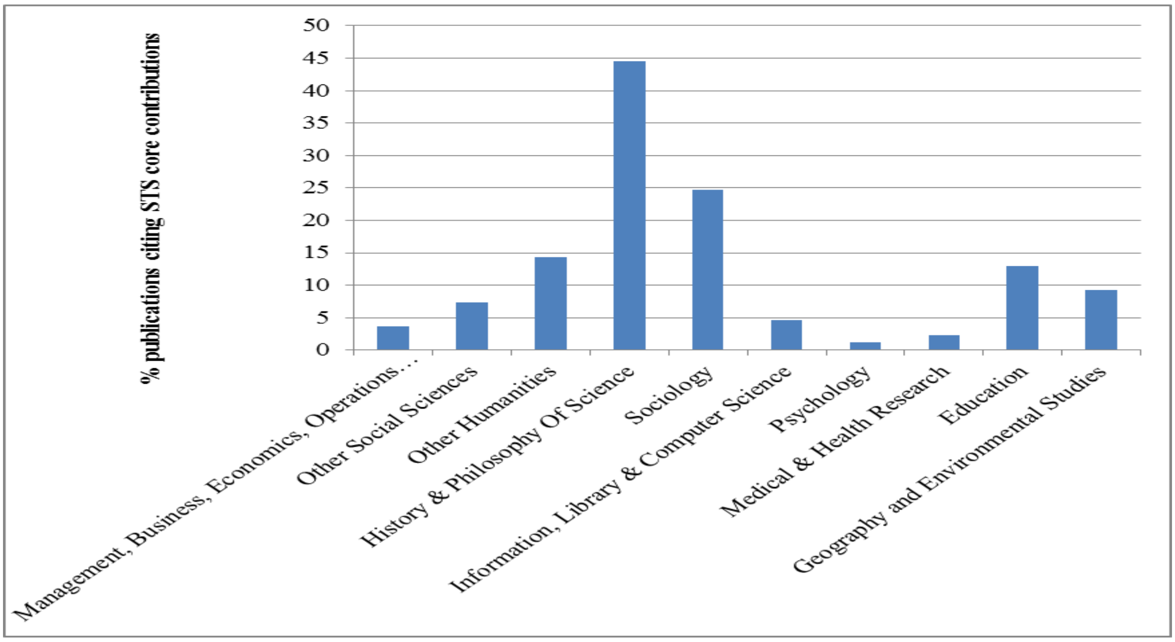
[24] For example, Information Science & Library Science and Computer Science were closely correlated ($r=0.872$, $p<0.01$) so they were merged.

citations in the Web of Science. Hence, if the authors within a specific subject area show an above average interest in the literature on STS, the adjusted figure for the degree of 'specialisation' will be above one, and vice versa. Because in earlier years the necessary data are not available, this calculation could be made only for the period 2003-2008. The results are shown below in Figure 3 below.

Figure 3. Specialisation of those citing STS core contributions (6-year average, 2003 – 2008)



As is clear from Figure 3, the reason why the composite field of 'Management, Business, Economics, etc.' contained the largest number of references to the core STS literature is more to do with the size of this field than with the propensity of its researchers to cite STS. In contrast, scholars in the much smaller field of 'History and Philosophy of Science' are nearly 45 times more likely to cite the STS core literature than the 'average scholar', while for Sociology the equivalent figure is nearly 25.

When we look at where the authors citing the core literature are located (based on the institutional addresses of authors), we find that the largest group of researchers citing the core literature are in North America (50%), some way ahead of Europe (40%), with the rest of world accounting for only 10%.[25] This may in part be a reflection of the more limited coverage by the WoS of journals from outside these two main regions. However, there have

[25] Note that such institutional information is generally missing prior to 1998 and in the case of multi-authored papers. Therefore, the analysis reported here is based on a subset of around 20,000 single-authored papers published after 1997 (after excluding just over 1,000 papers that gave no institutional address) and an analysis of the nearly 30,000 citations they made to the STS core literature.

been some significant trends over this period, with the number of European authors citing the STS core contributions rising by 40% and that for the 'Rest of the World' by 24%, while the number of North American citing authors fell by 11% in the 10-year period after 1998.

6. Core contributions and the development of STS

6.1 The historical origins of STS

Having mapped out the core contributions and explored their structure, this section uses the quantitative data to provide a qualitative account of the development of STS based on analysis of the content of the papers. These tables and the data in Appendix A provide a reasonably close match with what one might expect with respect to the history of STS. The period from the latter part of the 19th Century up to the emergence of STS in the 1960s had been dominated by a particular view of science that saw it as a process of discovering progressively more about the law-governed order of the natural world (Dupré, 1993). These laws were captured using 'the' scientific method that allowed nature to decide between rival theories. As a result, epistemology and epistemologists (such as Popper or Ayer) were particularly valued because they might be able to shed light on this method, allowing it to be extended to other areas, such as the social sciences, where it might potentially enable them to replicate the success of science.

History and sociology of science, on the other hand, were less valued, with history conceptualised as an internal process, during which sociological factors influenced which of various routes were taken to the single end-point where the structure of the material world is ultimately revealed.[26] Because the context of discovery and the context of justification were considered distinct, streams of research on the history (e.g. Butterfield, 1949), philosophy (e.g. Popper, 1934, 1959 & 1962; Polanyi, 1958), and sociology of science (e.g. Barber, 1952) operated largely in isolation.

During the 1950s American sociologists such as Barber (1952) and Merton (e.g. 1957) began to lay the groundwork for the integration of the sociology and history of science. The institutionalist approach of Merton and his colleagues added social norms and values to this traditional account. They highlighted that science serves a social function of providing certified knowledge, and that it requires the norms of universalism, disinterestedness,

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[26] Even Karl Mannheim (1925/1952, p.170), the sociologist of knowledge, argued that "we can picture the [scientific-technological] process of thought as direct progress towards ultimately 'correct' knowledge that can be formulated in one fashion" (quoted in Hacking, 2001, p.59).

communism (or communalism) and organised scepticism to function effectively, these providing the social regulations that bind the scientific community together. Mertonian science is progressive, cumulative and impartial, undertaken by people socialised into professional communities, and it is these communities, not some transcendent scientific logic, that provide the standards and practices needed to generate and evaluate knowledge claims.[27]

Lotka (1926) and Zipf (1949) similarly pioneered quantitative analyses of science. Of the three earliest papers in the top 20, two, de Solla Price (1963) *Little Science, Big Science*, and Cole and Cole (1973) *Social Stratification in Science,* extended the Mertonian tradition[28], establishing the foundations of the quantitative analysis of citation patterns to reveal social structure and stratification. In this and later work, the Cole brothers highlighted how citations reflect in part an 'old boys' network rather than offering a clear-cut picture of impact, while Price (1963) uncovered a macro-level structure that had grown exponentially for 300 years.[29]

This quantitative work was boosted by the development of science indicators, a form of research infrastructure that required a heavy investment. In the early 1960s the *Science Citation Index* was developed, and this was subsequently followed by the National Science Board's *Science Indicators* Report and the development of high-quality indicators in Canada, Australia and subsequently the EU. Such indicators were often resisted in the STS community, not least because, even many years later, there was still a lack of theoretical understanding as to what a citation actually represents (Cozzens, 1989). However, during the 1960s and 1970s, the field happily combined quantitative studies (e.g. de Solla Price, 1963; Small, 1973; Narin, 1976; Garfield, 1979) with qualitative sociological case-studies, and prominent sociologists made extensive use of various science indicators (e.g. Crane, 1965; Cole & Cole, 1967; Zuckerman, 1967; Spiegel-Rösing, 1977a).

A distinct non-Mertonian approach to STS also emerged, with a key early role played by scientists (particularly former physicists) with wartime experiences or memories (including

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[27] Later Mertonian research (e.g. Gieryn, 1983) became more compatible with STS. Mertonian norms provide a means to mark the 'boundaries' of science, and often act in the interests of the powerful. During the initial stages of the development of a discipline, there is a larger degree of flexibility and of disagreement, but as a degree of consensus starts to emerge, a process of 'cumulative advantage' begins, with the successful accruing the benefits of being able to define terms, which in turn attracts more prestige and power. In this way, an invisible college may start to form at the core of the emerging field (Barnes, 2001).

[28] Merton had supervised J.R. Cole's thesis.

[29] Its share of GDP had been steadily doubling every 20 years, and the number of journals, members of institutions, and people with technical degrees had been doubling every 15 years, with the result that 80-90% of all scientists that have ever worked were working at the time Price made this observation.

Derek de Solla Price, Paul Feyerabend, Thomas Kuhn, Stephen Toulmin and John Ziman), . They drew on earlier 20th century writers such as Duhem (1906/1954), Fleck (1935), Bernal (1939) and Polanyi (1958) to formulate an alternative framing (Ziman, 1968; Fuller, 2000). Fleck (1935), for example, had been very critical of the underlying metaphysical assumption of the received model of science in which the world has a unique pre-packaged structure, and of sociologists who endorsed it.[30]

Their views developed in the 1960s and ’70s in the wider context of emerging social movements concerned with nuclear disarmament, environmentalism and feminism.[31] They were critical of the role of science in society, not least about links between research (especially in physics) and the military (Vietnam in the US case, and nuclear weapons in Europe). They shared concerns about how “science” was used to naturalise, justify and hide politicised social structures that they did not regard as either natural (i.e. inevitable) or legitimate (Fuller, 2000). The only politics book on the top 20 list, Dickson’s (1984) *The New Politics of Science*, is part of this tradition, and it highlights the concentration of control of scientific funding in military and business circles, along with its consequences.

In Europe, one of the key institutional developments was the creation of the Dutch ‘science shops’, which represented efforts by scientists and others to open up science to the wider public (e.g. Farkas, 1999; Wachelder, 2003; Leydesdorff and Ward, 2005). These set the scene for subsequent developments in Constructive Technology Assessment (CTA – see e.g. Schot, 1992; Schot and Rip, 1997). Similarly, in the UK, scientific organisations such as the British Society for Social Responsibility in Science (BSSRS) and the Radical Statistics Group were actively engaged in public controversies to show how data and statistics were constructed to reflect particular political positions (e.g. Irvine et al., 1979), foreshadowing later theoretical developments in STS. Also involved was the Radical Science Collective (e.g. 1985), which formed the *Radical Science Journal*[32] (see e.g. Young, 1977). STS emerged within these social networks in opposition to the traditional view of science with its apolitical internalist history and its ahistorical, epistemologically-focused philosophy of science.

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30 He was openly critical that sociologists such as Durkheim had “an excessive respect, bordering on pious reverence, for scientific facts” that overlooked how those facts evolved and only made sense within historically contingent styles of thought (or *Denkstile*) (Fleck, 1979, p.47, quoted in Hacking, 2001, p.60).

31 Although feminism was only to enter mainstream STS in the 1980s.

32 Later in 1987 this became *Science as Culture*.

6.2 The emergence of STS[33]

The third of the three top-20 contributions from this earliest period – Kuhn's (1962) *The Structure of Scientific Revolutions* – had an enormous impact outside of STS, as indicated by its very high ISI citation score. While Kuhn is often represented (including here) as the 'father' of STS, it should be recalled that he regarded himself as primarily an 'internalist' historian; while his analysis certainly opened up the social analysis of science, his 'social' was largely restricted to the 100 or so scientists that form the core of a paradigm at the heart of each field, and he had little to say about anything wider (Hacking, 2001). Kuhn and Popper may have disagreed on many things (Lakatos and Musgrave, 1970), but the vast intellectual gulf between Kuhn and, say, Carnap or Popper is in part a construction of later authors seeking to downplay the extent to which epistemology had started to address the social nature of scientific knowledge production (Galison, 1987; Chalmers, 1994).

However, where Kuhn was decidedly radical was in seeing scientific progression as a mundane process of problem-solving *away* from older science rather than *towards* a 'correct' account of the universe's inherent structure, with changes in direction during revolutionary periods of change influenced as much by the death of existing scientists as by the steady progress of reason. His rather poorly defined 'paradigms' (Masterman, 1970) represented sets of ideas and world-views that contributed new categories and frameworks to provide shared ways of solving problems. Consequently, despite his personal conservatism and respect for authority, his work provided a wider, more critical academic community with a new set of tools to understand science (using paradigms as versions of culture), its claims to authority, and how its processes and products interact.

The high number of citations from both STS and the wider academic community to Kuhn's 1962 book highlights its core contribution in successfully integrating the history, philosophy and sociology of science. With inputs from various researchers beginning to cluster around STS such as Hagstrom (1965), Ben-David (1971), Ravetz (1971), Crane (1972), Cole & Cole (1973), Merton (1973), Barnes (1974), Blume (1974) and Mitroff (1974), all of which appear among the STS core contributions (see Appendix A), and from others such as Berger and Luckmann (1966) and Habermas (1971), the STS 'field' began to emerge with its distinctive

[33] For a detailed history of STS, see Jasanoff (2010). She sees the formation of STS as coming about through the merger of two streams of research: studies of the nature and properties of science and technology; and studies of the impacts and control of science and technology. It is notable that this account contains no mention of bibliometrics or science indicators.

emphasis on unmasking the external (i.e. extra-scientific) social factors behind the processes of science but also the content of science.

From the 1960s onwards, this STS community grew in size and geographical coverage, and developed into a number of distinct specialised groups with the scale and political and intellectual clout to appropriate resources and become self-sustaining in the medium to long term; for example, at Columbia (where Robert Merton and his colleagues developed the Program in the Sociology of Science), Yale (where Derek de Solla Price had been appointed as Professor of the History of Science in 1960), UC Berkeley (where Kuhn worked from 1961 to 1964), Cornell (where the Science, Technology and Society Program was set up in 1969 under the directorship of Frank Long), Edinburgh (where the Science Studies Unit was founded in 1966 by David Edge), York (Michael Mulkay), Bath (Harry Collins), Bielefeld (Peter Weingart), Ecoles des Mines Paris (Bruno Latour and Michel Callon at CSI), Amsterdam (Stuart Blume, head of the Science Dynamics group set up in 1982), and Leiden (Antony van Raan, founding Director of CWTS, the quantitative science studies group set up in the early 1980s).

Work in STS up until the publication of the first handbook in 1977 built on these foundations. The first handbook divided its 15 chapters into three sections – normative and professional contexts, disciplinary perspectives on science studies, and interdisciplinary perspectives on science policy – that reflected the emerging formation of the discipline. One of its editors, Spiegel-Rösing (1977b, pp.20-30) identified and discussed certain “cardinal tendencies” of STS: a humanistic focus on people; a relativistic focus on place and history; a reflexive critical self-awareness; a de-simplifying focus on revealing the hidden complexity of seemingly natural ‘black-boxed’ phenomena; and a normative focus on the values implicit in science and technology (Hackett et al., 2007, pp.6-7).[34]

At the same time, STS became professionalised with the formation of bodies such as the Society for Social Studies of Science (4S, founded in 1975) and the European Association for Studies of Science and technology (EASST, founded in 1981), each with their own regular conferences, as well as the creation of specialist STS journals, in particular *Social Studies of Science* (*SSS*, established in 1971), and *Science Technology & Human Values* (*ST&HV*, set up in 1976).

[34] Spiegel-Rösing also highlighted four deficiencies: rhetorical pathos, focusing on problems rather than solutions; intra- and inter-disciplinary fragmentation; limited comparative research; and a bias towards ‘hard’ sciences (ibid.).

6.3 1975-1985 – From the sociology of science to the sociology of scientific knowledge

During the 1960s, several teaching programmes were launched to teach British scientists about the complexity of social problems (Fuller, 2000). One of these, the Science Studies Unit at the University of Edinburgh, employed a number of natural scientists, including David Edge (a former radio astronomer), Barry Barnes (a chemist) and David Bloor (a psychologist and mathematician), who, informed by Wittgenstein, Kuhn and Polanyi, developed a research programme called 'the Strong Programme[35] in the Sociology of Scientific Knowledge'. This switch in emphasis from the 'sociology of science' associated with Merton and his colleagues to the 'sociology of scientific knowledge' (often abbreviated to SSK) was picked up by others. For example, the 'Bath School' of Collins and Pinch began developing a parallel 'Empirical Programme of Relativism', while Mulkay and colleagues at the University of York set about applying discourse analysis to science.

Bloor's (1976) *Knowledge and Social Imagery*, number 9 in the list in Table 2, set out the philosophy behind SSK. This philosophy stressed social causality, an impartial attitude to success and failure in science (under the traditional view, sociologists had been confined to raking over the 'leftovers' of explaining 'failed' science), a methodological principle of symmetry (according to which the same explanations should apply to success and failure in science, which in turn implied the adoption of a relativistic methodology), and a self-conscious reflexive recognition that these rules applied to SSK itself.

Through a series of important historical studies that revealed science "as it is actually done" and the social and contingent nature of scientific facts, the Edinburgh School produced a systematic criticism of the traditional epistemology of science (see, for example, Bloor, 1976, and the subsequent discussion in Ladan, 1981, and Bloor, 1981).[36] Their philosophy involved a Kuhnian-Wittgensteinian emphasis on knowledge as a form-of-life, and they sought to decode the world-views proposed by scientists by showing that micro-level theories and facts (i) were contingent and could be explained in quite different terms ("it could be otherwise") and (ii) were selected and stabilised by the social and cognitive interests and the activities of

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[35] The contrast here was with what they termed 'the weak programme', which focussed on identifying sociological explanations for 'erroneous' scientific beliefs, as opposed to developing an understanding of the sociological factors shaping *all* scientific beliefs.

[36] This tradition of work unpicked the intellectual foundations of scientism and stressed the materialist-embodied dimensions of scientific activity (in contrast to the traditional focus on intellectual and conceptual change), thus revealing the hidden world of the technicians and others such as glass blowers and animal handlers.

key social actors. They justified their relativist methods because, first of all, they only had access to social actors, who mediate the natural entities they invoked in their arguments, and not to the natural entities themselves. Secondly, the truth or otherwise of a scientific proposition does not explain why anyone might believe in it, and explaining why someone believes in something in terms of the truth of 'facts' misapplies the grammar of the verb 'to explain'.

They emphasised the local and complicated against the essential, simple and universal, using 'thick' micro-level descriptions of the day-to-day activities and arguments involved in the often controversial process of establishing scientific facts. Three other books in the top 20 fall broadly within this tradition. The first, Shapin and Schaffer's (1985) *Leviathan and the Air-Pump*, provides a detailed social history of the scientific revolution, the second, Collins' (1985) *Changing Order: Replication and Induction in Scientific Practice*, illustrates the Bath School's more micro-sociological focus, while the third, Traweek's (1988) *Beam-times and Lifetimes: the World of High Energy Physicists*, offers a revealing anthropological analysis of high-energy physics at the Stanford Linear Accelerator Center (SLAC).

Collectively, this 'local' approach, itself the natural implication of the under-determination of theory by evidence, undermines both the idea of cumulative progress, as knowledge claims are always relative to what is salient to the local culture, and the moral superiority of science that was previously assumed to come from a privileged access to truth. Within this work, there is a key distinction between the product and process of science. The old history and sociology of science followed processes but assumed they all arrived at the same place or product, while according to the new STS perspective the process determined the end-point. Quantitative sociology and scientometrics, by contrast, focus on the products of science, an approach that, for the qualitative philosopher-historian, only captures an overly stable and potentially misleading snap-shot of something "in the process of becoming", or, worse still, attempts to impose order and therefore social difference on people, their worlds and the dynamic connections that give them their properties.

This internal difference may help explain the subsequent qualitative-quantitative schism in STS.[37] By the end of the 1970s quantitative and qualitative STS had started to diverge. The emerging sub-field of science indicators established its own journals (e.g. *Scientometrics*, established in 1978) and regular conferences (e.g. the 'Leiden' conferences on S&T

[37] For another analysis of the dynamics of STS, see Leydesdorff and Van den Besselaar (1997).

indicators, first held in 1988). Over time, quantitative and qualitative STS drifted further apart, with the 4S/EASST conference of 2000, unlike that of 1996, having no mainstream scientometrics sessions, and the qualitative STS community becoming more isolated from the scientometric and policy-focused communities (Van der Besselaar, 2001).[38]

6.4 1980s -1995 – The laboratory and the technological turn

During the 1980s, the focus of academic research on science changed from understanding Kuhnian revolutions and Popperian refutations to understanding the considerable stability of science. One book in the top 20, Latour and Woolgar's (1979) *Laboratory Life: the Social Construction of Scientific Facts*, was a groundbreaking study that moved away from the analysis of controversies and the intentional (in the philosophical sense) aspects of scientists' cosmologies to explore the actions and materiality of scientific work.[39] Latours's central importance is reflected in his ISI and J-score positions in Tables 2 and 3.

While much previous work explored how truth and legitimacy are constructed between scientists, Latour and his colleagues, in particular Callon, Woolgar and Law, explored how science is effective in action (Pestre, 2004, p.357) and how it has such a significant impact on the world. Building on a tradition that argued that science has power through its ability to act at a distance, typically by outsourcing action to autonomous non-human things (or 'actants'), they helped shift attention from science to 'techno-science' and the interactions between entities that give them their form and attributes. These interactions form a network,[40] whose effects, "captured in the precarious process of becoming", extend through space and time to create 'Nature' and 'Society' (Pestre, 2004, p.358), reversing the previous conception of the relationship between society and technology. This work was central in the development of actor-network theory, which has since found application in a wide range of fields.

The power of science therefore has less to do with its internal workings or its ability to reveal a hidden order in nature (reflecting an earlier sociological position that scientific theories do not succeed because they are true but because they attract funding), and more to do with practices that produce order (Pestre, 2004, p.357). As such, this new approach downplays the

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[38] The scientometrics community cites the qualitative STS community (but receives few citations in return), although in recent years it has had an increasing mutual interaction with policy-focused STS, particularly in relation to indicator studies and evaluations (Van der Besselaar, 2001, p.442). Reflecting this, the 2011 4S meeting included a session on 'Re-imagining the Relationship between Scientometrics and Science Policy'.

[39] By materiality, we mean apparatus, instruments, practices, techniques and physical organisation.

[40] The original French term '*réseau*' has more fuzzy implications and was used by Diderot for entities that blur the Cartesian categories of body and mind (Barnes, 2001, p. 528).

conflicts involved in the formulation of the content of science to focus more on a (more traditional) field of mutually antagonistic interactions. Not surprisingly, this shift generated serious disagreement (see Bloor, 1999, and Latour, 1999).

Latour developed his theoretical ideas further in two more books in the top 20, his (1987) *Science in Action*, and his (1988) *The Pasteurization of France*, both of which were highly influential and helped shift the focus of analysis from historical processes though time to spatial changes. Later, Pickering's (1995) *The Mangle of Practice* extended the increasing attention on techno-science back to the heart of experimental science with a detailed examination of the contingencies involved in experimental research, in which continuous adjustments to the 'mangle' of instruments, theories and data maintain the stability of science.

A parallel 'technological turn' extended the SSK perspective from science to technology, heralding the emergence of 'the social construction of technology' (SCOT). Two of the top 20 publications were pivotal in this shift: Bijker et al.'s (1987) *The Social Construction of Technological Systems*, and Pinch and Bijker's (1984) *The Social Construction of Facts and Artifacts*, which drew parallels between science and technology, and highlighted the interpretive flexibility in the design and use of artefacts, and the lack of a unique design process or pattern of use across cultures or time. As a consequence, they argued for the analytical and policy value of studying technical change using methods associated with the Empirical Programme of Relativism by mapping technological controversies through time to document the social processes involved in the formation of technological consensus. These ideas have subsequently been extended into the evolutionary tradition in Science Policy by sociologists such as Rip and Geels working within a Dutch tradition of democratising technical decision-making.

This connection between the Dutch Constructive Technology Assessment tradition and the STS theoretical mainstream was also part of a turn towards more practical involvement in STS reflected in the results of the cluster analysis described above. Jasanoff's (1990) *The Fifth Branch: Science Advisers as Policymakers* (number 4 on the list in Table 2) and Gibbons et al.'s (1994) *The New Production of Knowledge* (number 13) both provide good illustrations of how theoretically informed STS can engage directly with issues in science and technology policy. Interestingly, however, the study that arguably had the largest impact on science policy, at least in the US, during this period was Narin et al.'s (1997) article on 'The increasing linkage between US technology and public science' (number 10 in the list), which was a traditional, product-focused, scientometric study showing that the most valuable US technology (as measured by patents) drew on the highest quality academic science (as measured by citations).

The changing nature of STS in the 1980s and 1990s can be seen in the structure of the second STS Handbook published in 1995, which contains 28 chapters focusing on processes rather than disciplinary perspectives on science. Its seven sections cover the conceptual and historical foundations of STS, the people, places and practices involved in research, the politics of science and technology, the institutions and economics of science and technology, and emerging areas of STS research.[41]

6.5 From the 1990s onwards: 'Science Wars', fragmentation and the culture of science

As these ideas developed during the 1990s, STS debates became more lively both internally and externally. Internally, Latour's projection of agency onto non-human 'actants' provoked considerable debate, particularly as it was felt to mask the conflict between human beings (Bloor, 1999). Similarly, the focus on the capacity of human beings to construct their world-views, to act and to generate meaning, restricted researchers to relatively narrow analyses, making many STS practitioners critical of large-scale frameworks.[42]

The symmetry principle and the practice of only using frames of analysis invoked by actors makes it very difficult, if not impossible, to take a normative stance (Dupré, 1993).[43] Given that much of the original emphasis in constructivist STS was political, this self-imposed policy isolationism caused rifts, and in the case of Latour (2004) a criticism of 'critique' and a re-articulation of his earlier positions. Lack of attention to what lies behind actors' assertions opens STS scholars up to an accusation of helping to construct misleading expectations that favour powerful social actors (see Nightingale and Martin, 2004 on genomics). Similarly, because Actor-Network Theory (ANT) and the Social Construction of Technology start from an (existing) actor perspective, their analysis emphasises powerful rather than marginalised or missing actors (Russell and Williams, 1996). As a result, the role of women in science and technology may often be overlooked (Cockburn and Ormrod, 1993),

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[41] However, there were no chapters from scientometric researchers.

[42] Political criticism is made difficult if responsibility is something that is understood to emerge from processes rather than being a product to be identified.

[43] As Dupré (1993, p.12) highlights, "By asserting that all scientific belief should be explained in terms of the goals, interests, and prejudices of the scientist, and denying any role whatever for the recalcitrance of nature, it leaves no space for the criticism of specific scientific beliefs on the grounds that they do reflect such prejudices rather than being plausibly grounded in fact."

which may explain why STS research has traditionally had relatively little interest in the limited role of women in technological decision-making, despite the early importance of feminist thinking.

These problems reflect path-dependent responses to the aggregation problems inherent in the study of science and technology. One can either adopt a traditional reductionist approach and attempt to integrate seemingly distinct phenomena and categories to explore 'more fundamental' drivers; or one can expand the number of categories chosen to analyse a phenomenon and unmask its complexity, which then drives the research to explore larger numbers of smaller units of analysis and interactions. Disciplines help define where the middle ground is. For scientometrics it is towards the former.

For another stream of work it is towards the latter. Knorr's (1999) *Epistemic Cultures* (number 16 on our list), by contrast, opens up the complexity of how scientists create knowledge, and contrasts the epistemic cultures of physicists and molecular biologists. Similarly, Star and Griesemer's (1989) article on 'Institutional ecology, "translations" and boundary objects' explores the role of material objects in translating between the viewpoints of different sets of scientific actors.[44] Haraway's (1991) *Simians, Cyborgs, and Women* pushes de-simplification further, seeing the human body as a federation of beings rather than a single entity. Haraway builds on earlier work by Lynn Margulis to use the idea of cyborgs to explore how the body and technology continuously interact and to open up new possibilities previously closed off by a view of the body as fixed. Research of this kind now has less connection to bibliometrics than it has to cultural studies and social anthropology.

Given these divergences STS gradually became more a federation rather than a common discipline, with fragmentation driven further by external developments. During the 1990s the STS community's attempts to understand the power, influence and outcomes of science led to conflict with self-styled leaders of the academic scientific community and public intellectuals from across the political spectrum. STS became caught up in wider public criticism in what became known as the 'Science Wars', which in turn formed part of the wider 'Culture Wars' of the period (see e.g. Ross, 1996; Gould, 2000; Segerstråle, 2000; Ashman and Baringer, 2001). Having tweaked the tiger of science by the tail for 20 years, it perhaps should not have come as a complete surprise to the STS community when the tiger finally turned around and

[44] In the subsequent translation of the notion of 'boundary objects' into the management literature, the original emphasis on discrete communities of meaning has been inverted and boundary objects have become translation machines of shared meaning.

swatted them. Prominent American physicists[45] and British biologists lined up to attack STS, linking it with a wider community of cultural studies researchers (outside the core of STS) under an often inappropriate banner of 'social constructivism' that embraced many of social constructivism's critics within STS. Bizarrely STS was even blamed for the Superconducting Supercollider (SSC) failing to be funded and, as the debate expanded, much else besides in an unpleasant and very public debate.[46] However, the citation data highlighted previously indicate that the impact of STS was rather limited outside a handful of cases, even within academia, suggesting they were seen as a convenient scapegoat for social changes well outside their control.

Internal divisions within STS have also emerged and deepened. For example, after 20 years the Amsterdam Science Dynamics department dissolved at the end of 1999, as increased specialisation meant that the sub-groups had little to discuss amongst themselves. More worryingly perhaps, qualitative scholars in the Dutch graduate school in STS excluded scientometrics from their canon (Van der Besselaar, 2001). As a consequence of all this, STS today is a rather divided community, with quantitative scientometrics and qualitative STS researchers operating largely in isolation from one another, one or two individual exceptions notwithstanding. The qualitative side of STS continues to expand its work on technology (including constructive technology assessment) and innovation, with the original programme of work analysing the social influences on the content of science having diffused into the mainstream and now attracting less interest. At the same time, scientometric research has been moving beyond science into areas previously the domain of traditional sociology (such as innovation and the analysis of social networks within and between organisations), as well as forming links with information science (as reflected, for example, in the recent creation of the *Journal of Informetrics*).[47]

7. Concluding remarks

The field of STS, like those of Innovation Studies and Entrepreneurship, is now some four or five decades old. This means that very few of researchers today were around when the field

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45 The reputation of STS was also severely dented around the same time when it was revealed that a physicist at New York University had published a spoof article in *Social Text* (see Sokal, 1996) in a test of the journal's supposed intellectual rigour.

46 Interestingly it looks as though STS may perhaps have been on the 'winning' side in the long run. The ESRC Science in Society research programme, for example, found the British public to have a very sophisticated understanding of the construction of scientific facts, rather than a gullible belief that people in authority naturally tell the truth.

47 We are indebted to a referee for this latter point.

first started to emerge in the 1960s. With memories beginning to fade, it is timely to develop an overview of what have been the main contributions to the field over this period. To do this, instead of relying solely on a subjective approach as in most previous reviews, we have adopted a more quantitative approach based on an analysis of authoritative handbooks and what the authors of individual chapters in these see as having been the core contributions in the development of the field. The results presented here suggest that the approach developed by Fagerberg et al. (this issue) seems to work reasonably well in STS, although perhaps not quite as well as in the case of Innovation Studies because of the rather more fragmented nature of STS. For this reason, it was necessary to 'tweak' it somewhat in the light of the distinct characteristics of STS. In particular, the thematic analysis on the basis of key words in titles proved less fruitful than in the case of Innovation Studies. As a result, we were unable to pursue the relationships between the literature clusters and variables as far as we might have hoped.

So what are the main findings to emerge from this study? First, the methodology has succeeded in identifying just 155 'core contributions' to STS as perceived by the authors of chapters in a number of authoritative handbooks. This suggests that there is a fair degree of consensus (at least between handbook authors) as to what constitute the most important contributions to the field, who have been the most influential authors, and which institutions have played the most prominent role in the development of the field. Moreover, by analysing these contributions, one can develop an understanding of how the field has evolved as new perspectives or approaches emerged over time.

One very obvious conclusion to emerge from this analysis is the growing apart of qualitative STS and quantitative science studies during the 1980s and 1990s. These two sets of research activities are now quite distinct – to such an extent that some readers may wonder why we chose to include the latter as 'part' of STS. However, as was stressed at the start, and as the results of this analysis confirm, the two were originally part of a single set of activities, with the central figure in science indicators (de Solla Price) being one of the two editors of the first STS Handbook, and with several prominent sociologists of science (such as the Cole brothers, Crane, Spiegel-Rösing and Zuckerman) making extensive use of science indicators during the 1960s and early '70s. However, at that point, the paths began to diverge. Those working with science indicators established their own groups, journals and conferences, while many other STS scholars became less interested in using science and technology indicators. As Table 4 shows, the area of quantitative science and technology studies now has quite distinct characteristics from that of ‘mainstream’ STS. Indeed, the subfield may now be closer to Innovation Studies, not least as a result of the NSF program on science policy in US as well as the growing use of science indicators for purposes related to science policy (such as in research assessment exercises) in a range of countries.

The cluster analysis reported here suggests that there is another relatively distinct strand of work within STS – namely, the research labelled as Cluster 1 in Table 5. Here, the emphasis is more on ‘technology’ and ‘politics’ (or ‘power’ or more recently ‘governance’) rather than ‘science’ (or ‘scientific knowledge’) and ‘sociology’, while the central contribution is seen as Jasanoff’s 1990 book on science advisers rather than the work of Latour or Kuhn.

In addition, although it is not apparent from the cluster analysis, examination of the core contributions of the main STS cluster (i.e. Cluster 2 in Table 5) reveals a degree of fragmentation between different approaches or ‘schools’ such as Mertonian functionalism and institutionalism, the ‘strong’ programme, relativism, discourse analysis, actor-network theory, social construction, and so on, each structured around a hierarchy of implicit assumptions that gives it a cognitive coherence (Nightingale, 2008). The competition and disputes between these schools have often been fierce, as reflected in the pages of journals as well as in conference debates between ‘authors’ and ‘critics’. In this respect, STS would seem to be rather ‘tribal’ (Becher, 1989), with each ‘tribe’ having its own language, culture and interests, as well as a predilection in some cases for marching into ritualistic battles with other tribes. Indeed, the strong interest in scientific controversies over the history of STS may reflect the views of many STS practitioners about what research is all about.

The establishment of a new field – and of new research groups to work in that field – is not easy. The pioneers are likely to meet resistance from established fields and departments. They may have no obvious source of funds. There is no established community of colleagues and collaborators. To overcome all this, the establishment of a new field requires acts of ‘entrepreneurship’, and hence the presence of individuals willing and able to identify or create opportunities that can then be exploited. Such individuals must be willing to act as ‘innovators’ not only in terms of making core intellectual contributions (i.e. attempting to construct a common conceptual and analytical framework or ‘paradigm’), but also in creating the necessary institutions essential for the field to grow – research groups, conferences, journals, textbooks, networks and so on.

As Fagerberg et al. (this issue) show in the case of Innovation Studies, there have been two particularly prominent contributors to the core literature of the field (both in the top three) who were also remarkable institution-builders – Chris Freeman (who set up SPRU and created the journal *Research Policy* – see Fagerberg et al., 2011), and Richard Nelson (who for 50 years has been central in developing and maintaining an extensive network of leading scholars). In the case STS, perhaps the nearest equivalent institution-builder was David Edge, who set up the Science Studies Unit at Edinburgh University, co-founded the journal *Social Studies of Science*, was one of the founders of EASST and also played a prominent role in the 4S society. However, he is not among the authors of the 155 core publications identified here. In the early years, Derek de Solla Price, the author of three publications among the STS core literature, performed a role of institution-builder in the United States, but he died relatively early (in 1983). Another who showed early signs of becoming an institution-builder in the US was Nicholas Mullins, but he too died early (in 1988). Other individuals have certainly contributed, for example, in the establishment of academic departments or journals, but for many the emphasis has been more on attempting to make intellectual contributions to the field rather than such institution-building.

An alternative explanation might be suggested by Cultural Theory, in which the emphasis on deconstructing claims to hierarchical knowledge, combined with the strong group identification, give STS more an ‘egalitarian’ flavour that finds building consensus difficult and which makes it especially prone to fragmentation (Hood, 1998). Such an interpretation might also explain why STS was attacked from both the political left and right in the science wars, why STS researchers have an almost theological concern with reflexivity, and why institution-building would be so difficult.

In conclusion, this study has demonstrated that the methodology developed by Fagerberg et al. works reasonably successfully in identifying the core contributions for STS. Although analysis of those core contributions provides supporting evidence for the divisions between different approaches or ‘schools’ as STS has evolved, there would nevertheless appear to be a fair degree of consensus, at least among the authors of chapters in handbooks, as to what have been the most important contributions to STS, who have been the most influential authors, and which institutions have played the most prominent role in the development of the field.

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Appendix A

Table A. Core STS literature (ranked by J-index)

No.	Author	Title	Type	Book / Journal	Year	J-Index
1	Latour B	Science in action: how to follow scientists and engineers through society	Book		1987	24.0
2	Latour B; Woolgar S	Laboratory life: the social construction of scientific facts	Book		1979	19.0
3	Kuhn T	The structure of scientific revolutions	Book		1962	16.9
4	Jasanoff S	The fifth branch : science advisers as policymakers	Book		1990	15.0
5	Shapin S; Schaffer S	Leviathan and the air-pump: Hobbes, Boyle and the experimental life	Book		1985	14.0
6	Price DJ	Little science, big science	Book		1963	14.0
7	Traweek S	Beamtimes and lifetimes: the world of high energy physicists	Book		1988	12.0
8	Star SL; Griesemer J	Institutional ecology, "translations" and boundary objects: amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907-1939	Journal	Social Studies of Science	1989	12.0
9	Bloor D	Knowledge and social imagery	Book		1976	11.8
10	Narin F; Hamilton KS; Olivastro D	The increasing linkage between us technology and public science	Journal	Research Policy	1997	11.1
11	Haraway D	Simians, cyborgs, and women: the reinvention of nature	Book		1991	11.0
12	Bijker WE; Hughes T; Pinch TJ	The social construction of technological systems: new directions in the sociology and history of technology	Book		1987	10.7
13	Gibbons M; Limoges C; Nowotny H; Schwartzman S; Scott P; Trow M	The new production of knowledge: the dynamics of science and research in contemporary societies	Book		1994	10.0
14	Collins HM	Changing order: replication and induction in scientific practice	Book		1985	9.9
15	Pickering A	The mangle of practice: time, agency and science	Book		1995	9.7
16	Knorr K	Epistemic cultures: how the sciences make knowledge	Book		1999	9.7
17	Cole JR; Cole S	Social stratification in science	Book		1973	9.6
18	Dickson D	The new politics of science	Book		1984	9.1
19	Pinch T; Bijker WE	The social construction of facts and artifacts, or how the sociology of science and the sociology of technology might benefit each other	Journal	Social Studies of Science	1984	9.1
20	Latour B	The pasteurization of France	Book		1988	9.0

21	Bernal JD	The social function of science	Book		1939	8.8
22	Merton RK	The sociology of science: theoretical and empirical investigations	Book		1973	8.8
23	Nowotny H; Scott P; Gibbons M	Re-thinking science: knowledge and the public in an age of uncertainty	Book		2001	8.3
24	Etzkowitz H; Leydesdorff L	The dynamics of innovation: from national systems and "mode 2" to triple helix of university-industry-government relations	journal	Research Policy	2000	8.3
25	Callon M	Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieux bay	Chapter	Power action and belief: a new sociology of knowledge?	1986	8.3
26	Lynch M	Art and artifact in laboratory science: a study of shop work and shop talk in a research laboratory	Book		1985	8.3
27	Bush V	Science: the endless frontier	Book		1945	8.1
28	Ravetz JR	Scientific knowledge and its social problems	Book		1971	8.1
29	Beck U	Risk society: towards a new modernity	Book		1992	8.0
30	Ezrahi Y	The descent of Icarus: science and the transformation of contemporary democracy	Book		1990	8.0
31	Griliches Z	Patent statistics as economic indicators: a survey	Journal	Journal of Economic Literature	1990	8.0
32	Knorr K	The manufacture of knowledge: an essay on the constructivist and contextual nature of science	Book		1981	7.4
33	Winner L	The whale and the reactor: a search for limits in an age of high technology	Book		1986	7.4
34	Schmookler J	Invention and economic growth	Book		1966	7.4
35	Salomon JJ	Science and politics	Book		1973	7.4
36	Collins HM; Yearley S	Epistemological chicken	Chapter	Science as practice and culture	1992	7.0
37	Edwards PN	The closed world: computers and the politics of discourse in cold war America	Book		1996	6.9
38	Ben-David J	The scientist's role in society: a comparative study	Book		1971	6.6
39	Polanyi M	Personal knowledge: towards a post-critical philosophy	Book		1958	6.6
40	MacKenzie D; Wajcman J	The social shaping of technology: how the refrigerator got its hum	Book		1985	6.6
41	Small H; Sweeney E	Clustering the science citation index using co-citations, I: a comparison of methods	Journal	Scientometrics	1985	6.6
42	Gieryn TF	Boundary work and the demarcation of science from	Journal	American Sociological	1983	6.6

		non-science: strains and interests in professional ideologies of scientists		Review		
43	Keller EF	Reflections on gender and science	Book		1985	6.6
44	Callon M; Law J; Rip A	Mapping the dynamics of science and technology: sociology of science in the real world	Book		1986	6.6
45	Garfield E	Citation indexing: its theory and application in science, technology and humanities	Book		1979	6.6
46	MacKenzie D	Inventing accuracy: an historical sociology of nuclear missile guidance	Book		1990	6.0
47	Harding S	Whose science? Whose knowledge?: thinking from women's lives	Book		1991	6.0
48	Myers G	Writing biology: texts and the social construction of scientific knowledge	Book		1990	6.0
49	Star SL	Regions of the mind: brain research and the quest for scientific certainty	Book		1989	6.0
50	Lynch M; Woolgar S	Representation in scientific practice	Book		1990	6.0
51	Small H; Griffith BC	The structure of scientific literatures I. Identifying and graphing specialties	Journal	Science Studies	1974	5.9
52	Hagstrom WO	The scientific community	Book		1965	5.9
53	Rose H; Rose S	Science and society	Book		1969	5.9
54	Latour B	Give me a laboratory and i will raise the world	Chapter	Science observed: perspectives on the social study of science	1983	5.8
55	Moed HF; Burger WJM; Frankfort JG; Van Raan AFJ	The use of bibliometric data for the measurement of university research performance	Journal	Research Policy	1985	5.8
56	Fujimura J	Constructing "do-able" problems in cancer research: articulating alignment	Journal	Social Studies of Science	1987	5.8
57	Narin F; Noma E	Is technology becoming science?	Journal	Scientometrics	1985	5.8
58	Pinch T	Confronting nature: the sociology of solar-neutrino detection	Book		1986	5.8
59	Suchman L	Plans and situated actions: the problem of human-machine communication	Book		1987	5.8
60	Nelkin D	Controversy, politics of technical decisions	Book		1979	5.8
61	Ellul J	The technological society	Book		1964	5.1
62	Fleck L	Genesis and development of a scientific fact	Book		1935	5.1
63	Blume S	Toward a political sociology of science	Book		1974	5.1

64	Merton RK	Science, technology and society in seventeenth century England	Journal	Osiris	1938	5.1
65	Fujimura J	The molecular biological bandwagon in cancer research: where social worlds meet	Journal	Social Problems	1988	5.0
66	Nelkin D; Tancredi L	Dangerous diagnostics: the social power of biological information	Book		1989	5.0
67	Law J	A sociology of monsters: essays on power, technology and domination	Book		1991	5.0
68	Collins HM	Artificial experts: social knowledge and intelligent machines	Book		1990	5.0
69	Wynne B	Sheepfarming after Chernobyl: a case study in communicating scientific information	Journal	Environment	1989	5.0
70	Fujimura J	Crafting science: standardized packages, boundary objects and "translation"	Chapter	Science as practice and culture	1992	5.0
71	Woolgar S	Science, the very idea	Book		1988	5.0
72	Engelhardt HT; Caplan AL	Scientific controversies: case studies in the resolution and closure of disputes in science and technology	Book		1987	5.0
73	Small H; Sweeney E; Greenlee E	Clustering the "science citation index" using co-citations. Ii. Mapping science	Journal	Scientometrics	1985	5.0
74	Kevles DJ	The physicists: the history of a scientific community in modern America	Book		1978	5.0
75	Gilbert GN; Mulkay M	Opening Pandora’s box: a sociological analysis of scientists discourse	Book		1984	5.0
76	Noble D	America by design: science, technology, and the rise of corporate capitalism	Book		1977	5.0
77	Hughes TP	Networks of power: electrification in western society, 1880-1930	Book		1983	5.0
78	Law J	Technology and heterogeneous engineering: the case of Portuguese expansion	Chapter	The social construction of technological systems	1987	5.0
79	Pickering A	Constructing quarks: a sociological history of particle physics	Book		1984	5.0
80	Barnes B	Scientific knowledge and sociological theory	Book		1974	4.4
81	Greenberg DS	The politics of pure science	Book		1967	4.4
82	Rogers EM	Diffusion of innovations	Book		1962	4.4
83	Barber B	Science and the social order	Book		1952	4.4
84	Griffith BC; Small H; Stonehill JA; Dey S	The structure of scientific literatures II: toward a macro- and microstructure for science	Journal	Science Studies	1974	4.4
85	Gilpin R	American scientists and nuclear weapons policy	Book		1962	4.4
86	Mitroff II	The subjective side of science:	Book		1974	4.4

		a philosophical inquiry and the psychology of the Apollo moon scientists				
87	Crane D	Invisible colleges: diffusion of knowledge in scientific communities	Book		1972	4.4
88	Small H	Co-citation in the scientific literature: a new measure of the relationship between two documents	Journal	Journal of the American Society for Information Science	1973	4.4
89	Price DJ	Networks of scientific papers	Journal	Science	1965	4.4
90	Feyerabend PK	Against method: outline of an anarchistic theory of knowledge	Book		1975	4.4
91	Collins HM	The seven sexes: a study in the sociology of a phenomenon, or the replication of experiments in physics	Journal	Sociology	1975	4.4
92	Etzkowitz H; Webster A	Science as intellectual property	Chapter	Handbook of science and technology studies	1995	4.2
93	Wajcman J	Feminist theories of technology	Chapter	Handbook of science and technology studies	1995	4.2
94	Gieryn TF	Boundaries of science	Chapter	Handbook of science and technology studies	1995	4.2
95	Björneborn L; Ingwersen P	Perspectives of webometrics	Journal	Scientometrics	2001	4.2
96	Henderson K	On line and on paper: visual representations, visual culture, and computer graphics in design engineering	Book		1999	4.2
97	Irwin A; Wynne B	Misunderstanding science?: the public reconstruction of science and technology	Book		1996	4.2
98	Etzkowitz H; Leydesdorff L	Universities and the global knowledge economy: a triple helix of university-industry-government relations	Book		1997	4.2
99	Rudwick MJS	The great Devonian controversy: the shaping of scientific knowledge among gentlemanly specialists	Book		1985	4.1
100	Galison P	How experiments end	Book		1987	4.1
101	Wynne B	Rationality and ritual: the Windscale inquiry and nuclear decision in Britain	Book		1982	4.1
102	Narin F; Noma E; Perry R	Patents as indicators of corporate technological strength	Journal	Research Policy	1987	4.1
103	Keller EF	A feeling for the organism: the life and work of Barbara McClintock	Book		1983	4.1
104	Hacking I	Representing and intervening:	Book		1983	4.1

		introductory topics in the philosophy of natural science				
105	MacKenzie D	Statistics in Britain: 1865-1930	Book		1981	4.1
106	Nelson RR; Winter S	An evolutionary theory of economic change	Book		1982	4.1
107	Forman P	Behind quantum electronics: national security as basis for physical research in the united states, 1940-1960	Journal	Historical Studies in the Physical and Biological Sciences	1987	4.1
108	Winner L	Autonomous technology: technics-out-of-control as a theme in political thought	Book		1977	4.1
109	Star SL	Power, technologies, and the phenomenology of conventions: on being allergic to onions	Chapter	A sociology of monsters: essays on power, technology and domination	1991	4.0
110	Collins HM; Pinch T	The golem: what everyone should know about science	Book		1993	4.0
111	Lundvall BA	National systems of innovation: towards a theory of innovation and interactive learning	Book		1992	4.0
112	Knorr K	The couch, the cathedral, and the laboratory: on the relationship between experiment and laboratory in science	Chapter	Science as practice and culture	1992	4.0
113	Schwarz M; Thompson M	Divided we stand: redefining politics, technology and social choice	Book		1990	4.0
114	Schiebinger L	The mind has no sex? Women in the origins of modern science	Book		1989	4.0
115	Haraway D	Primate visions: gender, race, and nature in the world of modern science	Book		1989	4.0
116	Wynne B	Knowledges in context	Journal	Science, Technology & Human Values	1991	4.0
117	Brown P; Mikkelsen E	No safe place: toxic waste, leukemia and community action	Book		1990	4.0
118	Pickering A	Science as practice and culture	Book		1992	4.0
119	Greenwood T	Why military technology is difficult to restrain	Journal	Science, Technology & Human Values	1990	4.0
120	Mukerji C	A fragile power: scientists and the state	Book		1989	4.0
121	Ashmore M	The reflexive thesis: wrighting sociology of scientific knowledge	Book		1989	4.0
122	Winner L	Upon opening the black box and finding it empty: social constructivism and the philosophy of technology	Journal	Science, Technology & Human Values	1993	4.0

123	Mulkay M	Norms and ideology in science	Journal	Social Science Information	1976	3.7
124	Foucault M	The birth of the clinic: an archaeology of medical perception	Book		1973	3.7
125	IIT Research Institute	Technology in retrospect and critical events in science (TRACES)	Book		1968	3.7
126	Gilpin R; Wright C	Scientists and national policy-making	Book		1964	3.7
127	Collins HM	The tea set: tacit knowledge and scientific networks	Journal	Science Studies	1974	3.7
128	Skolnikoff EB	Science, technology and American foreign policy	Book		1967	3.7
129	Mullins NC	The development of a scientific specialty: the phage group and the origins of molecular biology	Journal	Minerva	1972	3.7
130	Narin F	Evaluative bibliometrics: the use of publication and citation analysis in the evaluation of scientific activity	Book		1976	3.7
131	Freeman C	The economics of industrial innovation	Book		1974	3.7
132	Kornhauser W	Scientists in industry: conflict and accommodation	Book		1962	3.7
133	Marcuse H	One-dimensional man: studies in the ideology of advanced industrial society	Book		1964	3.7
134	Boffey P	The brain bank of America: an inquiry into the politics of science	Book		1975	3.7
135	Woolgar S	Interests and explanation in the social study of science	Journal	Social Studies of Science	1981	3.3
136	Garvey WD	Communication, the essence of science—facilitating information exchange among librarians, scientists, engineers and students	Book		1979	3.3
137	Hughes TP	The evolution of large technological systems	Chapter	The social construction of technological systems: new directions in the sociology and history of technology	1987	3.3
138	Elkana Y; Lederberg J; Merton RK; Thackray A; Zuckerman H	Toward a metric of science: the advent of science indicators	Book		1978	3.3
139	Rip A; Courtial JP	Co-word maps of biotechnology an example of cognitive scientometrics	Journal	Scientometrics	1984	3.3
140	Werskey G	The visible college: the collective biography of British scientific socialists of the	Book		1978	3.3

		1930s				
141	Brickman R; Jasanoff S; Ilgen T	Controlling chemicals: the politics of regulation in Europe and the united states	Book		1985	3.3
142	Callon M; Courtial JP; Turner WA; Bauin S	From translations to problematic networks: an introduction to co-word analysis	Journal	Social Science Information	1983	3.3
143	Harding S	The science question in feminism	Book		1986	3.3
144	Turkle S	The second self: computers and the human spirit	Book		1984	3.3
145	Douglas M; Wildavsky A	Risk and culture: an essay on the selection of technical and environmental dangers	Book		1983	3.3
146	Spiegel-Rösing IS; Price DJ	Science, technology and society: a cross-disciplinary perspective	Book		1977	3.3
147	Eisenstein E	The printing press as an agent of change: communications and cultural transformations in early modem Europe	Book		1979	3.3
148	Carpenter MP; Narin F; Woolf P	Citation rates to technologically important patents	Journal	World Patent Information	1981	3.3
149	Rouse J	Knowledge and power: toward a political philosophy of science	Book		1987	3.3
150	Small H; Crane D	Specialties and disciplines in science and social science an examination of their structure using citation indexes	Journal	Scientometrics	1979	3.3
151	Pavitt K	Patent statistics as indicators of innovative activities: possibilities and problems	Journal	Scientometrics	1985	3.3
152	Collingridge D; Reeve C	Science speaks to power: the role of experts in policy making	Book		1986	3.3
153	Studer KE; Chubin DE	The cancer mission: social contexts of biomedical research	Book		1980	3.3
154	Foucault M	Power/knowledge: selected interviews and other writings 1972-1977	Book		1980	3.3
155	Rossiter M	Women scientists in America: struggles and strategies to 1940	Book		1982	3.3

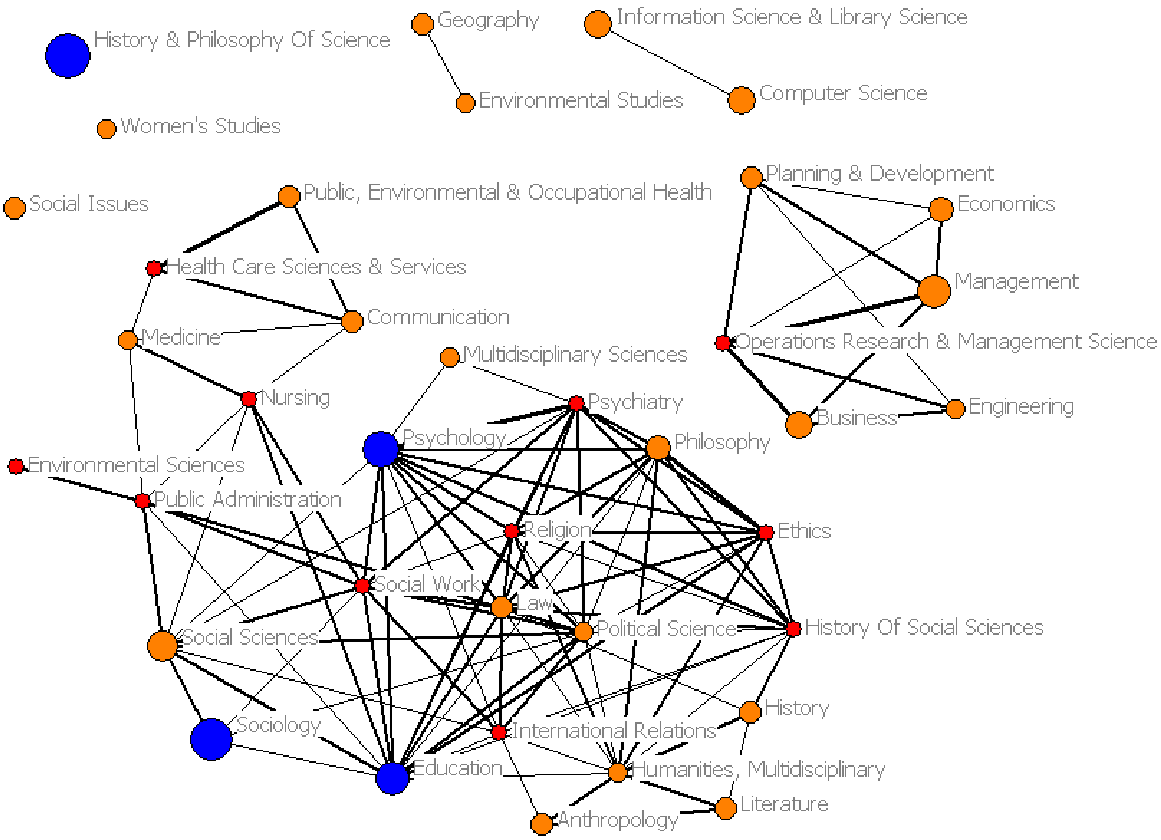
Appendix B

Table B. Subject-areas (with > 500 citations to the core STS literature) and sub-categories

Subject-areas	No. of citations	ISI subject categories merged
Management, Business, Economics, Operations Research, & Engineering	17,044.2	Management; Business (General, Finance); Economics; Planning & Development; Operations Research & Management Science; Engineering (Aerospace, Biomedical, Chemical, Civil, Electrical & Electronic, Environmental, Geological, Industrial, Manufacturing, Marine, Mechanical, Multidisciplinary, Ocean, Petroleum)
Other Social Sciences (including Professional & Vocational Studies)	15,059.5	Social Sciences (Biomedical, Interdisciplinary, Mathematical Methods); Social Issues; Law; Anthropology; Political Science; Public Administration; International Relations; Social Work
Other Humanities	10,573.2	Philosophy; Literature (General, African Australian Canadian, American, British Isles, German Dutch Scandinavian, Romance, Slavic); History; Humanities, Multidisciplinary; Ethics; Religion; History Of Social Sciences
History & Philosophy Of Science	9,332.9	-
Sociology	8,637.2	-
Information, Library & Computer Science	8,294.3	Information Science & Library Science; Computer Science (Artificial Intelligence, Cybernetics, Hardware & Architecture, Information Systems, Interdisciplinary Applications, Software Engineering, Theory & Methods)
Psychology	7,082.3	Psychology (General, Applied, Biological, Clinical, Developmental, Educational, Experimental, Mathematical, Multidisciplinary, Psychoanalysis, Social); Psychiatry
Medical & Health Research	6,612.8	Public, Environmental & Occupational Health; Medicine (General & Internal, Legal, Research & Experimental); Nursing; Health Care Sciences & Services; Communication
Education	6,097.2	Education (General & Educational Research, Scientific disciplines, Special)
Geography and Environmental Studies	4,018.5	Geography (General, Physical); Environmental Studies
Other Sciences	2,268.2	Environmental Sciences; Multidisciplinary Sciences
Women's studies	1,074.9	-

Source: citations to STS core contributions as downloaded from the Web of Science in April-May 2010 (using fractional counting for journals classified in two or more fields).

Figure B1. Relationships between subject-areas (cut off = 0.85)



Note: This network graph illustrates the relationship between the (main) subject categories, which involves authors citing the (core) STS literature. These relationships refer to the extent to which the sampled publications from two different subject categories cited the same literature (each of the 155 most important works on STS). Several subject-areas were composed based on these relationships (see Table B). The strength of the relationships is indicated by line thickness, where no lines mean rather weak relationships (less than 85% correlation). The subject categories are represented by circles of different sizes and colours, based on their total amount of citations to the core innovation literature (large blue, medium orange and small red circles).

Appendix C

Table C. Two-Step Cluster Analysis (best solutions based on the Bayesian information criterion (BIC) and log-likelihood distance)

Number of clusters BIC Ratio of Distance Measures	4 -6324,170 1,191				3 -6379,825 1,416			2 -6362,115 1,665	
Cluster (Number of members)	1/4 (37)	2/4 (43)*	3/4 (28)	4/4 (47)*	1/3 (38)*	2/3 (89)*	3/3 (28)	1/2 (127)	2/2 (28)
Disciplinary orientation									
Management, Business, Economics, Operations Research, & Engineering	0.13	0.09	**0.37**	0.13	0.13	0.11	**0.37**	0.12	**0.37**
Other Social Sciences	**0.40**	0.22	0.07	0.18	**0.40**	0.19	0.07	**0.25**	0.07
Other Humanities	0.19	0.23	0.03	**0.26**	0.19	**0.25**	0.03	**0.23**	0.03
History & Philosophy Of Science	0.29	**0.50**	0.06	0.22	0.29	**0.35**	0.06	**0.34**	0.06
Sociology	0.27	**0.45**	0.08	0.30	0.27	**0.37**	0.08	**0.34**	0.08
Information, Library & Computer Science	0.06	0.05	**0.50**	0.07	0.06	0.06	**0.50**	0.06	**0.50**
Psychology	0.09	0.15	0.07	**0.27**	0.09	**0.21**	0.07	**0.17**	0.07
Medical & Health Research	0.18	0.16	0.10	**0.28**	0.20	**0.22**	0.10	**0.21**	0.10
Education	0.20	0.20	0.07	**0.44**	0.21	**0.32**	0.07	**0.29**	0.07
Geography and Environmental Studies	0.24	0.21	0.14	**0.25**	**0.25**	0.23	0.14	**0.23**	0.14
Generation and Selection									
SSS	0.21	**0.35**	0.05	0.13	0.21	**0.23**	0.05	**0.22**	0.05
ST&HV	**0.17**	0.14	0.02	0.06	**0.17**	0.10	0.02	**0.12**	0.02
Scientometrics	0.01	0.02	**0.38**	0.03	0.01	0.02	**0.38**	0.02	**0.38**
Insider	**0.07**	0.03	0.04	0.02	**0.07**	0.02	0.04	**0.04**	**0.04**
Excellence	0.22	**0.45**	0.27	0.20	0.22	**0.32**	0.27	**0.29**	0.27
CSI, École des Mines	0.01	**0.10**	0.01	0.00	0.01	**0.05**	0.01	**0.04**	0.01
UC Berkeley	0.01	**0.19**	0.00	0.00	0.01	**0.09**	0.00	**0.07**	0.00
Univ. Edinburgh	0.01	**0.10**	0.00	0.00	0.01	**0.05**	0.00	**0.04**	0.00
Thematic orientation/Key words									
Construction/Constructivism	**0.11**	0.09	0.00	0.04	**0.11**	0.07	0.00	**0.08**	0.00
Gender	0.03	**0.09**	0.00	**0.09**	0.03	**0.09**	0.00	**0.07**	0.00
Knowledge	0.00	0.12	0.00	**0.30**	0.00	**0.21**	0.00	**0.15**	0.00
Politics & Power	**0.54**	0.02	0.00	0.02	**0.53**	0.02	0.00	**0.17**	0.00
Research	0.00	**0.14**	0.04	0.02	0.00	**0.08**	0.04	**0.06**	0.04
Science	0.41	0.44	0.54	**0.66**	0.42	**0.55**	0.54	0.51	**0.54**
Science Indicators	0.00	0.02	**0.50**	0.00	0.00	0.01	**0.50**	0.01	**0.50**
Scientists & Other Professions	0.05	**0.19**	0.04	0.06	0.05	**0.12**	0.04	**0.10**	0.04
Sociology	0.35	**0.40**	0.04	0.19	**0.34**	0.29	0.04	**0.31**	0.04
Technology	**0.57**	0.00	0.25	0.02	**0.58**	0.00	0.25	0.17	**0.25**

*Denotes the two groups of STS literature which are integrated in the subsequent stage. Note that one core contribution (Pickering, 1984 – see item 79 in Table A in Appendix A) moved from cluster 4/4 to cluster 1/3 in moving from the 4-cluster to the 3-cluster solution.

Note: For Thematic orientation, numbers represent shares of literature within each group which have the respective keyword in the title. Numbers represent variable means for the other two dimensions (Disciplinary orientation, Generation and selection process). Numbers in bold indicate the highest means/shares.