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Growth dynamics of scholarly and scientific journals

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Results are presented on journal growth dynamics at both the micro and macro levels, showing that journal development clearly follows researcher behaviour and growth characteristics. At the subject discipline level, the journal system is highly responsive to research events. Overall journal growth characteristics clearly show the predominance of 3.3% compound annual growth under a number of different socio-political climates. It is proposed that this represents a lower limit to journal growth rates and that this growth is the outcome of a self-organizing information system that reflects on the growth and specialization of knowledge. Potential models are suggested which could form attractive theoretical further lines of enquiry.

Introduction

Debates rage about the nature of the scholarly communication system and its future. Some observers perceive it as a static system acted upon by one or more of the parties in the information chain (academics, publishers, librarians, vendors, government funders, etc.), while others see it as a self-organizing system with characteristics to which the parties have to respond as much as follow.

The numbers of STM journals in the system and their overall growth characteristics have been matters of comment for some considerable time. The well-known early studies in this area were published by *de Solla Price*.[1] The problems of defining exactly what constitutes a scientific journal have led to broadly-defined and seemingly very large estimates.[1–3] Others have argued for some time that taking a broad purview results in misleading notions about scholarly journals.[4] One earlier study[5] to improve on estimates of scholarly and scientific literature growth concedes the limitations of source material available then, particularly Ulrich's periodicals directory. Recent improvements and introduction of a new classification scheme in Ulrich's international periodicals directory allow for more realistic estimates. Anecdotally, within particular specialities, the introduction of new journals has been explained as a response to changes in science. We believe that this has not hitherto been systematically studied.

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This paper reports an analysis of journal growth characteristics at the micro level in terms of the rise and fall of journal titles in specific fields, and also the macro-level behaviour in terms of overall journal growth throughout the whole of the 20th century.

Data sources and methodology

The micro-level or subject specific studies examined the response of the journal system to changes in the number of research papers in two areas: superconducting materials and plate tectonics. These two fields were chosen because key papers or discoveries that lead to a change in interest in these areas could be identified. Furthermore, the "languages" of these subjects are reasonably precise for relevant papers to be identified readily. The macro-level study examined growth characteristics of scholarly journals (or serials) overall. Data sources for these studies are summarised in the table below:

Study	No of Articles	No of Journals	No of Researchers	R&D Funding
Superconducting Materials	INSPEC	INSPEC	na	na
Plate Tectonics	GeoRef	GeoRef	na	na
Overall Journal Growth	ISI*	Ulrich's	NSF**	NSF

*ISI – Institute for Scientific Information; ** NSF – National Science Foundation

Superconducting materials

Data for the study in the field of superconducting materials comes from INSPEC (the Database for Physics, Electronics and Computing) published by the Institution of Electrical Engineers. The INSPEC database corresponds to the print publications *Physics Abstracts*, *Electrical and Electronics Abstracts*, and *Computer and Control Abstracts* which cover 4,100 journals and serials, of which 750 are abstracted cover-to-cover.

The INSPEC database was accessed via Dialog, an online host. Articles on superconducting materials were identified by using INSPEC classification codes for this area.

The two main classification codes (A7470 and B3220) and their constituents correspond to the following terms:

superconducting materials
elemental superconductors
superconducting A15 compounds and alloys
superconducting interstitial compounds and alloys
chevrel phase (ternary molybdenum chalcogenide) superconductors
magnetic superconductors
superconducting layer structures and intercalation compounds
organic superconductors
amorphous, highly disordered, and granular superconductors
laves phase (C15) superconductors
superconducting metastable nonstoichiometric phases
heavy-fermion superconductors
perovskite phase superconductors
fullerene superconductors
other superconducting materials

The total number of articles corresponding to this classification scheme was determined for each year (using publication year) in a range around the introduction of the key scientific discovery for that field. A ranked list of journals was produced for each year of data using the "Rank" facility in the Dialog system. (Note: some databases, including INSPEC, hold both full and abbreviated forms of journal titles. Ranking on Dialog can lead to a duplicated list containing both forms and these need to be de-duplicated.) Using a de-duplicated list for each publication year, the number of journals containing: (1) any article with this classification, (2) between than twenty and forty-nine articles per annum, and (3) fifty or more per annum, were also calculated.

Plate tectonics

Data for the study of the field of plate tectonics comes from GeoRef, the database of the American Geological Institute (AGI), which covers the technical literature on geology and geophysics globally. GeoRef corresponds to the print publications:

Bibliography and Index of North American Geology, *Bibliography of Theses in Geology*, *Geophysical Abstracts*, *Bibliography and Index of Geology Exclusive of North America*, and the *Bibliography and Index of Geology*. For the plate tectonics study the following keywords were used to identify relevant papers:

plate tectonics
sea-floor spreading
tectonophysics
geotectonics
subduction zone(s)
continental drift
plate collision

The number of articles per annum and a ranked list and count of journals were determined using the same approach as described above for superconducting materials.

Overall journal growth

Data for the main study on journal growth over the 20th century is taken from *Ulrich's International Periodicals Directory* on CD-ROM (Summer 1999 update).[6] Using the "year first published" field in Ulrich's, data was extracted on the cumulated number of serials for each year (i.e., first published in or prior to any given year) from 1900 to 1996. Years after 1996 were not included in the analysis because of time lag in Ulrich's updating for recently launched journals. The data were put into groups according to Ulrich's classifications as follow:

"All" serials (i.e., no filter applied)
"Academic/Scholarly" serials (hereinafter referred to as "Academic" journals)
"Refereed, Academic/Scholarly" serials (or "Refereed, Academic" journals)
"Active, Refereed, Academic/Scholarly" serials (or "Active, Refereed, Academic" journals)

The classification "Academic/Scholarly" is one of Ulrich's *media type* terms; "Refereed" is an Ulrich's *special index* term; and "active" is a *status* term that identifies if a journal was still active at the time of the last database update (summer 1999 in this case). Two further groups were calculated from the above classifications: all "Non-academic" journals ("All" – "Academic" journals) and all "Unrefereed, Academic" journals ("Academic" – "Refereed, Academic" journals).

In addition to journal growth, data on the research community (number of R&D workers and R&D funding) were obtained from the National Science Foundation *Science and Engineering Indicators 2000*,[7] while data on the number articles world wide is taken from ISI data sources (a composite data-set, representing all journals covered by ISI).

Results

Specific field studies

1. Superconducting materials. The results for the study of superconducting materials are plotted in Figure 1. The left y-axis shows the number of articles, the right y-axis the number of journals for the time period 1975 to 1998. Prior to 1986 the number of articles published was below 1000 per annum and these were spread around about 100 different journal titles. From 1986 both the number of articles and the number of journals grows rapidly, with the number of articles peaking in 1991 at over 7000 and the number of journals peaking in 1990 at about 350 titles. Prior to 1986 the articles were fairly evenly spread among the journals, as the lines for the number of journals publishing 20–49 articles per annum and ≥50 articles per annum show, the former representing about 10 titles and the latter one or two of the 100–110 total. After 1986 the number of journals publishing 20–49 and ≥50 both rise (as does the total population of journals), with the 20–49 category peaking in 1988 at about 40, and the ≥50 category peaking two years later in 1990 at about 30. Following its 1988 peak, the 20–49 category declines immediately thereafter to about 25 in 1998. The ≥50 category, after its peak in 1990 declines rapidly to about 10–15.

Given that the average journal publishes about 100 papers per annum, this behaviour can be interpreted as follows. Prior to 1986, superconductivity research was spread over about 100 more general journals, with ten of these having sections on superconductivity (the 20–49 category, i.e., 20–40% of the average journal) and a couple probably being specialized superconductivity journals (the ≥50 category, i.e., 50% or more of the average journal). In 1986 *Bednorz* and *Muller*[8] announced the discovery of high temperature superconductivity, which eventually won them the Nobel Prize for Physics.

Interest in the field surged following this paper, as the steep growth in papers and journals from 1986–1990/1 shows. Initially, the existing journals published more papers, then a wider list of physics and materials science titles got into the act, each contributing to the overall totals. From 1987, the journals publishing sections on the topic (the 20–49 category) grew as the publishing system sought to concentrate knowledge into a few key places in response to author and reader demands. A similar development occurred with the specialized journals (the ≥50 category), with new titles appearing from 1987–1990. With the relative decline in research interest following a peak in 1991, the number of specialized titles (the ≥50 category) starts to decline, followed by the specialized sections (the 20–49 category) and to a lesser extent the wider range of journals that published a couple of papers per annum.

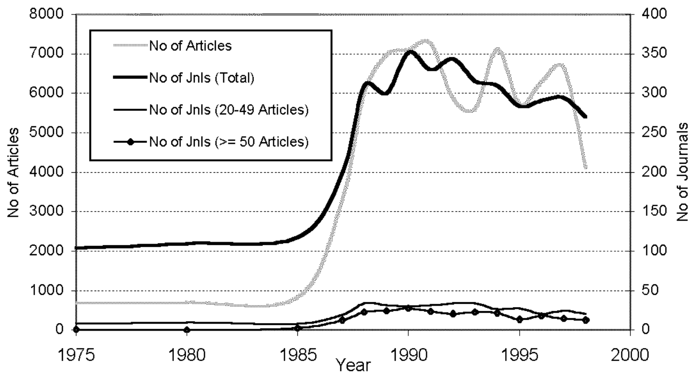

Figure 1. Superconducting materials articles and journals, 1975–1998

2. Plate Tectonics. A very similar picture can be seen in the field of plate tectonics, where the results are plotted in Figure 2 for the period 1940 to 1998. Here the key event occurs in 1964, when the number of papers and journals discussing continental drift and the plate tectonic theories rises from barely 100 papers per annum in a handful of titles, to a peak of over 3500 papers in 1980, and just under 450 journals in 1984. As in the previous case, the growth in journals publishing these papers as probably a section (the 20+ papers per annum category) precedes the probably specialized title launches (the 50+ category), the former peaking at 40 in 1982, and the specialized titles at just under 10. Following the relative decline of interest in the area after 1980, the total number of journals show a sharp decline from 450 to 250, while the sections and specialized titles also show less marked declines.

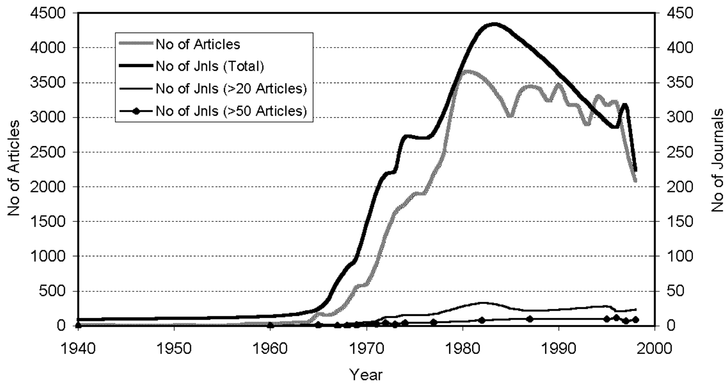

Figure 2. Plate tectonics articles and journals, 1940–1998

The ideas of continental drift were first proposed by *Wegner*[9] in 1912, but met with little support because there was no mechanism known. The revival of the idea in the 1960s followed the announcement of deep-sea spreading from the oceanic ridges and the first surveys of the topography of the sea floor.[10,11] A series of workshops, especially one Royal Society event in the later 1960s acted as the spur to research interest in this case. Once again the data shows the response by the journal system in geology was dramatic, with virtually all the titles in the field wanting to publish something about the hot new topic, the concentration of papers into a few specialized sections and then new specialized journals.

Interestingly, the article growth curves in both subject specific studies show the tell-tale oscillations described by *de Solla Price*[1] as an outcome of logistic growth curves reaching ceiling conditions.

Overall journal (serial) growth characteristics over the 20th century

Data from Ulrich's periodicals database on CD-ROM for various classifications of periodicals over the range 1900 to 1996 are plotted in Figure 3. Here the growth characteristics of all "non-academic" journals, all "unrefereed, academic" journals and all "refereed, academic" journals are compared , with the first on the right *y*-axis scale, the latter two on the left. The "non-academic" and "unrefereed, academic" journals curves show a familial relationship not displayed by the "refereed, academic" journals line. The "true" number of scientific journals which represent the formal communication channels of science has been often inflated,[2,3] partly because of defining what constitutes a scientific journal.[4] Further review of this area, including other estimates of scientific journal numbers, is provided by *Tenopir* and *King*.[14] We believe that examination of "refereed, academic" journals, now possible with the Ulrich's database, reveals a different and better picture of the size and dynamics of the global journal system supporting formal scholarly communication.

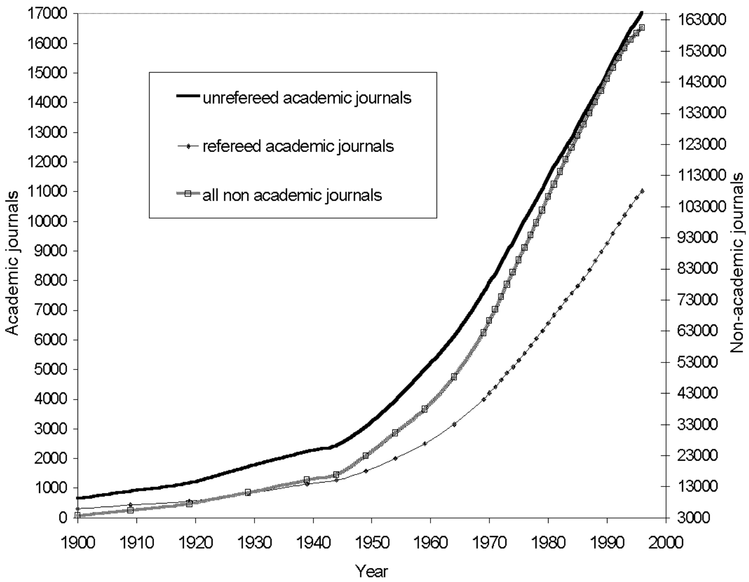

Figure 3. Academic and non-academic journal growth (data from: Ulrich's)

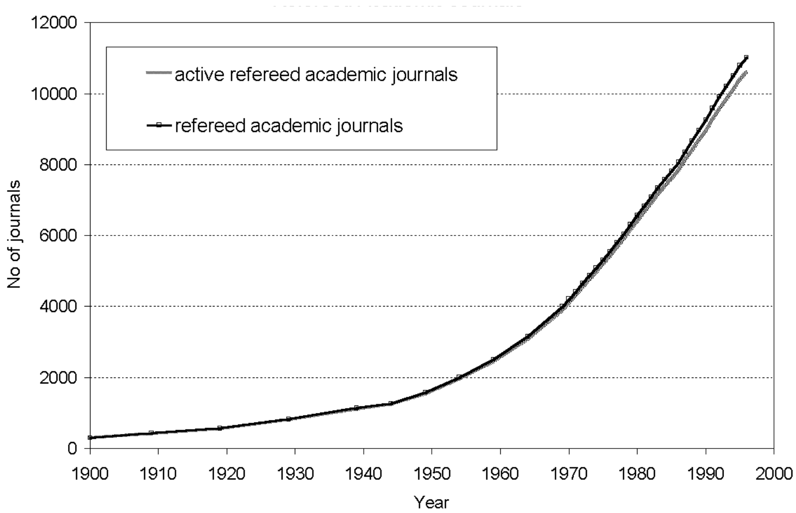

Figure 4. Growth in refereed, academic journals

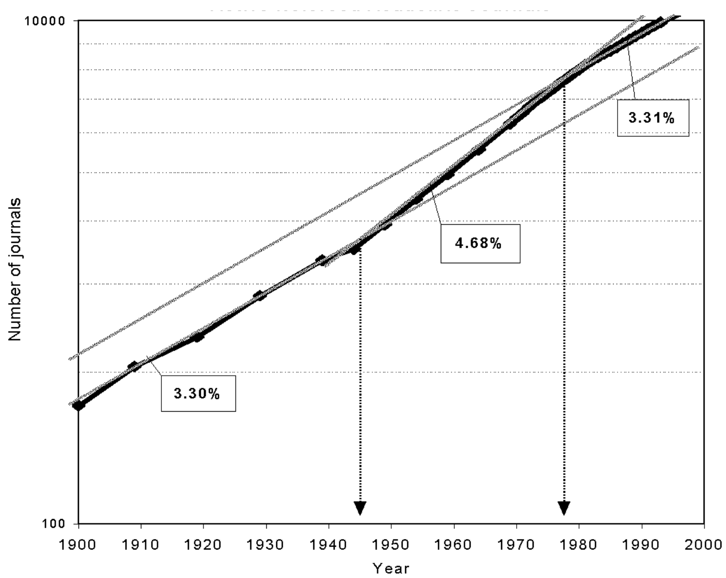

Figure 5. Growth characteristics of active refereed academic journals over the 20th century

Figure 4 looks at the "refereed, academic" journal data in more detail by also showing those journals that were still active in 1999 ("active, refereed, academic" journals). Although the two sets of data differ, the amount and the generalized shape of the curves are very similar.

Concentrating on the "active, refereed, academic" journals data and plotting this on a logarithmic scale against time, reveals the underlying structure of Figure 5. The data shows three straight-line episodes, from 1900 to 1944, from 1944 to 1978, and from 1978 to 1996. Best-fit lines for these three episodes have gradients that correspond to compound annual growth rates for each episode of 3.30%, 4.68% and 3.31%, respectively. *Archibald* and *Line*[5] reported a similar overall pattern in article growth post 1950 in their study based on samples of journals.

Discussion

Specific field studies

The two cases studied show the dynamic nature of the journal system at the level of a research sub-discipline. The areas chosen for study were those in which a major discovery had been made that went on to change the nature of those fields. Clear cut cases, which can be revealed by the methodology of key word searching, are quite difficult to identify, but the clear similarity in the response of the systems under study in this paper is suggestive of a general phenomenon. One of the authors of this paper witnessed the changes that took place in the field of superconductivity during 1986-1998: the discovery of high-temperature superconductivity in ceramic metal oxides by *Bednorz* and *Muller*[8] stimulated huge research interest, both theoretically and because of potential commercial exploitation. Large numbers of researchers from all parts of condensed matter science moved into the area; the researcher flows were then mirrored by the paper flows and journal changes seen in the study.

The plate tectonic example is very similar. Here, new experimental evidence[10,11] in the 1960s revived interest in a long overlooked theory (*Wegner*'s 1912 theory of continental drift),[9] which culminated in the creation of the modern theory which explains such disparate phenomena as mountain building, deep-sea ridge spreading, continental drift, volcanism and earthquake activity. Once again, researcher flows lead to paper flows, which in their turn lead to journal realignments.

The general phenomenon in both cases can be described as follows. There is an initial system response to the perturbation of a key research event:

(i) as paper flows increase journals strive to attract those papers by invitation, special issues and aims and scope shifts. The papers are spread around a large number of titles

(ii) demands among the research community for information to be collected together rather than spread apart, leads to existing journals creating specialized sections to concentrate the "hot" topic papers

(iii) if the research boom continues, these sections are either spun off as new journal titles or entirely new stand-alone titles are launched to satisfy researcher demands.

Inevitably booms peter out. As the paper flow starts to decline the system responds again. This time, if the decline in paper flows is significant, the new specialized journal titles are closed or merged back into long-standing titles. If the decline continues, the specialized sections are then jettisoned as the system further relaxes back to its pre-major discovery state. If the discovery was truly ground breaking, of course, the system never fully returns to the pre-discovery position. However, viewed from a systemic perspective, the journal system is highly dynamic to world events, responding to change with both expansion and decline.

Journal growth characteristics over the 20th century

The behaviour of journal growth over the 20th century has some intriguing characteristics. Not only does the century split into three separate growth episodes, but also the first and the third appear to have identical rates. It is quite possible this is an artefact of the way Ulrich's collect and analyse data. It may simply be a coincidence or a simple outcome of macroeconomic factors. More work needs to be done to establish whether these simple explanations can account for the results. However, the return to the same growth rate in the last episode (1978–1996) as the first (1900–1944) and the uniqueness of the refereed journal data over all other journal types in Ulrich's is highly suggestive of more systematic features.

This type of growth pattern is reminiscent of an ecosystem in equilibrium with a standard growth rate, which is perturbed when higher levels of nutrient are added. The growth rate of the system expands to consume the excess nutrient, returning to its earlier levels when the excess has been fully consumed and equilibrium re-established. This analogy seems apt if we consider the background to events during the period covered by the study.

The period 1900–1944 represents what we might call small-scale "innocent" science, a period where little funding is available for science from governments and growth is almost entirely driven by the collective behaviour of the disciplines themselves. For this period the journal system is almost entirely in the hands of the scientific societies.

The years 1944–1978 are *de Solla Price*'s "Big Science". Science had "won" the war, it could now "win" the peace and the Cold War. All over the world, governments threw as much funding as possible into the advancement of science and technology. This is the period of the maximum expansion of nuclear weapons technology, the space race and the NASA moon landings. We might expect science under these conditions to be growing at its maximum rate. For this period the journals system is moving from a largely society driven one to a mixed commercial and society marketplace.

The final phase may be thought of as "scape-goat" science: a time when the failure of science investments to yield the overambitious expectations of the previous era result in disappointment, disillusionment and scepticism. Public perception of the oil crisis of the 1970s, increasing awareness of potential ecological disaster, the turning away from nuclear technology and weapons in the 1980s, lead to a relative diminution of government support. The journal system continues in mixed market ownership and the period sees the greatest retrenchments in library journal collections of the century. Yet overall, journal growth continues at a constant rate for the whole episode, although back at its pre-1944 values.

For this latter period at least there are other data that can shed a little light on the problem. The National Science Foundation's *Science and Engineering Indicators 2000*[7] show a 3.2% annual growth in research and development manpower for a selection of six countries in total over the period 1981 to 1995. Data for the rest of the world is hard to obtain, but a figure of around 3%–3.5% is not unlikely for the world as a whole. Interestingly, article growth in ISI databases has also been estimated at 3.5% in recent years (see Figure 6a below).

General causation

The data collected and displayed in Figure 6a offer the best explanation for most of the phenomena observed in this paper. Using the value of each series in 1981 as an index point of 1.00, the relative change of research and development manpower, the number of peer reviewed academic journals and numbers of articles can be compared from 1981 to 1995. Although R&D manpower information given here is for selected countries only (USA, Canada, Japan, France, UK and Italy, the countries for which consistent data is available in the NSF's Science & Engineering Indicators), we believe that these represent a reasonable sample for evaluating world-wide changes. For this period at least, the connection between journal title growth and researcher numbers growth is unmistakable. Are, however, the changes in journal numbers simply a reflection of R&D funding? Global R&D funding data is not readily available to compare directly with global journal numbers. However, comparing US R&D funding with US R&D manpower (Figure 6b) suggests that even if global R&D data for several years were available, the correlation between R&D funding and refereed academic journals is likely to be weaker (or indirect) than that between journals and R&D scientists. It may therefore reasonably be supposed that the effects noted in the results in this paper can be attributed to movement of researchers between subspecialty areas and growth in their total number. That the growth in the number of articles (and hence journals) appears to be a product of growth in the number of research scientists has been noted by others.[2,12] However, reliable data on number of R&D scientists are not available for the two earlier periods (1900–1944 and 1944–1978) either side of the second world war to confirm if this is a fundamental relationship or a relatively recent phenomenon.

Overall figures indicate that an increase of about 100 refereed papers per year world-wide results in the launch of a new journal. Given that the ratio of unique authors to papers annually ranges from 1.1 to 0.8 for the period under consideration,[13] and allowing for rejections of papers, this suggests a growth in the potential annual author community of about 100–150 per annum for each new journal. Recent studies[13,14] suggest that the whole reader community may be up to four times larger than the core annual author community. In this case, the potential new reader community being served by the new journal would be about 400–600, the size of a typical specialized international workshop or conference or sub-section of a learned society.

New titles will be the outcome of several factors: the growth of fields versus the decline of others as well as the overall growth rates of scientists. Connecting the journal growth rates with other sociological phenomena will be difficult but not impossible. Potentially, a surface tension or bubble formation model could be used. Here, the growth in new titles is the outcome of attractive fusion forces ("going with the crowd" or peer pressure, and the advantages of social interaction) making subject specific social groupings grow in number, versus the repulsive, fissile forces (impersonality, clique formation and unwieldy size) tending to split large existing groupings apart. Give the tendency of each grouping to have a journal, the journal growth characteristics can be modelled in terms of the average number of these groupings at any one time.

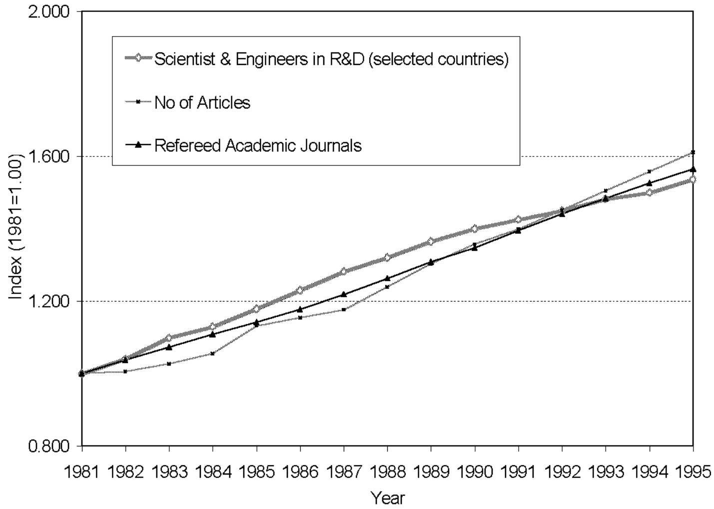

Figure 6a. Growth in R&D workers, articles and refereed academic journals

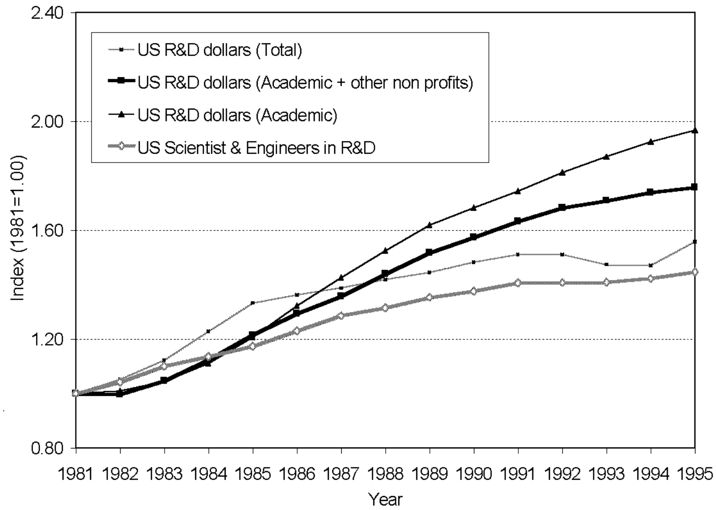

Figure 6b. Growth in US R&D funding and R&D workers

Do changes in information technology affect this dynamic? Some[15] argue that the new technologies will free scholarly communications from the ‘papyrocentric’ stronghold of scholarly journals. This, we believe, confuses the value and purpose of the scholarly journal with the medium it is available on. New information technologies may indeed affect usage behaviour and increase informal communication of preliminary or supplementary work.[16] However, the basic functions of a journal – formal, public and permanent recording of scholarly work – are technology independent. Uhlrich’s periodicals directory does not discriminate between electronic and print in classifying periodicals as “academic/scholarly” and “refereed”. Predictions of paradigm shifts abound but evidence so far suggests that the basic dynamic of scholarly journals (or similar information packages) reflecting science and scientists is likely to remain unaffected by the new information technologies other than in a mechanical sense.

Conclusions

The results presented here for journal dynamics at both the micro and macro levels show that journal development clearly follows researcher behaviour and growth characteristics. At the subject discipline level, the journal system is highly responsive to research events. Overall journal growth characteristics clearly show the predominance of 3.3% compound annual growth under a number of different socio-political climates. The data is highly suggestive that this represents a lower limit to journal growth rates and that this growth is the outcome of a self-organizing information system that reflects on the growth and specialization of knowledge. Potential models (the ecological or bubble-formation models) have been suggested which could form attractive theoretical further lines of enquiry.

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