Scientometrics (2010) 84:391–401
DOI 10.1007/s11192-009-0119-6

Transition to postmodern science—related scientometric data

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Received: 26 July 2009 / Published online: 11 December 2009

Abstract A change in scientific developments in recent decades is widely proclaimed which may be associated with terms like postmodern science or steady state science. This change is usually discussed from a more epistemological viewpoint. In order to enhance the understanding of the underlying key factors, bibliometric, demographic and Nobel Prize recipient data spanning of the last hundred years are considered and analyzed. It is found that in general the considered data point to a quasi-steady state in bibliometric developments of highly developed countries. For emerging countries, such a steady state is not yet attained; therefore, the research output in scientific journal articles is still expected to rise considerably. Consequences and interpretations of an ever growing research output in relation to the increasing age of Nobel Prize recipients are discussed and conclusions are drawn from the considered data.

Keywords Biblometrics · Demography · Innovation · Steady state science · Postmodern science

Introduction

In the arts and humanities, the term postmodernity is widely used and accepted, but its meaning is quite diluted, as it is used to describe many different aspects of the last few decades beginning with the 1970s. The term postmodernism is also applied to the sciences

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(e.g. Horgan 2004; Forman 2007) for by and large the same time period. As in the arts, discussions about postmodernism the sciences are usually characterized and conveyed by epistemological considerations which renders the discussions rather diffuse and intangible. In order to have a clearer characterization of postmodern science (which also includes other applied terms like 'Steady State Science' Ziman (1994) or even the polemic expression 'End of Science' used by Horgan (2004)) and enhance the understanding of the underlying key factors, quantitative data would clearly be of advantage. To this aim, the evaluation of bibliometric and demographic data could be applied.

De Solla Price (1961, 1963) is widely credited as one of the early researchers to have initiated and established the analysis of such data (Godin 2006). De Solla Price considered various quantitative data sets (1963) to monitor scientific knowledge and its growth. From data in the years between 1900 and 1960, he concluded that scientific literature increased exponentially by an annual rate of about 5% which corresponds to a doubling of the scientific publications every 15 years. To sustain such growth, there has to be a corresponding growth in manpower. De Solla Price pointed out that up to about 1960 in the United States the growth of the annually awarded doctorates in science and engineering is exponential and increases faster than the overall population. Clearly such exponential growth cannot be sustained for many decades (otherwise the number of doctorates would approach the total population which would not be sustainable). De Solla Price further predicted that the annual growth rate will gradually diminish, saturate, and approach an upper limit, see Fig. 1. As an upper limit of scientific manpower is reached in the United States, de Solla Price predicted a decline in the growth of research output. Therefore, Fig. 1 represents not only the prediction with respect to scientists and researchers but also in their bibliometric output in published research articles.

Although de Solla Price's conclusion of a decline in the growth of annual scientific output approaching a saturation limit is quite plausible, there is uncertainty concerning the state of scientific output at that time of his prediction in 1961. The predictions of de Solla Price are often referred to in historic and also epistemological considerations (e.g. Lyotard 1984; Ziman 1994; Goonatilake 1999; Rip 2004; Forman 2007—just to name a few). It would be helpful to assess the actual data between 1900 and recent years for an understanding of the interrelationships of current and future developments often associated with steady-state and postmodern science. From the de Solla Price viewpoint, the era of

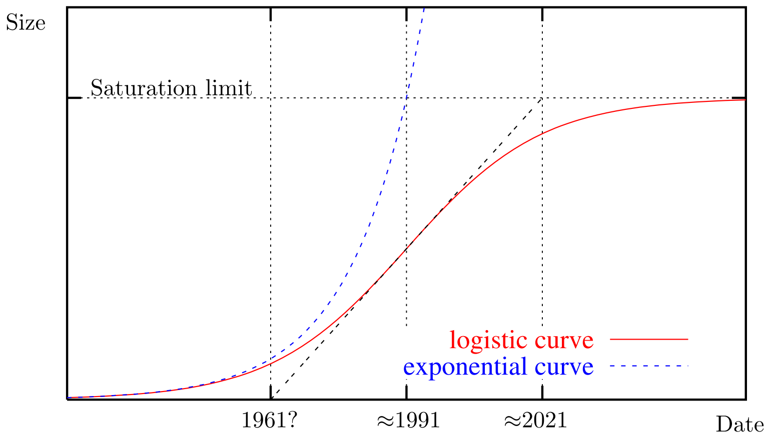

Fig. 1 General form of the logistic curve (de Solla Price 1961)

postmodernity probably just started to emerge in the 1960s, when de Solla Price already foresaw an increasing dilution of the contents of scientific articles which can be related to now common slogans as 'least publishable unit' (Abraham 2000), 'publish or perish', other trends like hyperauthorship (Cronin 2001). As de Solla Price already elaborated (de Solla Price 1961) the number of publications is quite limited for monitoring the actual growth in scientific knowledge. Scientific knowledge however is difficult to quantify and therefore, in spite of its shortcomings, demographic and bibliometric data spanning over the last hundred years will be presented and discussed. To compare and relate these demographic and bibliometric data to the advances in the sciences, additional data on the age of Nobel Prize recipients is considered thereafter.

Demographic and bibliometric data

The annual doctorate degrees awarded in the United States and the number of scientific journal articles over the last one hundred years shall be discussed in the following. The annually granted doctorate degrees have been illustrated in Fig. 2, where the ordinate is given in logarithmic scale. Three major events can be depicted from this figure: the short term effect of the world wars and a significant flattening of the growth in the 1970s. While the effect of the world wars is quite intuitive the diminishing growth in the early 1970s is worth reflecting on in more detail.

The growth in doctorate degrees approximated 7% in the first three quarters of the 20th century and then declined in the early 1970's. Prior to this 1970's decline in the growth of granted doctorate degrees, the growth rate actually peaked at about a 9% annual increase in the period of 1957–1973. The strong growth in the number of degrees awarded can be seen as a result of a strong increase in the research and development (R&D) expenditures between 1953 and 1969 fueled by public and government reaction to the launching of the

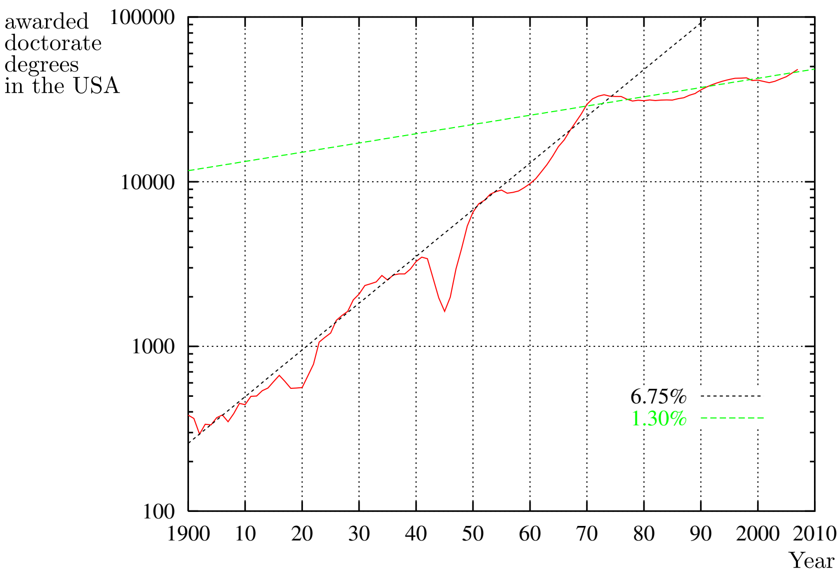

Fig. 2 Annual number of doctorates awarded in the United States. *Sources*: Thurgood et al. (2006) (1900–1998) and Falkenheim and Fiegener (2007) (1999–2007)

Soviet satellite Sputnik in 1957 (Thurgood et al. 2006). Cutbacks in R&D funding began as the moon landing was achieved and the Vietnam War and the 1973 economic recession weighed on the U.S. federal budget. During the late 1960's and early 1970's, the academic labor market became saturated in most fields, and there was a concern about an over-production of Ph.D.s. In spite of a defense buildup and gains in R&D spending in the 1980s, the growth in granted Ph.D. degrees declined to below 1.5%, which is about the growth of the overall population of the United States over the last decades (see, e.g., Carter et al. 2006). Similar tendencies related to the number of faculty members have been observed in Germany (Kölbel 2002).

The two world wars and the change in the 1970s can also be depicted in the annual number of published articles in medical fields, natural sciences, and engineering worldwide from 1900 to 2004 represented in Fig. 3. Figure 3 was extracted from a publication by Lariviere et al. (2008) where the authors used data from the publisher Thomson Scientific (the publisher of Science Citation Index and Web of Science) that does not include articles from humanities or social sciences (see Lariviere et al. (2008) for their discussion of their data source). Data between 1900 and 1944 are drawn from Thomson Scientific's Century of Science covering most natural sciences and medical fields. From 1945 to 1979, data are from natural sciences, engineering, and medical journals covered in Web of Science, and from 1980 to 2004, data are from the Science Citation Index. These changes in the sources are at least partly the reason for the change in the approximate slopes shown in 3 before and after 1945. Thompson Scientific has been established in the U.S., and although their coverage is international, there is a bias towards publications in the English language (Carpenter and Narin 1981; Phelan 1999) which results in an underrepresentation of the numbers of published articles and their growth prior to 1945. After the Second World War, English gradually became the dominant language of scientific publications, and this underrepresentation of foreign language articles diminishes. Because scientists of non-English speaking countries have gradually published more in English language journals, language could be one reason for the increased growth rate in

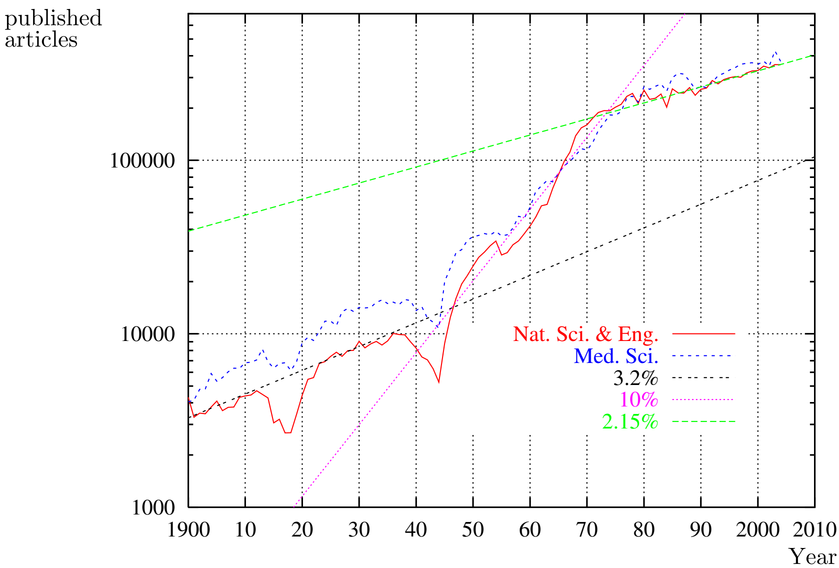

Fig. 3 Annual number of articles for medical fields and natural sciences and engineering, data from Lariviere et al. (2008)

scientific publishing between 1945 and 1975 compared to the growth in awarded doctorate degrees of Fig. 2. Linear increase rates for the Netherlands and the Scandinavian countries during the 1980s and for Japan, Italy, and Spain during the 1990s are related to ongoing tendencies to publish increasingly in English instead of their native languages (Leydesdorff and Zhou 2005). The language used for publication is still a factor today if the assessment of the scientific productivity of a non-English speaking nation is primarily performed on the basis of bibliometric data, as most international scientific journals are now published in English (Vasconcelos et al. 2009). Overall, however, it is arguably safe to claim that English has established itself as the official language in scientific publication and significant effects on the curves of Fig. 3 are unlikely.

With all these considerations, the change in the slope in Fig. 3 before and after 1945 will not adequately represent the growth rates in published articles. However, the change in the slope around 1973 has been found even when considering different data sets. Archibald and Line (1991) studied a sample of 190 journals that started life in or before 1950. Their analysis also showed a rapid growth in scientific publications up to 1970, a much slower growth between 1976 and 1980, and a slower growth or decline after 1980 which would also be in agreement with the number of awarded doctorate degrees of Fig. 2.

Although Figs. 2 and 3 indicate a correlation between the annual number of doctorates in the United States and the annual worldwide output of scientific articles, the rate of growth in article output is still higher than the rate of the U.S. awarded doctorate degrees starting about 1970. This increase in the article output, however, can be contributed mostly to growth in article output in China, India, and other emerging countries, like South Korea and Malaysia, see Fig. 4. The growth of scientific and technical articles in peer reviewed journals illustrated in Fig. 4 shows a slight increase in the output of U.S. based authors between 1995 and 2005 which corresponds to the slight increase in awarded doctoral degrees in Fig. 2. The average growth rates of scientific output in science and engineering

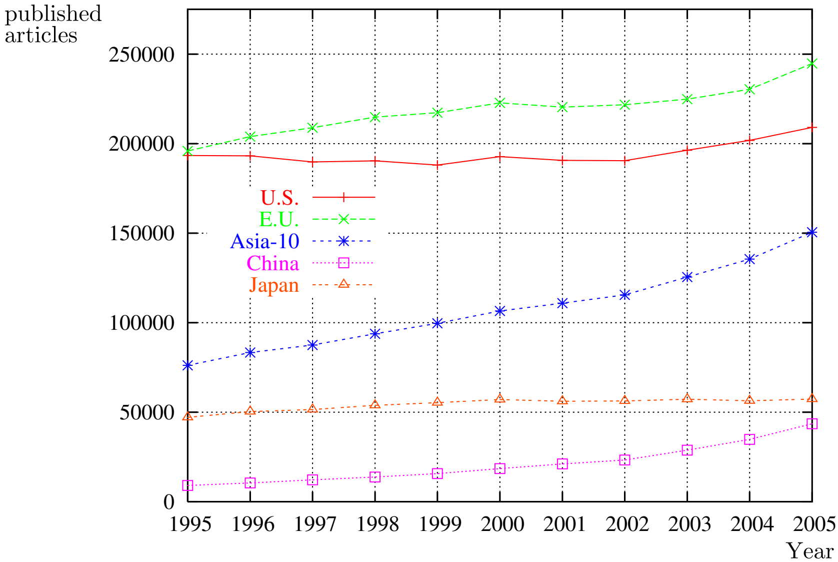

Fig. 4 Scientific and technical articles in peer reviewed journals. Asia-10 includes China, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand. China includes Hong Kong. (data from Science and Engineering Indicators 2008)

Table 1 Growth in science & engineering article output, by major publishing region or country/economy: 1988-2003. East Asia includes: China, Singapore, South Korea, and Taiwan (data from Science and Engineering Indicators 2006)

Average annual increase in %	1988–1995	1996–2003
France	5.3	1.3
United Kingdom	3.7	0.7
United States	2.0	0.6
Japan	4.8	3.0
East Asia	15.0	14.3

fields of highly developed and emerging East Asian countries are given in Table 1 showing that there is a considerable decline in the growth rate in western nations between the two periods 1988–1995 and 1996–2003, a moderate decline in Japan, and strong growth—and no decline—in the emerging East Asian countries of China, Singapore, South Korea, and Taiwan (see also Heylin (2004) or Leydesdorff and Wagner (2009) and the references therein). The East Asian growth rate of 15% corresponds to a doubling rate of merely 5 years and will not be sustainable for many years. Although there is still a considerable increase in Ph.D. degrees awarded in relatively highly developed countries like South Korea, there is already in those countries the perception of an over-production of Ph.D.s, just like in the U.S. during the late sixties. Data on doctoral degrees awarded in those relatively highly developed countries are showing corresponding non-exponential growth (Leydesdorff and Zhou 2005).

The European Union has increased its output of scientific articles in recent years (in Fig. 4). This increase can be related to the fact that the E.U. has included several new nations with strong economic growth with corresponding growth in higher education (see Leydesdorff and Wagner 2009). Older and highly developed E.U. members, such as France and the United Kingdom (see Table 1), share the same decrease in the average annual growth of scientific literature as the United States.

The annual number of awarded doctorate degrees in the United States (Fig. 2) and the number of published articles (Figs. 3, 4 and Table 1) from U.S. authors would indicate the U.S. and other highly developed countries are already very close to the saturation limit predicted by de Solla Price (Fig. 1). The slight increase in the annual number of published articles and awarded doctorate degrees may be due to the increase of the total population in the U.S. which would yield the projection that only little growth in published articles and awarded doctorate degrees could be expected and that this annual growth is proportional to the annual growth in the total population. It should be noted that exponential growth can be a good description for some research areas over different periods of time Fernandez-Cano et al. (2004). Depending on the research area, other than exponential expressions may describe the growth more accurately.

Among others, de Solla Price (1961) has noted that the growth in the number of scientific publications is not a good measure of the actual growth in scientific knowledge due to evolving publication standards, demographics, and publication practices, for example the aforementioned descriptive terms describing aspects of scientific publishing: 'least publishable unit', 'publish or perish', and 'hyperauthorship'. Different concepts for estimates of the actual growth in scientific knowledge are discussed in Tague et al. (1981) where it has been found that for a specific area the growth in knowledge was rather constant after 1970 while the annual number of publications was rapidly increasing. Therefore, it is important to relate this growing publication rate to other indicators which will be discussed in the following sections.

Demographics of Nobel Prize recipients

Another set of data over the last century and beyond is also available which in contrast to the number of published articles and awarded doctorate degrees is quite exclusively limited to the forefront in the sciences. The Nobel Prize is awarded for originality and innovation in different fields and will here be considered and related to the demographic and bibliometric data above. While the achievements of the Nobel Prize laureates can hardly be quantified, the age of the laureates and other demographic trends of this restricted population can be quantitatively analyzed. In Figs. 5 and 6, the age of the laureates in the disciplines physics, chemistry, and medicine/physiology is illustrated over the last 100+ years. Fig. 5 shows the age of each laureate, and Fig. 6 shows the ages averaged over 5 year periods. There are several features of the recipients that shall be pointed out here:

(i) the age of Nobel Prize recipients at the time of their award is trending upward from about 1950 to the present, illustrated in Figs. 5 and 6,

(ii) an increasing number of Nobel Prizes shared by three laureates—the maximal number of recipients in a field—after about 1950 which has been determined by Zhang and Fuller (1998) for the recipients in physics and which may be a little difficult to depict from Fig. 5, but it can be clearly be seen that the density of points after about 1950 is much higher than before 1940 (there were no awards in some years during the world wars).

That the age of Nobel Prize recipients at the time of the award is increasing can be interpreted in two ways: (a) either the recipients achieved their discoveries and findings at an earlier life period and are awarded the Nobel Prize after increasingly longer time periods which would apply at least for physics (Karazija and Momkauskaita 2004) or (b) the discoveries and findings were achieved at an advanced age, which would point to a requirement for longer education and greater experience to achieve important findings and discoveries.

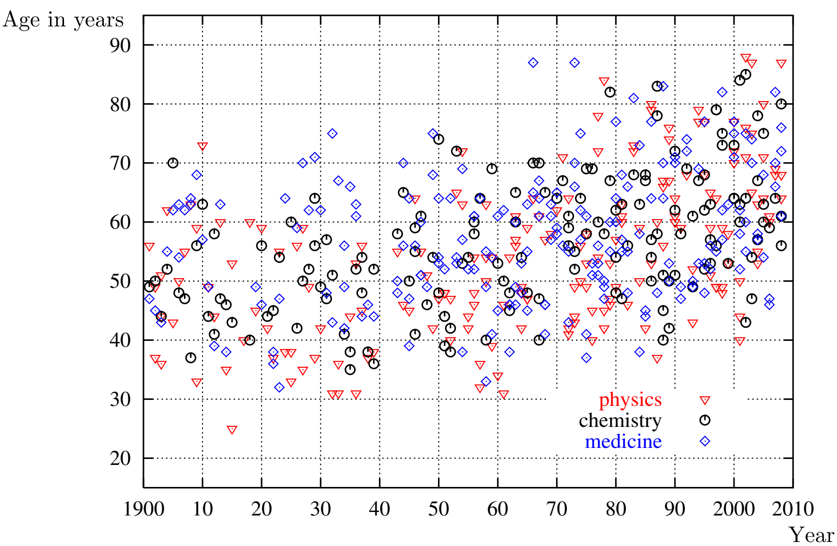

Fig. 5 Age of physics, chemistry and physiology/medicine Noble Prize laureates at awarded year. Data deduced from http://www.nobelprize.org/

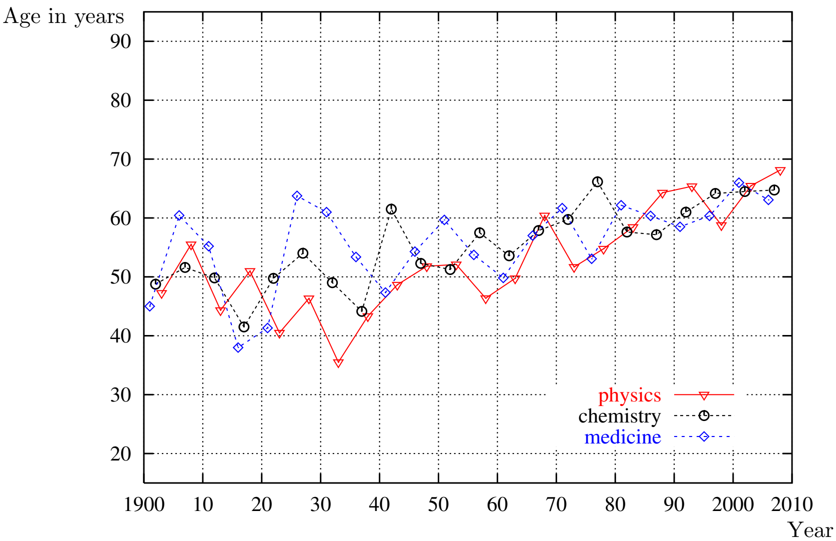

Fig. 6 Average age of physics, chemistry and physiology/medicine Noble Prize laureates at awarded year. Data deduced from http://www.nobelprize.org/

Discussions

The decreasing rate of growth in the annual number of published articles and awarded doctorate degrees in the U.S. and other western nations indicates that these nations are actually close to the growth limit predicted by de Solla Price (Fig. 1). In the U.S., it may be surprising that in spite of increasing research funds (Fig. 7) and slightly increasing manpower in form of Ph.D. students (Fig. 2), a corresponding increase in scientific research articles has not been generated and that the growth rate in this output has actually decreased (Table 1). That the output in scientific articles stays rather flat while the input in expenditures and Ph.D. students is increased may indicate that science in the U.S. as a whole has in fact entered or is close to entering an era of diminishing returns. Because of the competitive nature of research fund allocation and scientific publication, simpler, less expensive, less time consuming research will generally be performed first by scientists. Correspondingly, scientific projects will, on average, be more costly and time consuming in the future.

Concerning the sudden change in growth that can be depicted in Fig. 2 in the beginning of the 1970s it should be noted that real wages have peaked in the United States around the same time (Harvey 1990, p. 131; Carter et al. 2006). The first major post war recession of 1973 may be seen as the cause of this sudden change. Clearly the more or less sudden change in the growth rate of averaged wages and earned doctorates will be somehow related to the recession of 1973. That real averaged wages declined and earned doctorates did not increase since 1973 points to semi-permanent socio-demographic and economic changes. The causes of these changes will be arguably interrelated. The upper limit of the number of doctorates the society can sustain will in turn also affect the output in research articles. Conversely a halt in the growth of awarded doctorate degrees and related slower scientific growth will enable other less developed countries to catch up faster technologically and be more competitive with the highly developed countries. This in turn will also have an impact on the labor market and society in general in the highly developed country.

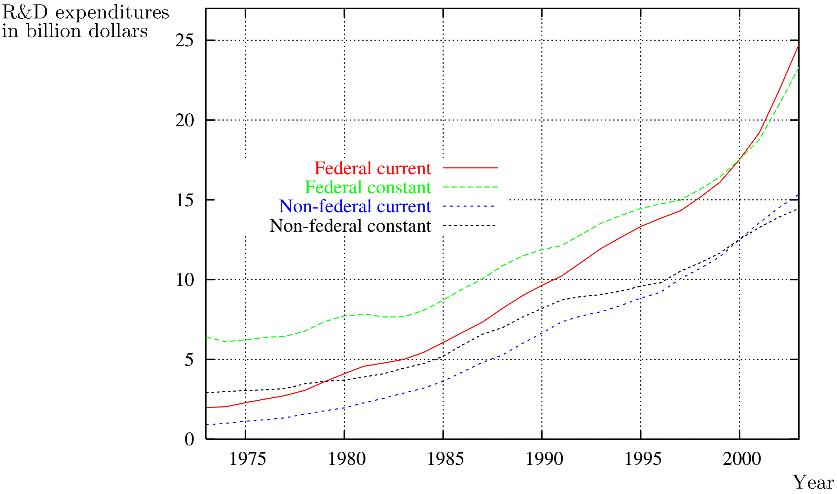

Fig. 7 Current federal and nonfederal academic R&D expenditures in billion dollars in the United States: 1973–2003. Federal and non-federal constant values are converted to 2000 dollars (data from Science and Engineering Indicators 2006)

That there is still an increase in scientific article output in recent years can be mostly related to developments in emerging and developing countries where the economic growth is accompanied by a significant growth in their higher education systems and education levels. In view of Fig. 4, one may therefore conclude that the head start in the cutting edge science of leading research groups and of developed countries is diminishing. One may speculate that this increase of scientific articles worldwide will only reach a saturation limit in growth when these emerging nations will have developed their scientific potential. The scientific potential of highly developed countries appears to have been reached, if scientific potential can be measured in the number of doctorate degrees awarded or the number of scientific journal articles published.

It may be also worth noting that in recent decades the research articles, as a form of scientific output, (i) have been citing increasingly more references in average and that (ii) the average age of the references in these articles has become older (see Lariviere et al. 2008). It should be intuitively clear that more articles are cited in the average scientific article: the published literature worldwide has been steadily increasing. From Fig. 3 it can be seen that presently ten times more papers are published annually than in the 1960's. If a Ph.D. candidate would actually like to get an overview of the literature published in a field this factor of ten may dissuade the student. To be in the forefront of research now involves significantly more time to read, assimilate, and organize the literature with a related loss in productivity compared to researchers in the 1960s. The increase in the average age of cited references (see Lariviere et al. 2008) also indicates that, on average, scientific articles are increasingly related to previous findings. This in turn can be seen as an indication that: (i) the advancement of the sciences is slowing in spite of increased manpower and funding, and that (ii) the quality of reported innovations within these articles may be decreasing.

In this respect, the advancing ages of Nobel Prize recipients appear to point towards the same tendencies: the average age of Nobel Prize recipients has steadily increased since about 1950 (see Fig. 6). Assuming that many Nobel Prize recipients, like those in physics, often achieve their notable scientific finding during an earlier life period (Karazija and

Momkauskaita 2004), it may be that the scientific discoveries of Nobel Prize recipients become older as well. This aging of Nobel Prize findings can be seen as similar to the aging of cited articles and as an indication of a decrease, or a slowing down, in significant discoveries within recent years. The change in the age of the Nobel Prize recipients occurred in 1950, 20 years earlier than the change in the numbers of awarded doctorate degrees and published scientific articles. This lagging may point to the relation between fundamental, transformative findings and routine scientific work firmly based upon past scientific achievements as it is defined as 'normal science' by Kuhn (1962). In this respect, it is interesting to note that if the dominance between science and technology is considered, the onset of the postmodern era may be related to about 1980 (Forman 2007). The lagging of developments in active sciences—monitored by the number of annually awarded doctorate degrees and published scientific articles—to the more mainstream perception could explain this difference. As a result, the fundamental changes in the scientific endeavor often discussed in the context of 'postmodern science' can in fact be traced with scientometric data (although additional quantitative data would be desirable to further corroborate the changes discussed above). Related perceptions of diminishing returns, for instance, in the sciences (Horgan 2004), the shift to the primacy of technology over science (Forman 2007), or that fundamental science is increasingly indistinguishable from technological advancement (Ziman 1994) can be associated with scientometric data.

Conclusions

The article suggests demography is one of the key driving factors of developments in the sciences and that the transition to the era of postmodern science can be traced to, and at least in part explained by, demographics and the bibliometric data of the sciences. To support this conclusion, demographic and bibliometric data has been evaluated along with data on Nobel Prize recipients.

A change in the growth of the annual numbers of awarded doctorate degrees and in the growth of scientific journal articles around 1970 has been observed. Changes in the age of Nobel Prize recipients can be traced to even earlier decades. Considering these data sets, one may conclude that the highly developed countries are already at, or rather close to, their saturation limit. With respect to the United States, this saturation limit does not appear to be static as it seems to develop more or less in sync with the total population growth. As such, it is suggested that the saturation limit of de Solla Price given in Fig. 1 may have to be seen in relation to the total population. Of particular interest in the decades to come is the evolving demography of scientists in highly developed countries which have a declining population. With respect to the annual growth numbers, economically rapidly growing countries like China and India are arguably still in strong growth stages and it probably will take several decades until they will reach their scientific potential and saturation limit. With respect to the discussed scientometric data different aspects of the notions of steady state or postmodern science can therefore be specifically differentiated and perceived.

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