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ORIGINAL ARTICLE

Radiological research activity 1998–2007: relationship to gross domestic product, health expenditure and public expenditure on education

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Abstract
Objective The purpose of this study was to evaluate the relationship of the radiological research activity from 1998 to 2007 to the gross domestic product (GDP), health expenditure and public expenditure on education.
Methods The population-adjusted research activity determined by the number of articles published, the cumulative impact factor (IF) and the cumulative IF per capita were correlated with per capita values of the GDP, health expenditure and public education expenditure. Linear regression analysis and multiple regression analysis were used for statistical analysis.
Results The cumulative IF per capita correlated with the GDP per capita (R=0.94, P<0.0001), health expenditure per capita (R=0.93, P<0.0001) and public expenditure on education per capita (R=0.93, P<0.0001). Multiple regression analysis demonstrated that public expenditure on education was an independent predictor of radiological research activity (P<0.001), whereas the year, GDP and health expenditure did not reach statistical significance (P>0.05).
Conclusion Radiological research activity demonstrates a close relationship to the GDP, health expenditure and public expenditure on education. The last factor *independently* predicts research activity.

Keywords Impact factor · Radiology · Research activity · Gross domestic product (GDP) · Health expenditure · Public education expenditure

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Introduction

Research requires financial resources [1, 2]. This may apply particularly to heavily technical fields such as radiology with large amounts of capital expenditure [3]. Increasingly, funding depends on evidence of favourable terms [4], and that resources for research are adequately employed. The situation is complicated by the fact that scientific research activity not only depends on project-related finances but also on the available research and medical infrastructure, such as dedicated research coordinators [5], faculty size [6], clinical workload [5], history of mentoring and pressure on productivity. Studies regarding the relationship between funding [2] or different macroeconomic variables and research activity have been published for various other medical disciplines and health topics in the past [7–19]. In radiology, research activity has been benchmarked according to population size [20, 21], GDP [20] and geographic region [20, 21, 24].

To the best of our knowledge, no study has analysed worldwide radiological research activity in relation to a set of socioeconomic parameters including population size, GDP, health expenditure and public expenditure on education. Thus, the purpose of our study was to evaluate the relationship of the radiological research activity over one decade to the GDP, health expenditure and public expenditure on education.

Materials and methods

Radiological research activity was determined between 1998 and 2007 on the basis of bibliometric data obtained from the most commonly cited radiology, nuclear medicine and medical imaging journals [22]. To estimate the quantity of research activity, the total number of publications was

Table 1 Mean impact factors (IF) for the analysed journals, 1998–2007

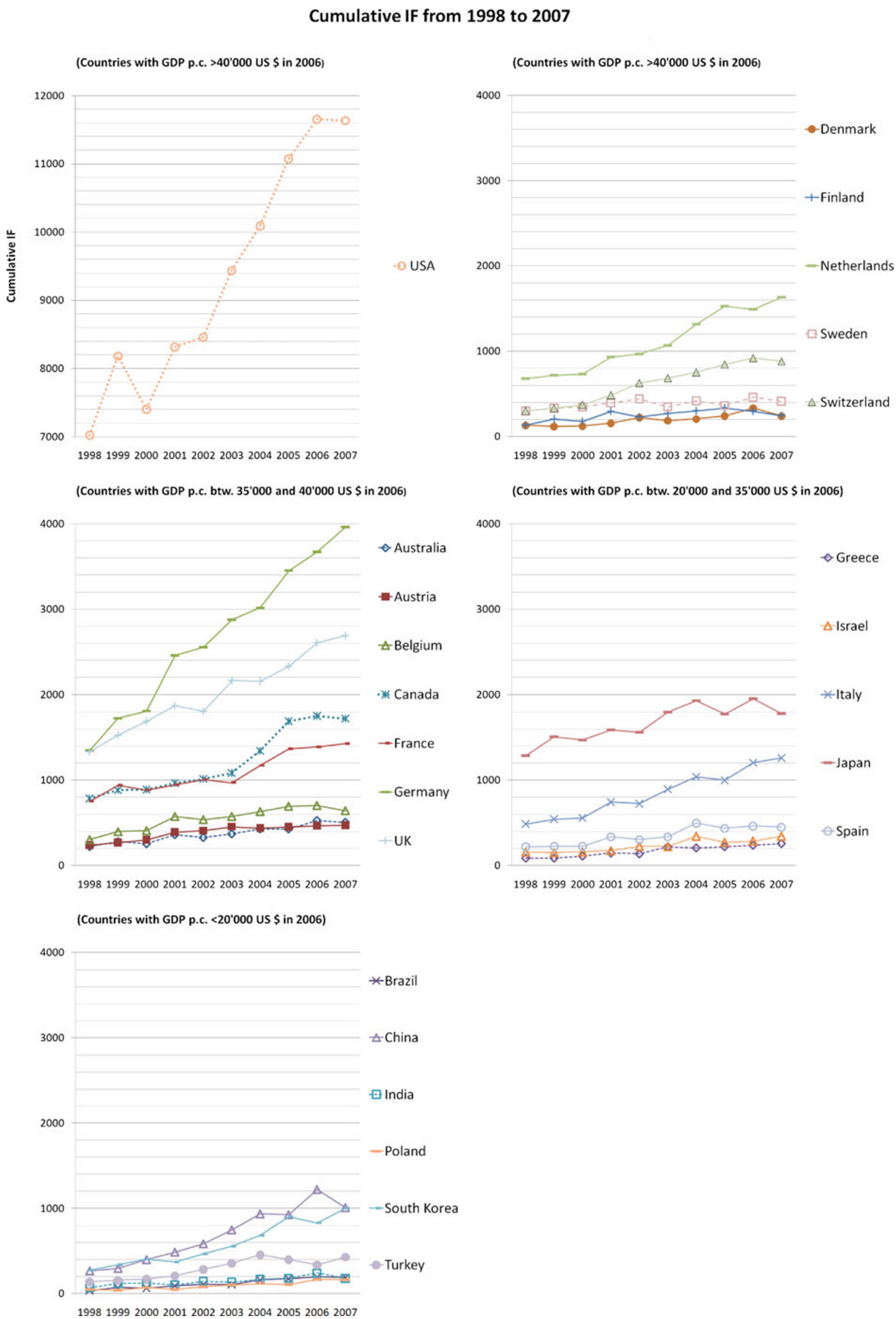
Journal	Mean IF
Academic Radiology	1.36
Acta Radiologica	0.96
American Journal of Neuroradiology	2.32
American Journal of Roentgenology	2.24
Applied Radiation and Isotopes	0.77
British Journal of Radiology	1.15
Cardiovascular and Interventional Radiology	1.07
Clinical Nuclear Medicine	1.14
Clinical Radiology	1.29
European Journal of Nuclear Medicine and Molecular Imaging	3.59
European Journal of Radiology	1.21
European Radiology	1.82
Human Brain Mapping	5.22
IEEE Transactions on Medical Imaging	3.25
International Journal of Radiation Biology	2.12
International Journal of Radiation Oncology Biology Physics	3.76
Investigative Radiology	2.42
Journal of Clinical Ultrasound	0.68
Journal of Computer Assisted Tomography	1.41
Journal of Magnetic Resonance Imaging	2.25
Journal of Nuclear Medicine	4.50
Journal of Ultrasound in Medicine	1.08
Journal of Vascular and Interventional Radiology	2.13
Magnetic Resonance Imaging	1.48
Magnetic Resonance in Medicine	3.34
Medical Physics	2.62
Neuroimage	6.23
Neuroradiology	1.30
NMR in Biomedicine	2.60
Nuclear Medicine and Biology	1.95
Nuclear Medicine Communications	1.21
Pediatric Radiology	0.83
Physics in Medicine and Biology	2.26
Radiation Protection Dosimetry	0.58
Radiation Research	2.87
Radiographics	1.98
Radiologic Clinics of North America	1.78
Radiology	4.92
Radiotherapy and Oncology	3.03
RöFo-Fortschritte auf dem Gebiet der Röntgenstrahlen	1.52
Skeletal Radiology	0.87
Ultrasonics	0.83
Ultrasound in Medicine and Biology	1.94
Ultrasound in Obstetrics and Gynecology	2.13

Table 2 Number of articles, mean cumulative impact factor (IF), mean population, mean cumulative IF per capita (p.c.) and mean IF between 1998 and 2007

	Number of articles, 1998–2007	Cumulative IF, 1998–2007	Population (10^6), 1998–2007	Cumulative IF p.c. (IF/10^6), 1998–2007	IF 1998–2007
Australia	1,534	370.2	19.7	18.6	2.41
Austria	1,675	387.3	8.2	47.1	2.31
Belgium	2,200	545.8	10.3	52.9	2.48
Brazil	730	119.3	180.5	0.7	1.63
Canada	4,320	1,211.1	31.5	38.2	2.80
China	3,185	687.0	1,291.1	0.5	2.16
Denmark	768	195.0	5.4	36.2	2.54
Finland	951	248.3	5.2	47.6	2.61
France	4,501	1,085.7	60.1	18.0	2.41
Germany	10,778	2,686.2	82.5	32.6	2.49
Greece	935	170.0	11.0	15.4	1.82
India	962	146.2	1,090.2	0.1	1.52
Israel	1,118	232.7	6.4	36.0	2.08
Italy	3,731	844.2	58.2	14.5	2.26
Japan	7,430	1,664.7	127.4	13.1	2.24
Netherlands	3,777	1,104.9	16.1	68.3	2.93
Poland	551	95.2	38.3	2.5	1.73
South Korea	2,556	581.8	47.3	12.2	2.28
Spain	1,826	346.5	41.8	8.2	1.90
Sweden	1,760	380.1	9.0	42.4	2.16
Switzerland	2,305	619.7	7.3	84.0	2.69
Turkey	1,925	294.0	70.5	4.1	1.53
UK	8,766	2,016.5	59.6	33.8	2.30
USA	34,698	9,327.8	292.4	31.8	2.69
All countries	102,982	1,056.7	148.7	27.4	2.46

determined. To reflect research quality, the mean impact factor (IF) was determined, and to estimate quantity and quality, a cumulative IF was calculated (by summing the IFs of all publications for a given year). The IF of the individual journals was taken from the Thomson ISI Web of Knowledge/Science database (http://apps.isiknowledge.com). The research activity was correlated with the socioeconomic factors population, GDP, health expenditure and public expenditure on education by calculating the following indexes: cumulative IF/population (in millions), cumulative IF/GDP (in current billions US$), cumulative IF/health expenditure (in current billions US$) and cumulative IF/public education expenditure (in current billions US$).

Fig. 1 Trend of the cumulative impact factor (IF) between 1998 and 2007 shown separately for different groups of gross domestic product per capita (GDP p.c.). Note that the USA graph is separately shown with a different *y*-axis because of the much larger cumulative IF in comparison with all other countries


Cumulative IF from 1998 to 2007
(Countries with GDP p.c. >40'000 US $ in 2006)
Cumulative IF
12000
11000
10000
9000
8000
7000
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
USA
(Countries with GDP p.c. >40'000 US $ in 2006)
4000
3000
2000
1000
0
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Denmark
Finland
Netherlands
Sweden
Switzerland
(Countries with GDP p.c. btw. 35'000 and 40'000 US $ in 2006)
4000
3000
2000
1000
0
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Australia
Austria
Belgium
Canada
France
Germany
UK
(Countries with GDP p.c. btw. 20'000 and 35'000 US $ in 2006)
4000
3000
2000
1000
0
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Greece
Israel
Italy
Japan
Spain
(Countries with GDP p.c. <20'000 US $ in 2006)
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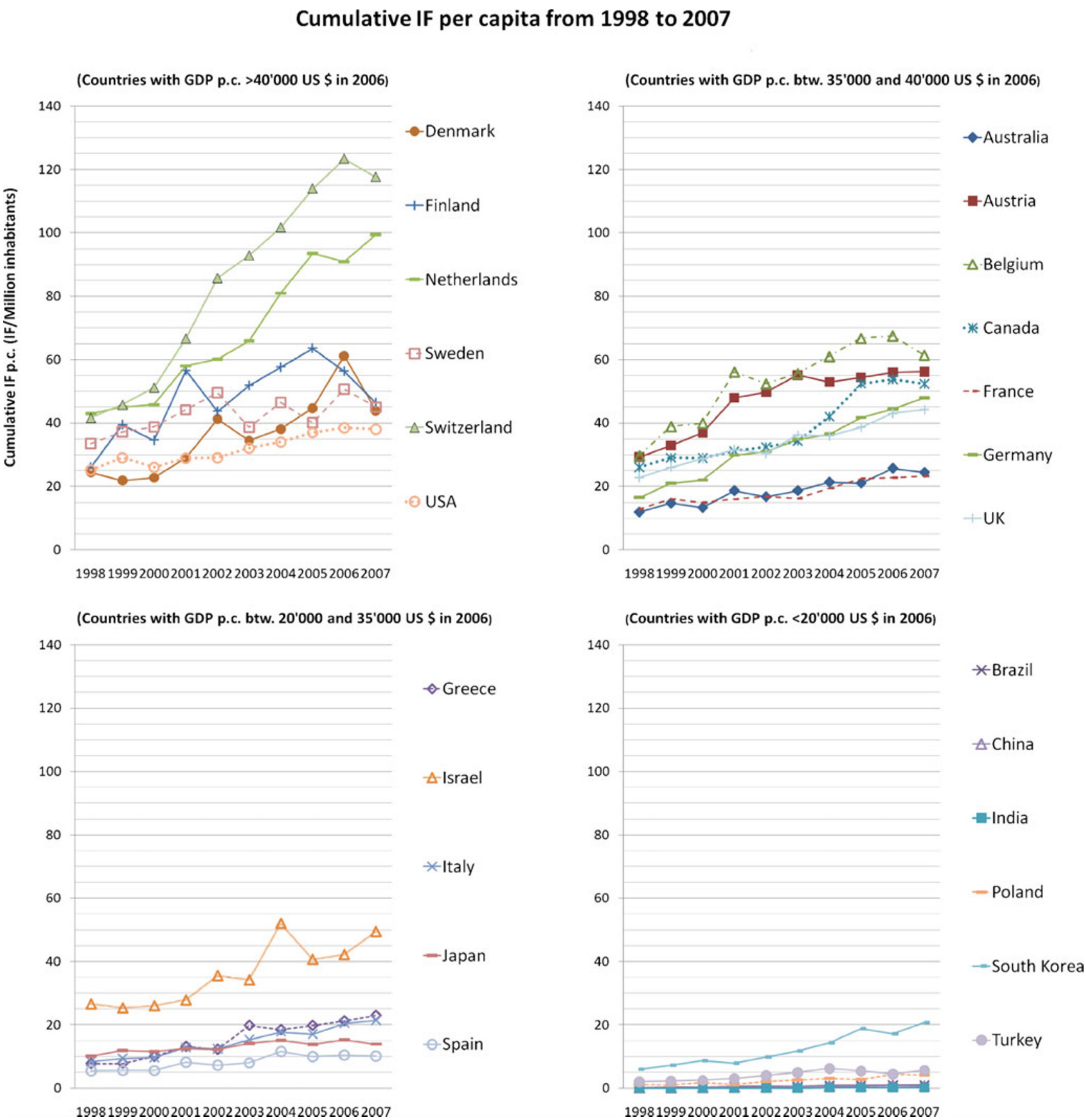

Fig. 2 Trend of the cumulative impact factor (IF) per capita (p.c.) between 1998 and 2007 shown separately for different groups of gross domestic product (GDP) per capita. Switzerland, followed by the Netherlands and Belgium, had the highest cumulative IFs per capita from 1998 to 2007

Socioeconomic factors

To obtain reliable socioeconomic parameters, we searched data that were as complete as possible for the selected countries between 1998 and 2007. To obtain comparable results, the data had to be from one single database. According to these specifications, we obtained the total population, GDP at market prices (in current billions US$), health expenditure per capita (in current billions US$) and public education expenditure as a percentage of GDP from the online databases of the World Bank [23] in October 2008.

Data on health expenditures were available in these databases for the period between 2001 and 2005. Data on public education expenditures were available from 1998 to 2005 but not for all countries throughout the entire period between 1998 and 2005.

Journal selection

The Thomson ISI Web of Knowledge/Science database (http://apps.isiknowledge.com) was used to select radiological journals for this study. Journals were included in our study when they met the following inclusion criteria: (1) indexed in the ISI Web of Science, Journal Citation Reports (JCR) under the category "Radiology, Nuclear Medicine and Medical Imaging" [22] for the entire period 1998–2007, (2) ranked among the first 40 journals sorted by total cites in the JCR for at least 1 year during the study period, (3) IFs available for all 10 years investigated. Using these criteria 44 journals were identified (Table 1). No restriction to English as journal language was performed.

Article selection

For article selection, a search was performed on the ISI database in August 2008. All original articles that appeared in the selected journals between 1998 and 2007 and were cited on the ISI database were included. Other types of publication such as reviews, letters, book reviews, editorial materials, meeting abstracts, meeting summaries, news items, notes or proceedings papers were not included.

Country selection

To restrict the total number of countries to a reasonable number, countries were included in our analysis when at least 90 articles were published within at least 1 year during the 10-year study interval in the selected journals. The following 24 countries fulfilled the inclusion criteria: Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Greece, India, Israel, Italy, Japan, the Netherlands, Poland, South Korea, Spain, Sweden, Switzerland, Turkey, the UK (England, Wales, Scotland and Northern Ireland), and the USA.

Number of articles

For each country the total number of articles per year and per journal was determined using the ISI web program. One count was given to every country listed as part of the address information/author affiliation. Multiple country counts were assigned to articles with authors from multiple countries.

Cumulative IF

For each country the articles published within 1 year were determined and assigned to their respective journals using the ISI web program. A product was calculated by multiplying the number of articles published in a journal with the journal's corresponding IF for that particular year. Then, the products of all selected journals were added to get the cumulative IF for each country per year.

Mean cumulative IF

A mean cumulative IF was calculated by dividing the sum of several cumulative IFs of each country throughout the time period (in years) that was studied. The time periods for the socioeconomic factors varied based on the availability of the data in the World Bank.

Mean IF

For each country the mean impact factor was calculated by dividing the total cumulative impact factor over the entire study time by the total number of articles published.

Statistics

Ratios were calculated for cumulative IF/GDP, cumulative IF/health expenditure and cumulative IF/public education

Table 3 Cumulative mean impact factors (IF) and gross domestic product (GDP), 1998–2006

	Cumulative IF (10^9 US$), 1998–2006	GDP (IF/10^9 US$), 1998–2006	Cumulative IF/GDP, 1998–2006
Australia	355.2	525.1	0.7
Austria	378.1	244.1	1.6
Belgium	535.1	295.5	1.8
Brazil	111.4	699.9	0.2
Canada	1,154.6	857.2	1.3
China	651.2	1,615.7	0.4
Denmark	190.1	203.6	0.9
Finland	248.7	156.0	1.6
France	1,047.4	1,700.0	0.6
Germany	2,544.7	2,333.4	1.1
Greece	160.4	206.0	0.8
India	142.6	592.0	0.2
Israel	220.6	119.2	1.8
Italy	797.8	1,411.8	0.6
Japan	1,652.0	4,295.5	0.4
Netherlands	1,046.4	497.3	2.1
Poland	87.8	223.4	0.4
South Korea	535.2	588.8	0.9
Spain	335.3	819.1	0.4
Sweden	376.7	289.5	1.3
Switzerland	590.7	303.9	1.9
Turkey	279.0	247.1	1.1
UK	1,941.9	1,768.6	1.1
USA	9,071.3	10,699.6	0.8
All Countries	1,018.9	1,278.8	1.0

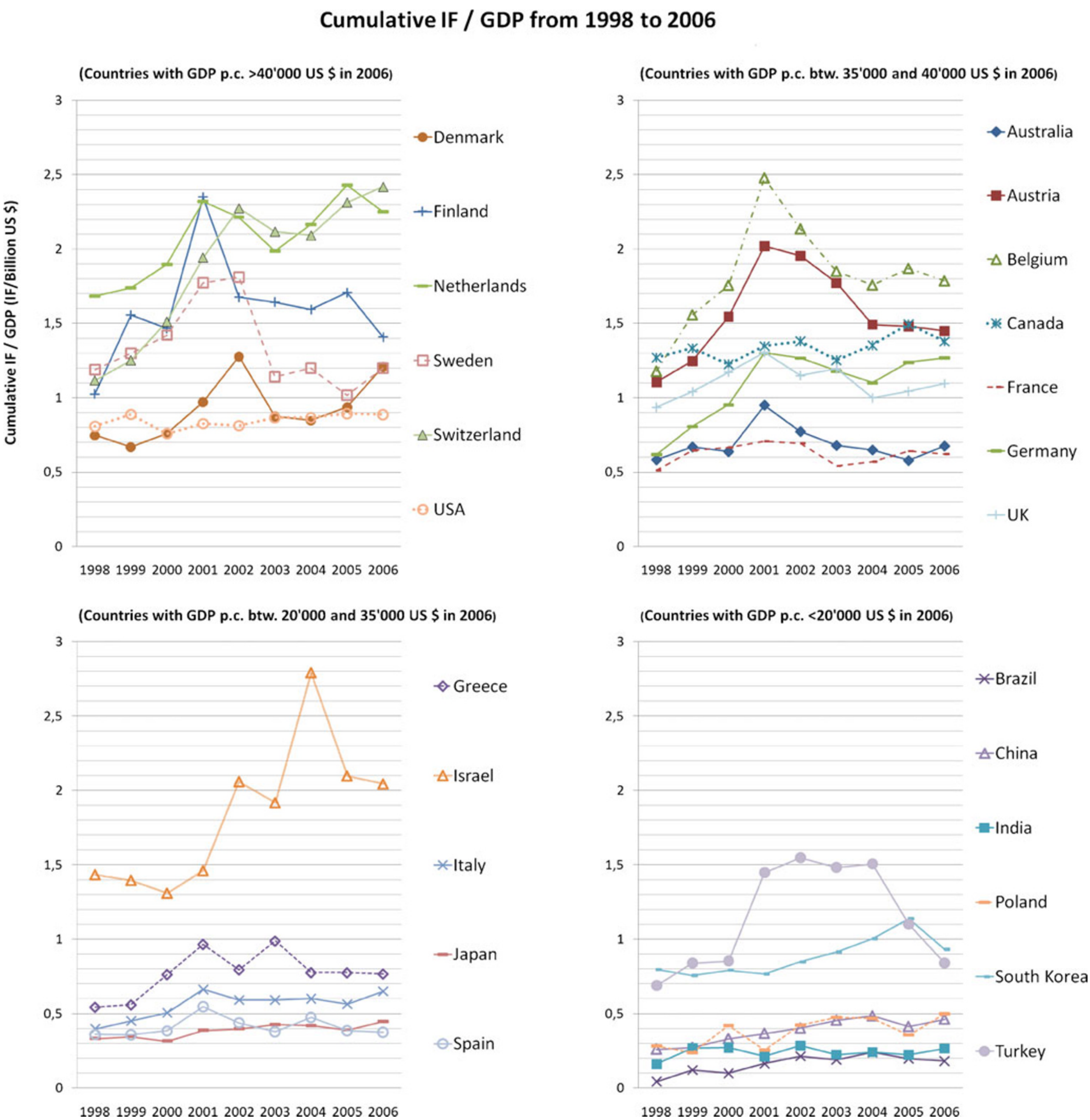

Fig. 3 Trend of the ratio of cumulative impact factor (IF) to gross domestic product (GDP) from 1998 to 2006

expenditure. The trends of these ratios over time are demonstrated with line charts. Linear regression analysis was used to assess the effects of per capita values of GDP, health expenditure and public education expenditure on cumulative IF per capita. All variables were analysed on logarithmic scales. Multiple regression analysis was used to find independent predictors. We used SPSS software (version 16.0.1, SPSS, Chicago, IL, USA) to perform the statistical analysis. Two-sided *P* values <0.05 were considered statistically significant.

Results

Number of articles

The total number of articles assigned to all selected countries for the period 1998–2007 was 102,982. The highest number of articles was published by the US (34,698), followed by Germany (10,778) and the UK (8,766) (Table 2). The total number of publications increased by 27% (9,248 to 11,711) between 1998 and 2007. The highest increases in published articles between 1998 and 2007 were seen for South Korea (127 to 400; +215%), Brazil (38 to 93; +145%) and Poland (32 to 77; +141%).

Cumulative IF

The USA had the highest mean cumulative IF (9,328) between 1998 and 2007, followed by Germany (2,686) and the UK (2,017) (Table 2). Figure 1 demonstrates the trend of the cumulative IF over time for all 24 countries. Generally, the mean cumulative IF for all countries increased between 1998 (691) and 2007 (1,396) (+102%). The highest increases in cumulative IF between 1998 and 2007 were found for Brazil (+437%), followed by China (+281%) and South Korea (+264%). The lowest increases were found for Sweden (+38%), Japan (+39%) and the USA (+66%).

Cumulative IF/population

The ranking order changed after adjusting for population. Switzerland (mean cumulative IF/million inhabitants: 84.0), followed by the Netherlands (68.3) and Belgium (52.9) had the highest mean cumulative IFs per capita (Table 2). Figure 2 shows the trend of the cumulative IF per capita over time for all 24 countries. The highest increases in cumulative IF per capita between 1998 and 2007 were found for Brazil (+373%), followed by China (+258%) and South Korea (+249%).

Mean IF

The mean IF of published articles over all countries and years was 2.46 (range 1.52–2.93) (Table 2). The highest mean IFs were found for the Netherlands (2.93), Canada (2.80) and Switzerland (2.69).

Cumulative IF/GDP

The highest mean values of the cumulative IF/GDP ratio were found for the Netherlands (mean cumulative IF/billion US$: 2.1) and Switzerland (1.9), followed by Israel (1.8) (Table 3). Figure 3 shows the trend of the ratio over time for all 24 countries. The highest increases in the cumulative IF/GDP ratio between 1998 and 2006 were seen for Brazil (cumulative IF/billion US$: 0.0 to 0.2; +333%) followed by Switzerland (1.1 to 2.4; +117%) and Germany (0.6 to 1.3; +105%).

Cumulative IF/health expenditure

The highest mean values of the cumulative IF/health expenditure ratio were found for Israel (mean cumulative IF/billion US$: 25.3), the Netherlands (25.1) and Finland (25.1) (Table 4). Figure 4 shows the trend of the ratio over time for all 24 countries. The highest increases in the cumulative IF/health expenditure ratio between 2001 and 2005 were seen for Israel (cumulative IF/billion US$: 17.4 to 26.5; +53%), South Korea (14.3 to 19.3; +35%) and Poland (4.3 to 5.7; +31%).

Cumulative IF/public education expenditure

The Netherlands (mean cumulative IF/billion US$: 42.1) and Belgium (34.0) showed the highest mean values of the cumulative IF/public education expenditure ratio followed by Turkey (32.7) (Table 5). Figure 5 shows the trend of the ratio over time for all 24 countries. The highest increases in the cumulative IF/public education expenditure ratio were seen for Brazil between 1998 and 2002 (cumulative IF/billion US$: 0.9 to 6.0; +597%), Israel between 1998 and 2004 (19.3 to 40.5; +109%) and Switzerland between 1998 and 2005 (20.8 to 39.9; +92%).

Table 4 Mean cumulative impact factor (IF) and health expenditures, 2001–2005

	Cumulative IF, 2001–2005	Health expenditures (10^9 US$), 2001–2005	Cumulative IF/health expenditures (IF/10^9 US$), 2001–2005
Australia	382.8	47.6	8.4
Austria	427.1	25.7	17.0
Belgium	601.9	29.0	21.3
Brazil	127.6	48.6	2.6
Canada	1,218.1	85.7	14.2
China	736.0	82.1	8.9
Denmark	202.3	18.9	11.0
Finland	285.2	11.7	25.1
France	1,092.7	186.1	6.0
Germany	2,870.0	253.1	11.4
Greece	185.1	21.6	8.7
India	145.7	29.8	4.9
Israel	246.7	9.7	25.3
Italy	879.2	126.2	7.1
Japan	1,730.0	345.2	5.0
Netherlands	1,161.5	46.6	25.1
Poland	92.3	14.4	6.4
South Korea	594.5	34.2	17.0
Spain	379.6	68.1	5.8
Sweden	392.2	26.8	15.3
Switzerland	678.8	35.9	18.9
Turkey	341.9	18.9	18.6
UK	2,064.7	145.6	14.5
USA	9,475.5	1,699.8	5.6
Mean	1,096.3	142.1	12.7

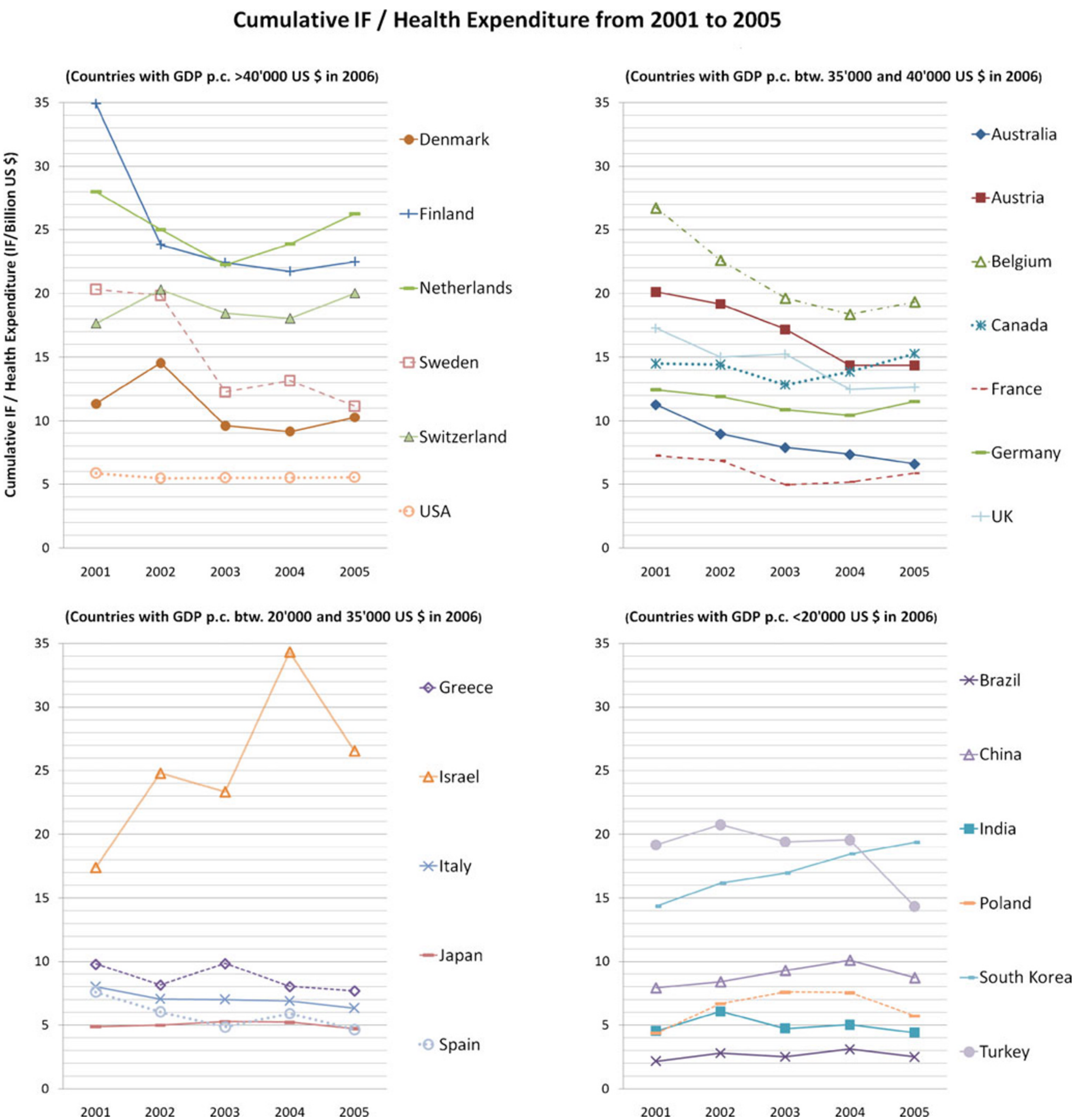

Fig. 4 Trend of the ratio of cumulative impact factor (IF) to health expenditure from 2001 to 2005

Correlation of radiological research activity with socioeconomic factors

The population-adjusted radiological research activity (cumulative IF per capita) correlated significantly with per capita values of the GDP (R=0.94, P<0.0001), health expenditure (R=0.93, P<0.0001), and public expenditure on education (R=0.93, P<0.0001) (Figs. 6, 7, 8). Per capita values of GDP and health expenditure are highly correlated (Spearman rank correlation rho = 0.964) and hence cannot be included into one multiple regression. Multiple regression analysis of per capita terms demonstrated that public expenditure on education (P<0.001) is an independent predictor of population-adjusted radiological research activity, whereas the year (P=0.23) and total GDP (P=0.075) do not reach statistical significance. Similar results were

Table 5 Mean cumulative impact factor (IF) and public education expenditure, 1998–2005

	Cumulative IF, 1998–2005	Publ. ed. exp. (10^9 US$), 1998–2005	Cumulative IF/publ. ed. exp. (IF/10^9 US$), 1998–2005
Australia	333.7	22.9	14.8
Austria	367.1	13.7	27.8
Belgium	514.0	17.4	34.0
Brazil	101.1	26.2	3.7
Canada	1,079.9	38.0	23.8
China	579.7	19.8	14.1
Denmark	172.3	16.2	10.6
Finland	242.7	9.6	27.2
France	1,004.4	93.5	10.9
Germany	2,404.0	100.0	22.5
Greece	150.9	7.6	20.0
India	130.2	21.7	6.0
Israel	212.3	8.3	24.5
Italy	746.8	62.8	11.8
Japan	1,614.2	155.4	10.4
Netherlands	991.0	24.3	42.1
Poland	77.7	11.0	7.0
South Korea	498.7	22.2	20.1
Spain	319.7	33.0	9.7
Sweden	366.3	20.5	18.3
Switzerland	549.6	16.7	32.1
Turkey	271.6	7.6	32.7
UK	1,859.2	87.1	21.9
USA	8,748.1	576.0	15.6
Mean	972.3	52.7	19.0

obtained when health expenditure was included instead of GDP, although the number of observations was then smaller because of the limited availability of health expenditure data.

Discussion

The current study demonstrates that radiological research activity increased over time in all countries. The overall number of articles published increased by +27% between 1998 and 2007. The cumulative IF doubled between 1998 and 2007. Some countries were able to increase their cumulative IF by several 100% (ranking leaders: Brazil, China, and South Korea).

Previously published studies have found that the USA falls behind in terms of both absolute numbers of published radiology papers [20] and also with regard to share of the total research output [25]. However, based on our results, the USA published the largest number of articles. They continuously increased their cumulative IFs and made by far the greatest contribution to radiological research activity. The growth rates of the number of articles, cumulative IF, and cumulative IF per capita for the USA did not decrease after NIH funding stagnation in 2003 [26] until 2007. On the contrary, the growth rates from 2003 to 2007 were even higher than between 1998 and 2003 (Figs. 1, 2).

However, the country ranking according to cumulative IF underwent a striking change after adjusting for population size and GDP. Small European countries (e.g. Switzerland, the Netherlands) led the rankings. This ranking has been previously shown for both radiology [20] and other disciplines [7, 10, 11]. Similar observations were made with regard to the standardisation according to health expenditure and public expenditure on education. The leading position of Israel in the ranking adjusted for health expenditure is at least partially explained by its low health expenditure per capita (average Israel: US $1,511 vs. average over all countries: $2,231) in combination with an above-average mean cumulative IF per capita (average Israel: 38.1/million vs. average over all countries: 29.2/million). A similar mechanism could be seen for the high ranking positions of Turkey with standardisation for health expenditure and public education expenditure; although for Turkey the high ratios can be explained by its low expenses.

The population-adjusted radiological research activity (cumulative IF per capita) correlated significantly with the per capita terms of the GDP, health expenditure and public expenditure on education. Multiple regression analysis demonstrated that public expenditure on education was the only parameter that was an independent predictor for the radiological research activity. GDP and health expenditure were highly correlated (Spearman rank correlation rho = 0.964). Potentially policy makers may use these data to argue for greater public education spending if research productivity is a goal.

It can be speculated that some health expenditure data given by the World Bank might have been calculated as a percentage of the GDP. A close relationship between increased GDP and high research activity has been found for other medical disciplines [8, 10, 12, 13, 17]. For ophthalmology, for example, Guerin et al. demonstrated a significant relationship between GDP per capita greater than $20,000 and the population-adjusted research output [27].

Obviously, productive medical research requires a strong and stable economy. Such a strong economy seems especially important in such medical disciplines as radiology, which requires large investment and has

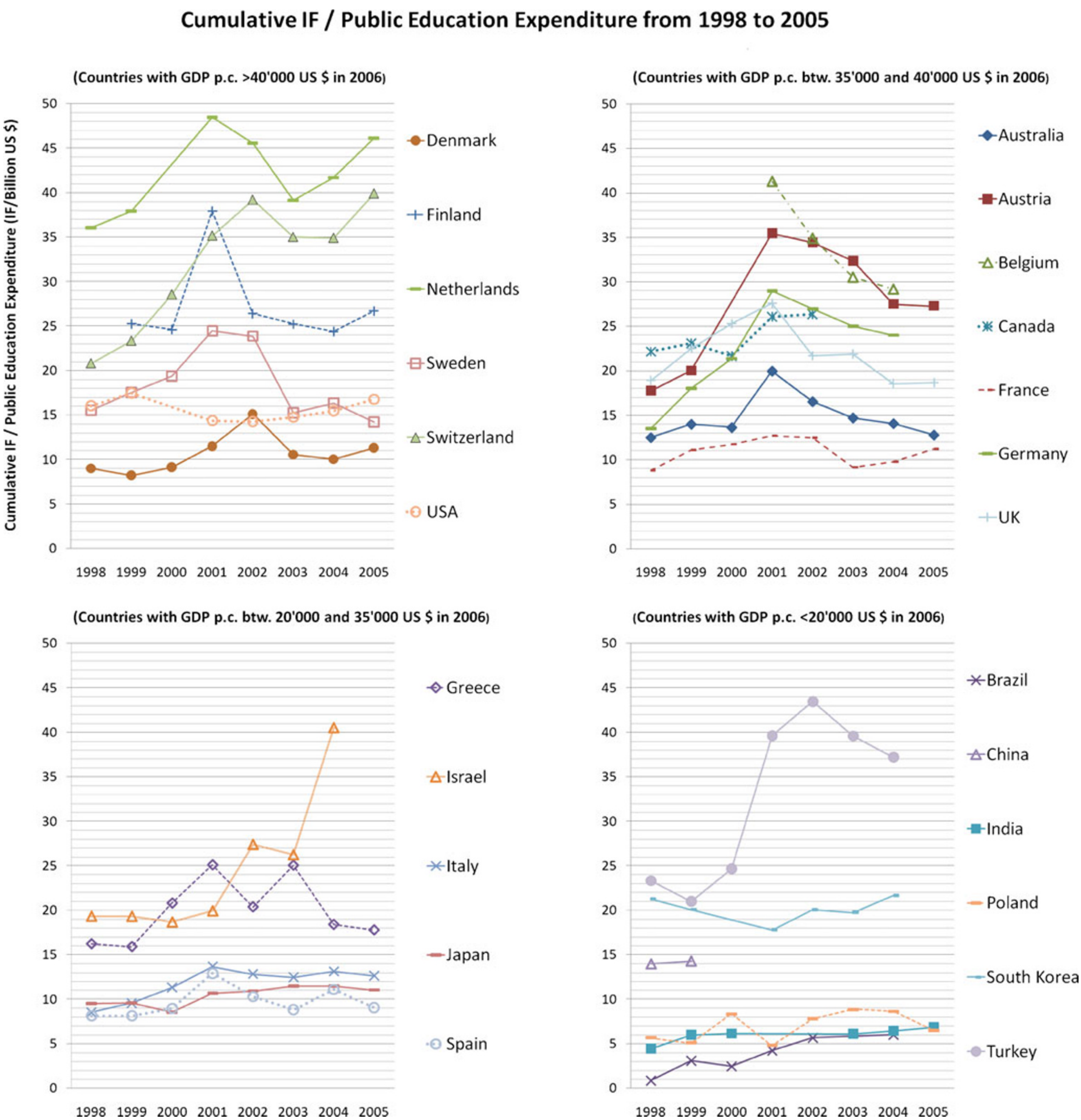

Fig. 5 Trend of the ratio of cumulative impact factor (IF)/public education expenditure from 1998 to 2005

high running costs [3]. Funding of research projects is another important aspect. A Canadian study [2] has shown that a significant relationship of national spending on research and English proficiency exists to publication output. These two variables explained approximately 70% of the variation in publication rate. Normalised for population size, English-speaking nations and certain European countries such as Denmark, the Netherlands, Switzerland, and Sweden had the highest rate of publication in the five highest ranked general medical journals (*The New England Journal of Medicine*, *The Journal of the American Medical Association*, *The Annals of Internal Medicine*, *The British Medical Journal* and *The Lancet*).

There are several limitations to our study: Radiology papers published in non-radiological journals were not

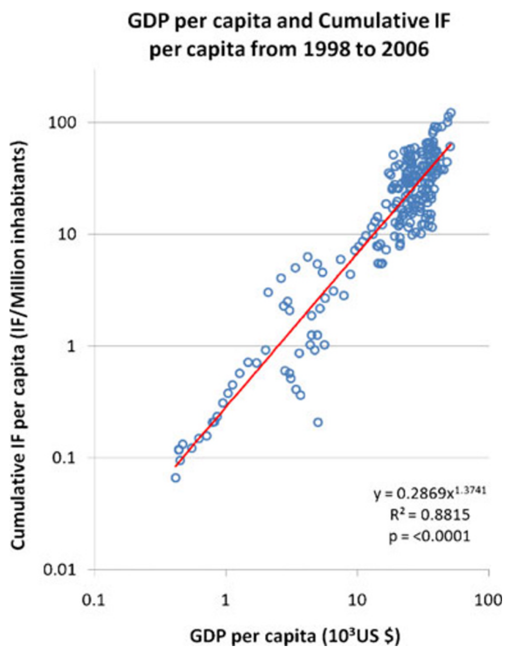

Fig. 6 Relationship between the gross domestic product (GDP) per capita and the cumulative impact factor (IF) per capita on a logarithmic scale (data from 1998 to 2006)

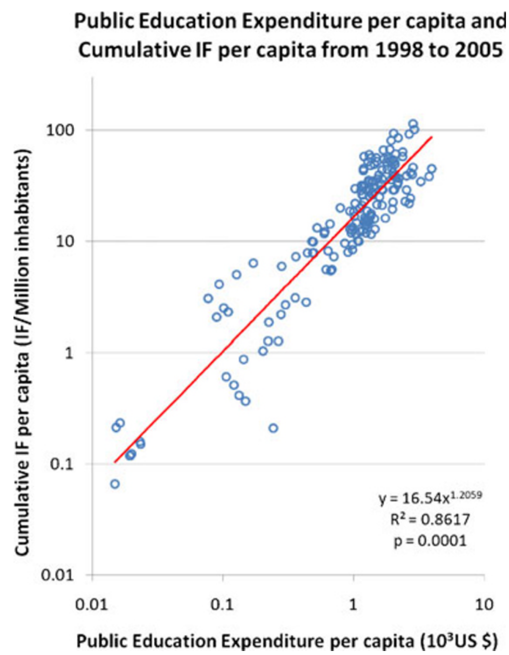

Fig. 8 Relationship between public education expenditure per capita and the cumulative impact factor (IF) per capita on a logarithmic scale (data from 1998 to 2005)

covered in this study. This is a substantial limitation of the study considering that a considerable number of radiological articles are published in non-radiology journals. Although we were not able to identify the radiological articles in non-radiology journals, we believe that our results in terms of relationships between research activity and the evaluated socioeconomic factors are probably not far from the real situation. The study was limited by considering only high-cited established journals over the last 10 years with the same length history of IFs. This may lead to an under-representation of very advanced topics for which journals have only recently been founded. Such journals are often not even indexed in the JCR but could have been relevant nevertheless [28]. There is an ongoing debate about the use of the IF as an estimate of the quality of scientific research [29, 30]. However, there is no generally acknowledged better marker of publication quality at present [31]. Another limitation was that the data on public education expenditure were incomplete for the study period. Therefore, comparability between results based on this parameter is not optimal.

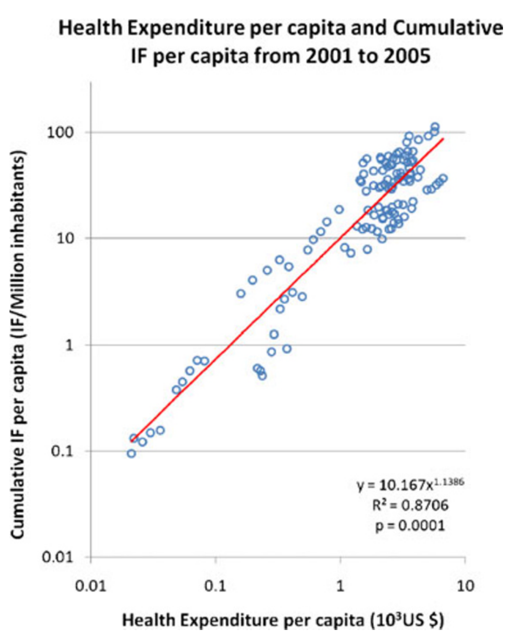

Fig. 7 Relationship between health expenditure per capita and the cumulative impact factor (IF) per capita on a logarithmic scale (data from 2001 to 2005)

Accepting these limitations, our study has shown that the United States had the highest radiological research activity for the period between 1998 and 2007, followed by Germany and the UK. The population-adjusted figures revealed the highest radiological research activity for Switzerland, followed by the Netherlands and Belgium. The radiological research activity demonstrates a close relationship to the GDP, health expenditure and public expenditure on education. However, of these three factors, only the latter factor *independently* predicts research activity.

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