Astronomy for the developing world
IAU Special Session no. 5, 2006
J.B. Hearnshaw and P. Martinez, eds.

doi:10.1017/S1743921307006618

A survey of published astronomical outputs of countries from 1976 to 2005 and the dependence of output on population, number of IAU members and gross domestic product

John Hearnshaw[1]

[1]Department of Physics and Astronomy, University of Canterbury, Christchurch, New Zealand
email: john.hearnshaw@canterbury.ac.nz

Abstract. In this paper I report the results of a survey of the astronomical outputs of all 63 IAU member countries as well as several non-member countries, based on an analysis of the affiliations of the authors given for nearly 900 thousand astronomical papers appearing in ADS between the years 1976 and 2005. The results show a roughly three-fold increase in the number of published papers per year over this 30-year interval. This increase is seen both in developed and also in most developing countries. The number of publications per IAU member correlates strongly with gross domestic product. It is over 2 papers per IAU member per year in the countries with the strongest economies but less than 0.5 in the countries with low GDP per capita. Since 2001 there has been a dramatic increase in the number of multi-author multinational papers published. This increase is especially noticeable for authors in developing countries, indicating that astronomers in these countries are increasingly participating in international collaborations for their research activities.

Keywords. Developing countries, published outputs, IAU members, gross domestic product

1. Introduction

In an earlier paper (Hearnshaw 2001) I presented some statistical data on the astronomical activity in various developed and developing countries, and correlated this activity against the wealth of the country measured by IMF quota per capita. The parameter to measure astronomical activity was simply the number of IAU individual members per million of population. However, that is a fairly crude measure of the astronomical activity in any country, especially as the percentage of professional astronomers joining the IAU differs widely from one country to another. In this paper the analysis is improved and extended, by using published astronomical outputs as recorded in the ADS (Astrophysics Data System) database as another and probably more reliable measure of astronomical activity. In addition, this paper adopts the more widely understood gross domestic product per capita (in $US/capita) as a measure of a nation's intrinsic wealth.

2. Use of the ADS affiliation field to count astronomical publications by country

The main task of this paper is to record and then analyse the number of astronomical papers published by astronomers in different countries as given by their affiliations in ADS. In addition, the growth in astronomical activity in each country, as given by ADS over 30 years between 1976 and 2005 is also explored. Although ADS has an affiliation field for many of the items in the database, and although the affiliation field of each

author nearly always lists the country or countries where each author is working, this information is by no means always given. Moreover, even when the country is listed, it is often done so in a variety of different formats: thus an astronomer in Cambridge, England might list his or her country as England, U.K., United Kingdom or Great Britain. For many papers published in the United States, the country is often not mentioned at all, and ADS might only give the state, and on occasions only the institution. It became obvious that the ADS affiliation fields represent fairly noisy data and the counts of papers based on country affiliations need to be used with caution.

In spite of this caution, there is still a large body of relatively good statistical data that can be extracted from the affiliation field in ADS which indicates in broad terms where the astronomical research and activity in the world is taking place. It also shows the growth in astronomical activity with time in the different countries.

The tool used in ADS for interrogation of the affiliation fields can be found at adswww.harvard.edu/affil/ and a discussion of the use of this tool can be found in the ADS frequently asked questions (FAQ). The sophistication of the affiliation interrogation tool has improved in recent years, and now enables mass statistical data to be gathered for most countries fairly readily. The USA and the countries that made up the former Soviet Union posed by far the greatest difficulties; in the former case, the country name is often omitted, and hence a search for all the individual state names and their abbreviations was necessary. (Puerto Rico was included in the publication count of the USA). As for countries of the former Soviet Union, the name of each republic is generally cited in each affiliation even before the Soviet break-up. If not, then city names were also useful for locating the country of origin.

In using the affiliation interrogation tool, the count of published papers was limited to refereed papers. Unrefereed papers have a much higher incidence of no country name in the affiliation field. They include items such as book reviews, published reports and popular articles in astronomy magazines for amateur astronomers. Unless otherwise stated, 'published papers' will henceforth refer to refereed published papers.

The tool was used with a date filter so as to count the number of published papers from each country selected in the time period January 1976 to December 2005. Within this 30-year span, the count was taken in 5-year intervals 1976–80, 1981–85, etc.

Results of the refereed paper counts by country and within 5-year time intervals from 1976 to 2005 are given in Table 1. The table lists results for 62 IAU members (based on membership in early 2006 before the 26th IAU General Assembly). Data for the Czech Republic and Slovakia are, however, combined into a single entry.

In addition, data for 24 non-IAU member countries are given in Table 2. These 24 countries comprise all 23 non-IAU member countries which have at least one IAU individual astronomer; in addition Mongolia (with no individual members) is included in this table. (In August 2006 Mongolia, Thailand and Lebanon all became member countries of the IAU, but their accession to IAU membership came after this analysis was completed.)

In Tables 1 and 2 the columns are:

- Col. 2–7. The number of papers published in 5-year intervals from 1976 to 2005, and where at least one author lists an affiliation to an institution in the country listed.
- Col. 8. The total number of papers 1976–2005.

It is noted that the paper counts in Tables 1 and 2 will count many papers more than once, if there are two or more countries in the affiliation field in ADS. This will be the case where a single author has affiliations to institutions in two or more countries, or multiple authors from different countries have collaborated. Hence the sum of papers counted over all countries may exceed the actual number of papers published. On the

Table 1. Refereed papers published, 1976–2005: IAU member countries

country	1976–80	1981–85	1986–90	1991–95	1996–2000	2001–05	total 1976–2005
Argentina	73	158	261	193	407	822	1914
Armenia	195	244	168	71	88	287	1053
Australia	1077	1346	1271	1088	1447	2967	9196
Austria	115	208	246	296	464	789	2118
Belgium	338	479	442	329	501	1121	3210
Bolivia	1	5	2	7	4	10	29
Brazil	211	359	486	493	847	1421	3817
Bulgaria	97	248	225	136	145	238	1089
Canada	1168	1609	2156	2040	1654	3617	12244
Chile	33	83	146	145	262	912	1581
China (P.R.C.)	153	1050	1092	935	950	2592	6772
China Taipei	10	17	24	73	188	577	889
Croatia	5	10	17	26	38	113	209
Cuba	0	1	2	5	6	10	24
Czech Rep + Slovakia	339	406	535	383	420	800	2883
Denmark	157	307	323	352	560	901	2600
Egypt	19	65	113	83	54	94	428
Estonia	46	59	68	58	72	100	403
Finland	103	200	288	314	443	884	2232
France	1829	3205	3735	3295	4665	8943	25672
Germany	2445	4240	4742	4163	6169	11594	33353
Greece	140	276	334	283	354	682	2069
Hungary	70	150	202	151	233	518	1324
Iceland	4	5	10	14	28	60	121
India	558	1190	1161	996	920	1408	6233
Indonesia	5	17	18	27	32	34	133
Iran	35	12	13	12	42	137	251
Ireland	49	74	96	112	179	403	913
Israel	288	285	405	377	469	967	2791
Italy	1228	2191	2513	2377	3474	7700	19483
Japan	804	1623	2266	2602	3196	5858	16349
Korea	26	59	112	276	538	1112	2123
Latvia	13	24	30	20	21	24	132
Lithuania	11	28	19	16	79	97	250
Malaysia	6	6	7	0	0	6	25
Mexico	97	189	271	296	802	1797	3452
Morocco	0	1	1	16	19	24	61
Netherlands	840	1422	1617	1222	1911	3549	10561
New Zealand	104	111	147	133	117	249	861
Nigeria	6	26	21	30	20	12	115
Norway	130	155	198	200	176	423	1282
Peru	9	5	7	8	5	31	65
Philippines	3	0	0	1	6	5	15
Poland	423	459	513	474	696	1338	3903
Portugal	5	21	24	40	191	541	822
Romania	31	27	8	126	103	149	444
Russia	3923	3892	3568	2668	2475	4035	20561
Saudi Arabia	1	10	19	16	15	38	99
Serbia, Montenegro	19	55	78	59	93	199	503
South Africa	216	276	394	275	401	583	2145
Spain	124	361	950	1009	2193	4337	8974
Sweden	310	529	604	480	668	1368	3959
Switzerland	438	495	584	540	895	1938	4890
Tajikistan	75	101	99	50	17	13	355
Turkey	52	82	122	90	102	281	729
Ukraine	486	566	505	418	690	832	3497
UK	3147	4232	4530	2916	1387	3270	19482
Uruguay	1	2	6	11	25	41	86
USA	10890	7800	7322	10103	16294	40745	93154
Vatican	6	20	40	27	52	94	239
Venezuela	18	38	47	59	86	147	395
totals	33005	41114	45203	43015	58388	123837	344562

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

Table 2. Refereed papers published, 1976–2005: IAU non-member countries

country	1976–80	1981–85	1986–90	1991–95	1996–2000	2001–05	total 1976–2005
Albania	0	0	0	0	0	0	0
Algeria	0	0	0	0	0	0	0
Azerbaijan	0	0	0	2	3	19	24
Columbia	0	1	3	2	0	1	7
Ecuador	0	0	0	0	2	0	2
Ethiopia	0	0	0	0	0	1	1
Georgia (Republic)	0	0	0	36	48	91	175
Honduras	0	0	0	0	1	0	1
Iraq	2	10	19	3	0	0	34
Kazakhstan	0	0	0	3	5	12	20
Korea DPR	0	0	0	0	0	0	0
Lebanon	1	4	5	2	4	14	30
Macedonia	0	0	0	1	1	1	3
Malta	0	0	0	1	0	1	2
Mauritius	0	0	0	1	1	12	14
Mongolia	2	2	5	1	2	4	16
Sri Lanka	2	2	1	0	1	1	7
Singapore	13	4	10	2	6	21	56
Pakistan	3	7	8	11	7	21	57
Slovenia	0	3	5	4	19	78	109
Thailand	0	0	0	3	4	54	61
United Arab Emirates	1	1	0	0	0	5	7
Uzbekistan	0	0	0	35	44	63	142
Vietnam	1	1	1	2	7	9	21
totals	25	35	57	109	155	408	789

other hand, it may also be less than the actual number of papers published, given that not all papers have countries in the affiliation field.

3. Country statistical data

The following data have been collected for the 86 countries in Tables 3 and 4:

• Col. 2. The number of IAU individual members in each country as at February 2006. These are professional astronomers resident and working in that country, according to IAU records. They are not necessarily citizens of the country in which they reside and work.

• Col. 3. The total number of refereed papers published 1976–2005 (from Tables 1 and 2).

• Col. 5. Gross domestic product per capita in $US/capita. The data have been taken from http://www.photius.com/rankings/economy/gdp_per_capita_2006_1.html and refer to data for the year 2006.

• Col. 6. Population in millions taken from http://www.photius.com/rankings/population/population_2006_1.html. These figures also refer to 2006.

From these data the following statistics have been calculated for each country:

• Col. 4. Published papers per IAU member per year. This is a measure of the productivity of the astronomers in a country. It is recognized that many publishing astronomers may not be IAU members. Hence the actual average published output per individual will in general be less than the figure given here. However, the parameter still allows

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

comparisons between countries to be made, and it should be regarded as a relative productivity index.

• Col. 7. IAU individual members/million of population. This is a measure of the support for astronomy in a given country

• Col. 8. Papers published per year per billion US dollars of GDP. This is a measure of the fraction of a country's financial resources that has gone into astronomical research outputs. The mean papers per year between 1976 and 2005 has been used. The GDP (GDP/capita times population) is for 2006.

These parameters are listed in Table 3 for IAU member countries, and in Table 4 for non-member countries having individual astronomers.

Table 5 summarizes some data pertaining to the statistics of IAU individual and national members. It shows that 112 out of 197 countries (almost 57% of all countries) have no IAU members and only 62 out of 197 (31%) adhere to the IAU. However, the non-member countries often have small populations. It is noted that only two countries (out of 11) with populations that exceed 10^8 do not belong to the IAU (these are Pakistan and Bangladesh).

In fact, 76% (4.9 billion out of 6.5 billion) of the world's total population lives in an IAU member country. Only 14% of the world's population (937 million people) live in a country with no professional astronomical activity. Likewise, almost 99% (8867 out of 8977) of the world's IAU individual members live in a country that adheres to the IAU. These numbers show that the IAU has been very effective in reaching a majority of the countries where professional astronomers operate.

Taken globally, the ratio of IAU individual members to the world's total population is 1.39 IAU astronomers/million of population. For the 62 IAU member countries, this ratio is 1.81, and for 135 non-member countries it is just 0.07 astronomers/million.

4. Global statistics of published papers in astronomy

Table 6 gives global statistics of published papers in astronomy and astrophysics listed in ADS for the 30 years 1976–2005. Over this period nearly 900 000 published items appeared in print, or an average of nearly 30 000 per year. Of these, 43% were refereed papers.

The table shows that unrefereed papers have grown from about 8000 per year in 1976–80 to nearly 30 000 annually in 2001–05, an increase of 3.7 times in 25 years. For refereed papers, the growth is from 9000 a year in the late 1970s to 17 500 annually now, a growth by a factor of 1.9. Unrefereed papers have therefore grown the more strongly. Refereed papers accounted for over half of all papers a quarter of a century ago, but they are little more than a third of all papers today.

5. Comparison of publications from IAU and non-IAU member countries

The data of Tables 1 and 2 allow a comparison of the number of refereed papers from IAU member countries (Table 1) with the number from non-IAU countries (Table 2) as a function of time for the years 1976–2005. The sums of the numbers of papers for IAU member countries, and for non-IAU members is given in Table 7. Over this period only 789 refereed papers came from non-IAU member countries, compared with over a third of a million from IAU member countries. The ratio of IAU individual members in non-member to member countries is 110:8860 (in February 2006) or 0.0124 – just over 1 per cent. But the ratio of refereed papers is 2.29×10^{-3}, indicating the roughly five

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

Table 3. Country statistical data: IAU member countries

country	2006 data # IAU members	papers 1976–2005 total	papers/ IAU memb. per yr.	2006 data $US GDP/cap.	2006 data millions popul.	IAU members per mill.	papers/yr /GDP (GDP $bill.)
Argentina	105	1914	0.61	13700	39.9	2.63	0.117
Armenia	25	1053	1.40	5300	3.0	8.33	2.208
Australia	225	9196	1.36	32000	20.3	11.08	0.472
Austria	35	2118	2.02	32900	8.2	4.27	0.262
Belgium	99	3210	1.08	31900	10.4	9.52	0.323
Bolivia	0	29		2700	9.0	0.00	0.040
Brazil	142	3817	0.90	8400	188.1	0.75	0.081
Bulgaria	48	1089	0.76	9000	7.4	6.49	0.545
Canada	220	12244	1.86	32900	33.1	6.65	0.375
Chile	55	1581	0.96	11300	16.1	3.42	0.290
China (P.R.C.)	282	6772	0.80	6300	1314.0	0.21	0.027
China Taipei	24	889	1.23	26700	23.0	1.04	0.048
Croatia	13	209	0.54	11600	4.5	2.89	0.133
Cuba	5	24	0.16	3300	11.4	0.44	0.021
Czech Rep+Slovakia	107	2883	0.90	16950	15.7	6.82	0.361
Denmark	60	2600	1.44	33400	5.5	10.91	0.472
Egypt	57	428	0.25	4400	78.9	0.72	0.041
Estonia	23	403	0.58	16400	1.3	17.69	0.630
Finland	53	2232	1.40	30600	5.2	10.19	0.468
France	631	25672	1.36	30000	60.9	10.36	0.468
Germany	486	33353	2.29	29800	82.4	5.90	0.453
Greece	97	2069	0.71	22800	10.7	9.07	0.283
Hungary	44	1324	1.00	16100	10.0	4.40	0.274
Iceland	4	121	1.01	34900	0.3	13.33	0.385
India	209	6233	0.99	3400	1095.4	0.19	0.056
Indonesia	19	133	0.23	3700	245.5	0.08	0.005
Iran	18	251	0.46	8100	68.7	0.26	0.015
Ireland	30	913	1.01	34100	4.1	7.32	0.218
Israel	63	2791	1.48	22300	6.4	9.84	0.652
Italy	448	19483	1.45	28400	58.1	7.71	0.394
Japan	503	16349	1.08	30700	127.5	3.95	0.139
Korea	67	2123	1.06	20400	48.8	1.37	0.071
Latvia	15	132	0.29	13000	2.3	6.52	0.147
Lithuania	16	250	0.52	13900	3.6	4.44	0.167
Malaysia	5	25	0.17	10400	24.4	0.20	0.003
Mexico	92	3452	1.25	10100	107.4	0.86	0.106
Morocco	7	61	0.29	4300	33.2	0.21	0.014
Netherlands	190	10561	1.85	30600	16.5	11.52	0.697
New Zealand	27	861	1.06	24200	4.1	6.59	0.289
Nigeria	4	115	0.96	1000	131.9	0.03	0.029
Norway	21	1282	2.03	42400	4.6	4.57	0.219
Peru	4	65	0.54	6100	28.3	0.14	0.013
Philippines	3	15	0.17	5100	89.5	0.03	0.001
Poland	129	3903	1.01	12700	38.5	3.35	0.266
Portugal	35	822	0.78	18600	10.6	3.30	0.139
Romania	37	444	0.40	8400	22.3	1.66	0.079
Russia	366	20561	1.87	10700	142.9	2.56	0.448
Saudi Arabia	11	99	0.30	12900	27.0	0.41	0.009
Serbia, Montenegro	23	503	0.73	2700	10.8	2.13	0.575
South Africa	73	2145	0.98	12100	44.2	1.65	0.134
Spain	239	8974	1.25	25200	40.4	5.92	0.294
Sweden	108	3959	1.22	29800	9.0	12.00	0.492
Switzerland	92	4890	1.77	35300	7.5	12.27	0.616
Tajikistan	6	355	1.97	1200	7.3	0.82	1.351
Turkey	45	729	0.54	7900	70.4	0.64	0.044
Ukraine	160	3497	0.73	6800	46.7	3.43	0.367
UK	589	19482	1.10	30900	60.6	9.72	0.347
Uruguay	4	86	0.72	16000	3.4	1.18	0.053
USA	2347	93154	1.32	42000	298.4	7.87	0.248
Vatican	5	239	1.59	0.0			
Venezuela	17	395	0.77	6500	25.7	0.66	0.079
totals/mean value	8867	344501	1.30		4925.3		

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

Table 4. Country statistical data: IAU non-member countries

country	2006 data # IAU members	papers 1976–2005 total	papers/ IAU memb. per yr.	2006 data $US GDP/cap.	2006 data millions popul.	IAU members per mill.	papers/yr /GDP (GDP $bill.)
Albania	1	0	0.00	4900	3.6	0.28	0.000
Algeria	3	0	0.00	7200	32.9	0.09	0.000
Azerbaijan	8	24	0.10	4700	8.0	1.00	0.021
Columbia	2	7	0.12	7100	43.6	0.05	0.001
Ecuador	1	2	0.07	3900	13.5	0.07	0.001
Ethiopia	1	1	0.03	800	74.8	0.01	0.001
Georgia (Republic)	18	175	0.32	3300	4.7	3.83	0.376
Honduras	2	1	0.02	2800	7.3	0.27	0.002
Iraq	6	34	0.19	3400	26.8	0.22	0.012
Kazakhstan	9	20	0.07	8800	15.2	0.59	0.005
Korea DPR	20	0	0.00	1800	23.1	0.87	0.000
Lebanon	2	30	0.50	5300	3.9	0.51	0.048
Macedonia	1	3	0.10	7600	2.1	0.48	0.006
Malta	1	2	0.07	19000	0.4	2.50	0.009
Mauritius	2	14	0.23	13200	1.2	1.67	0.029
Mongolia	0	16		2200	2.8	0.00	0.087
Sri Lanka	3	7	0.08	4300	20.2	0.15	0.003
Singapore	3	56	0.62	29900	4.5	0.67	0.014
Pakistan	1	57	1.90	2400	165.8	0.01	0.005
Slovenia	6	109	0.61	21000	2.0	3.00	0.087
Thailand	3	61	0.68	8300	64.6	0.05	0.004
United Arab Emirates	3	7	0.08	29100	2.6	1.15	0.003
Uzbekistan	11	142	0.43	2000	27.3	0.40	0.087
Vietnam	3	21	0.23	3000	84.4	0.04	0.003
totals	110	789			635.3		

Table 5. Statistics of astronomers in countries, 2006 data

	Number of countries	Population (millions)	Number of IAU individual members
Countries in world	197	6465	8977
IAU member countries	62	4892	8867
Non-IAU member countries but with individual members	23	635	110
Non-IAU member countries with no astronomers	112	937	0

Table 6. Global statistics of published papers in astronomy, 1976–2005

years	unrefereed	refereed	total	per cent ref.
1976–1980	40 157	45 430	85 587	53.1
1981–1985	60 673	52 091	112 764	46.2
1986–1990	73 257	58 823	132 080	44.5
1991–1995	80 362	65 192	145 554	44.8
1996–2000	109 013	74 671	183 684	40.7
2001–2005	148 657	88 239	236 896	37.2
total	512 119	384 446	896 565	42.9

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

Table 7. Statistics of refereed papers in astronomy, 1976–2005, comparing papers from IAU member and non-member countries

years	papers from IAU member countries	papers from non-IAU member countries	sum of IAU plus non-IAU member countries	ratio non-member to member countries
1976–1980	33005	25	33030	7.6×10^{-4}
1981–1985	41114	35	41149	8.5×10^{-4}
1986–1990	45203	57	45260	1.26×10^{-3}
1991–1995	43015	109	43124	2.53×10^{-3}
1996–2000	58388	155	58543	2.65×10^{-3}
2001–2005	123837	408	124245	3.29×10^{-3}
total	344562	789	345351	2.29×10^{-3}

times lower productivity of astronomers in non-IAU member countries. However, the proportion of papers coming from non-IAU member countries has been steadily rising over the last 30 years, as is shown in Table 7.

6. Analysis of the data by country

Fig. 1 shows a plot of IAU members/million versus GDP/capita in US dollars. This is a measure of the relative amount of astronomical activity in a given country. Both IAU member countries (Table 3) and non-members (Table 4)are included.

The results show a strong correlation between these parameters. The wealthier countries have more astronomers per million of population. For most countries the approximate relation IAU members/million = (1/3500)(GDP/capita)applies. The IAU members/million value varies between zero and about 14 for nearly all countries. All IAU non-member countries have relatively few astronomers (less than or equal to 3.0 per million) except for Georgia (3.8/million).

However, a few countries stand out from the overall trend. Estonia with 17.7 astronomers/million has easily the highest number of astronomers per capita, and Armenia (8.3 astronomers/million) is unusually high for its GDP/capita.

Among IAU member countries, South Korea, China Taipei, Japan, Austria and Norway have relatively few astronomers for their GDP/capita values. So do the United Arab Emirates and Singapore for non-members. All these are developed countries.

Fig. 2 shows a plot of the papers/IAU member/year versus GDP/capita, for both IAU member countries and for non-members (Tables 1 and 2). The papers/IAU member/yr applies to total papers over the interval 1976–2005 as discussed above, while the number of IAU members was taken in February 2006. Papers/IAU member/year is a relative indicator of the productivity of astronomers in a given country. It correlates strongly with GDP/capita, as shown in the figure. For most countries, the approximate relation papers/IAU member/year = (1/20 000)GDP/capita applies. For most countries the papers/IAU member/yr varies between zero and 2.0.

A few countries stand out from the trend, for apparently having an unusually high productivity for their GDP/capita values. These are Nigeria, Tajikistan, Serbia, India, Armenia, Mexico, Russia and Germany. Undoubtedly the first two of these have so few astronomers that there is no reliable statistical sample. Others have large populations that do not fully participate in economic production, thereby lowering GDP/capita rather than boosting astronomical productivity. Only in Germany can one say that the astronomers are unusually productive.

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

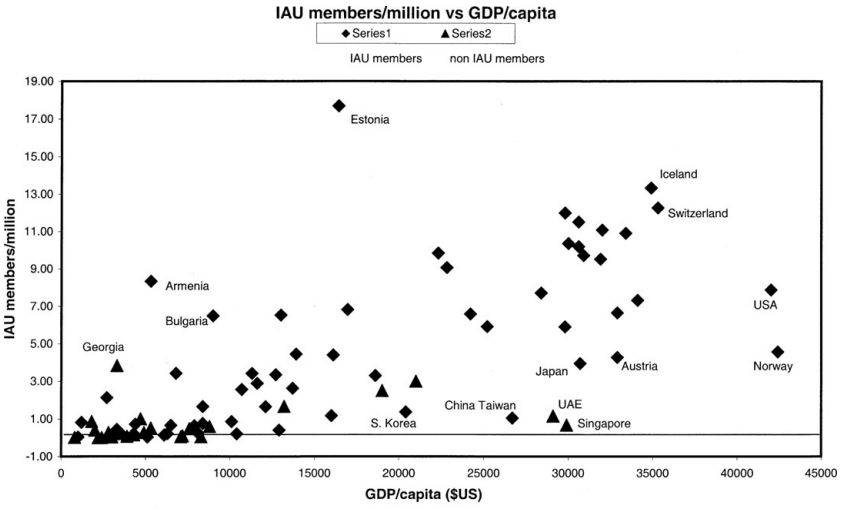

Figure 1. IAU individual members per million of population plotted against the wealth of a country given by GDP/capita. All figures are in $US. Solid squares: IAU member countries; solid triangles: IAU non-members

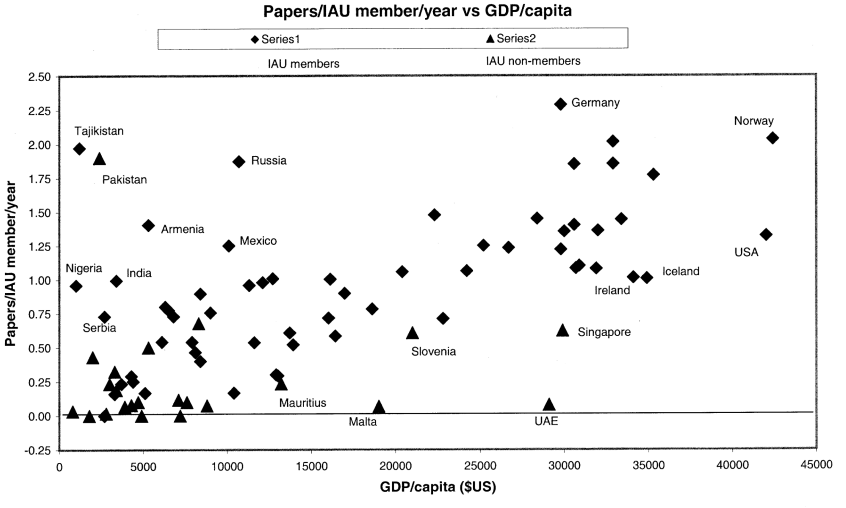

Figure 2. Papers/IAU member/yr plotted against the wealth of a country given by GDP/capita. All figures are in $US. Solid squares: IAU member countries; solid triangles: IAU non-members

Likewise, some countries stand out for astronomers of low productivity. These are Malta, United Arab Emirates and Singapore (all non-members of the IAU). Of the IAU member countries Ireland and Iceland have slightly low values of papers/IAU members/yr.

Finally, the parameter papers/year/billion dollars of GDP is plotted versus GDP/capita in Fig. 3. The ordinate (y) measures the fraction of a country's resources that have gone into astronomical research outputs, whereas the abscissa (x) is the intrinsic per capita wealth of a country. The figure shows that for IAU member countries there is a weak correlation between these parameters, as the wealthier countries tend to allocate a greater fraction of their GDP to astronomy. Approximately $y = (1./90\,000)x$. For

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

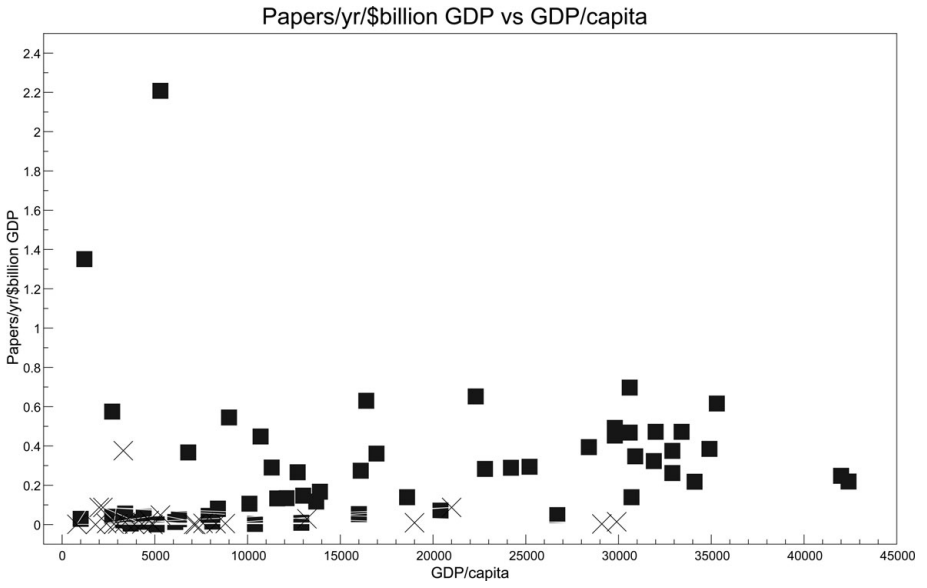

Figure 3. Papers/yr/billion dollars of GDP plotted against the wealth of a country given by GDP/capita. All figures are in $US. Solid squares: IAU member countries; crosses: IAU non-members

most IAU member countries, the values of the y parameter range between 0.0 and 0.7 papers/yr/billion dollars of GDP; however, two member countries stand out. These are Armenia ($y = 2.21$ papers/yr/billion dollars of GDP) and Tajikistan ($y = 1.35$). Apparently after the break-up of the Soviet Union, certain states such as these two were left with a strong tradition of support for astronomy, which was no doubt funded through the central Soviet economy. This strength has persisted through to recent times.

The mean value of papers/yr/billion dollars of GDP is $\overline{y} = 0.2925$ for 60 IAU member countries (excluding the Vatican and combining data for Czech Republic and Slovakia); excluding Armenia and Tajikistan gives $\overline{y} = 0.241$.

When we look at non-IAU member countries, the papers/year/billion dollars of GDP is dramatically lower. The mean value for 24 countries in Table 4 is $\overline{y} = 0.033$, which is about ten times less than for IAU members. Only Georgia ($y = 0.376$) has a value exceeding 0.1. The conclusion is that non-IAU member countries are generally applying a very small fraction of their resources to astronomy, whether or not they have strong economies (as measured by GDP/capita).

7. A comment on multi-author multi-country papers

A comparison of the numbers of refereed papers published in the period 1976–2005 in Tables 6 and 7 shows a discrepancy in the numbers reported. This is because Table 6 is the true number of individual papers published globally in astronomy, as obtained directly from ADS. On the other hand, Table 7 sums the papers published in 86 countries listed in Tables 1 and 2. (It is assumed that the papers published in countries not listed are negligible in number.) Bearing in mind the comments at the end of section 2, these two counts can differ. If the global paper count is larger than the sum of papers over all countries, this is because of the incompleteness of the country affiliations in ADS.

On the other hand, multi-author multi-country papers are counted more than once in Table 7, so the figure here can exceed the actual number of refereed papers in any year.

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

It is noted that between 1976 and 2000 the sum of refereed papers over countries was on average about 75 per cent of the total count. This is therefore an estimate of the lack of completeness of country affiliations in ADS.

On the other hand, for the time interval 2001–05, the sum of papers over countries exceeded the actual number by about 41 per cent. This represents a huge increase in the refereed paper count over countries in the last five years. The only simple explanation is that in these years each paper is counted something like twice, because there must be on average authors from two countries for each published paper. The actual number of countries per paper would depend on the completeness of the country affiliations in any time interval. The number two countries per paper comes from assuming that the completeness of country affiliations remains constant at 75 per cent.

8. Conclusions

In this survey, a number of key conclusions were reached. The main ones were as follows:

- There is a strong correlation between IAU individual members/million and GDP/capita.
- There is also a strong correlation between papers/IAU member/year and GDP/capita.
- The number of refereed papers published per year in astronomy has nearly doubled between 1976 and 2005.
- Just over one per cent of IAU individual members come from countries that do not adhere to the IAU. However, only about 0.3 per cent of papers are published by astronomers in non-IAU member countries. Although the proportion of papers from non-IAU member countries is very small, it is slowly rising.
- Non-IAU member countries allocate about a five times smaller proportion of their GDP to astronomy than do countries that adhere to the IAU.
- There has been a steep rise of multi-author multi-country papers published since 2001.

This survey represents an initial attempt to extract statistical information on country affiliations from the ADS data base. The uncertainties in the results obtained are acknowledged. Nevertheless much useful information on published paper statistics can be obtained.

It may be that more refined surveys can be carried out. In particular, a survey of citations to papers in different countries may be a better indicator of astronomical activity than simply counting the papers published from each country.

References

Hearnshaw, J.B. 2001. In *Astron. Soc. Pacific Conf. Series*, Special session on Astronomy in developing countries, ed. A.H. Batten, pp. 23–27.

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press

Jayant Narlikar

John Hearnshaw

https://doi.org/10.1017/S1743921307006618 Published online by Cambridge University Press