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Scientists who engage with society perform better academically

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Most scientific institutions acknowledge the importance of opening the so-called 'ivory tower' of academic research through popularization, industrial collaboration or teaching. However, little is known about the actual openness of scientific institutions and how their proclaimed priorities translate into concrete measures. This paper gives an idea of some actual practices by studying three key points: the proportion of researchers who are active in wider dissemination, the academic productivity of these scientists, and the institutional recognition of their wider dissemination activities in terms of their careers. We analyze extensive data about the academic production, career recognition and teaching or public/industrial outreach of several thousand of scientists, from many disciplines, from France's Centre National de la Recherche Scientifique. We find that, contrary to what is often suggested, scientists active in wider dissemination are also more active academically. However, their dissemination activities have almost no impact (positive or negative) on their careers.

Researchers and academic institutions seem to have admitted the importance of establishing strong ties between science and society. In the UK Martin Rees, president of the Royal Society, has pointed out that 'Researchers need to engage more fully with the public. The Royal Society recognizes this, and is keen to ensure that such engagement is helpful and effective'. A survey carried out by the Royal Society found that 'Most researchers have highlighted that social and ethical implications exist in their research, agree that the public needs to know about them, and believe that researchers themselves have a duty, as well as a primary responsibility, for communicating their research and its implications to the non-specialist public' (Royal Society, 2006).

In the 'Multi-year action plan', the document supposed to steer its long-term policy, France's CNRS (Centre National de la Recherche Scientifique) declared that one of its six top priorities is 'to transfer research results to industries' and another is 'to strengthen the relations between science and society' (CNRS, 2004). In February 2007, CNRS organized an official workshop on 'Science and society in transformation', which was attended by many CNRS officials (Allix, 2007). This attitude seems to be shared by the majority of researchers: in her study on the attitudes of researchers towards popularization, Suzanne de Cheveigné (2007) concluded: 'All interviewed researchers unanimously declared: popularization is now a key and unavoidable component of research work'. Motivations provided by the researchers are numerous: the yearning to inform the public, to make one's field of research better known and encourage students to take up science, or the need to account to civil society for the use of funds provided to laboratories.

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The reality in the field is generally aloof from these generous ideas. For example, in the CNRS application form for candidates to the *Directeur de Recherche* (senior scientist) grade, a mere nine lines are provided for summarizing 20 years of research dissemination. Likewise, the Royal Society survey concluded that, for most scientists, 'research is the only game in town', and popularization has to be done after one is through with 'real' work.

The purpose of this paper is to obtain an empirical picture of dissemination practices in France's CNRS. Although its prime responsibility is research done in France, the CNRS website claims that it is Europe's largest funder of research. We have presented (Jensen and Croissant, 2007) a statistical view of CNRS scientists involved in popularization. Here, we also include data on teaching (teaching is not a duty of CNRS researchers) and industrial collaborations. Moreover, we correlate these data with scientists' academic activity, as quantified by bibliometric records. We are therefore able, perhaps for the first time, to help answer two important questions about scientists active in dissemination beyond the usual professional publications and conference or workshop presentations: are they 'bad scientists' as some scientists have suggested (Royal Society, 2006)? Do they receive any institutional recognition in terms of their careers? We aim to answer these questions by analyzing extensive data about the academic production, career recognition and teaching or public/industrial outreach of several thousand CNRS scientists from many disciplines.

Methodology

Thanks to the CNRS Human Resources databases, we have gathered data on the wider dissemination activities (public outreach, industrial collaborations and teaching) of the 11000 CNRS scientists over a three-year period (2004–2006). It should be noted that this data has been provided by the scientists themselves in their individual annual reports (*Compte Rendus Annuels des Chercheurs*). This annual report is not judged to be very important for their career, serious evaluations only take place when scientists are candidates for more senior positions. However, filling out the report is mandatory and most researchers (over 90% each year) do submit it on time. Many reasons could lead to some underestimation of the amount of activities declared in these reports, including fear of misperception of popularization activities by committees, laziness in faithfully reporting these minor activities etc. Inversely, lack of control over these items could favor some overreporting of dissemination activities, although this is not likely since they have almost no perceived impact on one's career. Hence, we could anticipate some underestimation of wider dissemination activities in the figures below.

'Popularization' activities include: public or school conferences, interviews in newspapers, collaboration with associations, and similar activities. Clearly, there is no entirely satisfactory definition of popularization. As Hilgartner (1990) has convincingly shown, there is a continuous gradation going from the technical literature to popular science, with no clear cut-off point to indicate where popularization begins. Here, popularization actions are defined by scientists themselves, according to the following operational criterion: popularization means a wide audience, actions aiming at the non-specialized public. For more details, we refer the reader to Appendix 1 and Jensen and Croissant (2007). 'Industrial collaborations' include funding from non-academic sources (81% of the activities), patents (16.5%) and licenses (2.5%). The first subcategory (funding from non-academic sources) includes funding from contracts with industrial partners (the dominant category for the natural sciences) or funding from other non-academic partners (such as regional funds). 'Teaching' is only characterized by the annual number of hours dedicated to it. CNRS researchers have no teaching duties.

We have described previously (Jensen *et al.*, forthcoming) how we managed to obtain a large but robust database of bibliometric indicators of CNRS scientists. Briefly stated, our method used the 'author search' of the Web of Science (WoS) on the subset of 8750 scientists who had filled out the CNRS individuals' report in all of the years 2004–2006. We excluded researchers in social sciences (their bibliographic records are not well documented in WoS) and in high energy physics (there were too few records in the CNRS database), leading to 6900 names. After filtering out problem records where, for example, it was not clear whether the information was all for one person or for two with the same name, we obtained a database of 3659 scientists with reliable bibliometric indicators, as checked by close inspection of several hundred records. A more detailed description of our method is given in Appendix 2 and Jensen *et al*. (forthcoming).

We have used several bibliometric indicators as proxies for traditional academic research performance: number of papers published since they started their professional career, the average number of papers published per year since they started their professional careers, number of citations or Hirsch index (h) (Hirsch, 2005). It could be argued that h by itself is not a good measure when comparing the scientific output of researchers with different career lengths. A more relevant measure might be age divided by the career length in years (h_y) (Hirsch, 2005), although we have shown that it is not perfect either, since its average value for CNRS scientists decreases with the scientist's age and this complicates the later statistical analysis (Jensen *et al*., forthcoming). However, since h_y is closer to a constant than h for scientists with different career lengths (Jensen *et al*., forthcoming), we will use it, along with the average number of papers published per year (which, in our data, does not depend on the scientist's age) and other bibliometric indicators.

Proportion of scientists engaged in wider dissemination

A summary of the subdisciplines encompassed by our database, together with some characteristic average values, is shown in Tables 1 and 2. Figures 1 and 2 show the proportion of active scientists by age and grade, for each of the three wider dissemination activities. Overall, the CNRS scientists carried out more than 7000 popularization activities and more than 4000 industrial collaborations per year, and these figures are increasing. Table 1 shows, however, that the activity is very unequally distributed: over a three-year period, about half of our scientists remained inactive in popularization or industrial collaborations. More details on popularization activities, have been given in our previous analyses (Jensen, 2005; Jensen and Croissant, 2007).

These large scientific domains are in fact heterogeneous. It is interesting to study more disaggregated data, at the discipline level (corresponding to the CNRS scientific 'sections'). Table 2 shows in detail the proportion of scientists in each of the subdisciplines engaged in popularization, teaching and industrial collaborations. For example, life science scientists are, overall, among the least active in popularization (36% in Table 1). The subdiscipline level sheds some light on this surprising result. Scientists from the 'behavior, cognition and brain' and 'biodiversity' sections are much more active (around 60–65%) while the rest, working on more fundamental, esoteric fields, are even less active than chemists.

Academic achievement of scientists engaged in wider dissemination

Many scientists view wider dissemination activities (that is, going beyond papers in journals, conference presentations etc.) as a low status occupation, done by 'those who are not good enough for an academic career' (Royal Society, 2006). This common perception was captured by the well-known 'Sagan effect': popularity and celebrity with the general public are thought to be inversely proportional to the quantity and quality of the real science being done (Hartz and Chappell, 1997). Biographers of the American astronomer Carl Sagan (Shermer, 2002) have shown that Harvard's refusal of Sagan's bid for tenure, and the National Academy of Science's rejection of the nomination of Sagan for membership, was a direct result of the belief in this effect. By analyzing his publication record, they have also shown that there is no such effect: 'Throughout his career, which began in 1957 and ended in December 1996, upon his untimely death, Sagan averaged a scientific peer-reviewed paper per month. The 'Sagan effect', at least when applied to Sagan himself, is a

Table 1. Percentage of inactive (no action or no teaching, respectively), active (less than 10 outreach actions or less than 4 industrial collaborations or less than 210 teaching hours, respectively) and very active scientists for the various CNRS scientific sections. This division into subpopulations is more instructive than the mean number of actions, as the activity is very unequally distributed among researchers: the 5% most active account for half of the actions (Jensen, 2005). Figures correspond to the total activity in the period 2004–2006. CNRS researchers do not have any teaching duties

Domain	Popularization			Industrial collaboration			Teaching		
	Inactive	Active	Very active	Inactive	Active	Very active	Inactive	Active	Very active
Physical sciences	59	39	2	63	35	2	46	50	4
High energy physics	45	54	1	95	5	0	71	27	2
Life sciences	64	34	2	43	53	4	33	66	1
Engineering	52	46	2	19	74	7	22	69	8
Chemistry	65	34	1	39	52	9	42	55	2
Earth sciences, astrophysics	36	57	7	59	41	1	31	67	1
Social sciences	27	62	10	68	32	0	17	76	8
All CNRS	53	43	4	49	47	4	33	63	4

Table 2. Details of Table 1 by subdiscipline. The precise names of the CNRS 'sections' have been shortened for simplicity. The discipline 'high energy physics' of Table 1 corresponds to 'interactions, particles and strings' As in Table 1, we show the percentage of active (less than 10 popularization actions or less than 4 industrial collaborations or less than 210 teaching hours, respectively) and very active scientists (i.e. more active than the previous figures) for the CNRS scientific subdisciplines. For simplicity, we have not shown the percentages of inactive (no action or no teaching, respectively) scientists. These can be easily calculated from the difference to 100% of the sum of the two columns 'active' and 'very active'. Figures correspond to the total activity in the period 2004–2006

		Subdiscipline	Popularization		Industrial		Teaching	
			Active	Very active	Active	Very active	Active	Very active
Physical sciences	1	Mathematics	30	3	16	1	61	7
	2	Physics, theory and method	29	3	25	1	43	3
	3	Interactions, particles and strings	54	1	5	0	27	2
	4	Atoms and molecules	43	1	40	3	51	4
	5	Condensed matter: dynamics	44	3	45	2	51	3
	6	Condensed matter: structure	42	1	42	1	38	6
Engineering	7	Information science	47	1	71	3	76	6
	8	Micro and nano-technologies	44	2	72	15	59	11
	9	Materials and structure	48	2	80	3	76	14
	10	Fluids and reactants	45	4	80	5	68	6
Chemistry	11	Super/macromolecular systems	42	1	52	11	62	1
	12	Molecular architecture synthesis	29	0	47	8	54	4
	13	Physical chemistry	33	1	43	3	53	2
	14	Coordination chemistry	37	1	53	14	44	3
	15	Materials chemistry	35	1	59	12	57	1
	16	Biochemistry	28	1	52	7	66	0
Earth sciences, astrophysics	17	Solar systems and the universe	56	14	20	0	44	1
	18	Earth and earth plants	59	4	39	0	79	3
	19	Earth systems: superficial layers	56	5	52	1	64	1
	20	Continental surface	56	3	66	1	80	1
Life sciences	21	Molecular basis of life systems	27	1	58	6	61	3
	22	Genomic organization	26	1	43	2	62	2
	23	Cellular biology	25	0	50	4	63	2
	24	Cellular interaction	29	0	50	5	66	2
	25	Physiology	32	2	57	3	64	0
	26	Development, evolution	32	1	46	2	67	0
	27	Behaviour, cognition and brain	59	6	63	1	78	1
	28	Integrative vegetal biology	34	0	52	4	60	0
	29	Biodiversity, evolution	54	8	60	1	81	1
	30	Therapy, pharmacology	38	1	58	12	63	1
Human and social sciences	31	Human evolution	63	16	24	0	82	5
	32	Ancient and medieval history	66	9	13	0	71	8
	33	Modern and contemporary history	65	10	19	0	75	5
	34	Languages, language and speech	54	4	32	1	75	8
	35	Philosophy	58	10	20	1	63	8
	36	Sociology	68	11	42	0	80	9
	37	Economics and management	43	6	61	1	80	7
	38	Society and cultures	69	9	26	0	78	2
	39	Environment and society	71	9	62	0	82	11
	40	Politics, power	64	19	49	1	79	15

'chimera' (Shermer, 2002). In the following, we will test on a larger scale whether such an effect exists for CNRS scientists, i.e. whether scientists engaged in popularization perform less well academically than the average. To anticipate our conclusion: we find exactly the opposite correlation: scientists engaged with society are more active than average.

Comparing bibliometric indicators of narrow and wider disseminating scientists

We begin by comparing the average academic performance of scientists who disseminate widely with those who restrict themselves to the conventional journals and conferences. The precise question we investigate is: if we choose a scientist at random and ask her or him whether she or he is active in wider dissemination, does the answer tell us something about her or his academic performance? According to the common view quoted above, the answer should be that a wider disseminating scientist has, on average, a weaker academic performance, which should be reflected in lower bibliometric indicators. Our data shows exactly the opposite effect.

Figure 3 shows that activity in wider dissemination is correlated with higher academic indicators. Scientists inactive in both popularization and industrial collaborations (roughly 30%) have a lower academic performance (h_y = 0.65), which also decreases for those who are also inactive in teaching (15%, h_y = 0.62). If one uses the average number of papers published per year, the conclusion is similar:

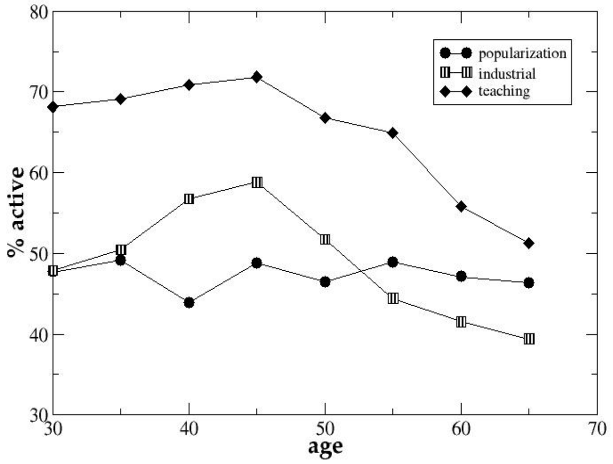

Figure 1. **Evolution of the proportion of scientists active in dissemination as a function of their age. Data correspond to the whole database, i.e. before filtering with bibliometric indicators**

the average value is 2.28, while dissemination-active scientists have significantly higher average values (popularization: 2.38, p-value 2.6 × 10^{-5}, industrial collaboration 2.45, p-value < 2.2 × 10^{-16}, teaching: 2.35, p-value 8 × 10^{-6}).

A potential danger of this kind of general comparison is the well-known variability of average h_y indexes among different scientific disciplines (Iglesias and Pecharromon, 2007). Therefore, we calculated the differences in h_y between scientists of the same discipline but engaged differently in dissemination activities. Our results (Table 3) confirmed that widely disseminating scientists are always, on average, academically more active than the inactive ones, even if the smaller number of scientists investigated prevents the results from being statistically significant for some disciplines. It should also be noted that h_y is not always the best indicator of academic activity. For engineering, the average number of papers published accounts better for promotion (Jensen *et al.*, forthcoming). Taking this indicator, differences between active and inactive scientists (in terms of wider dissemination) become significant in favour of active scientists (e.g. popularization-active scientists from engineering sciences have an average publication rate over their professional life of 2.12 papers per year, instead of 1.93 for the inactive ones, p-value = 0.07).

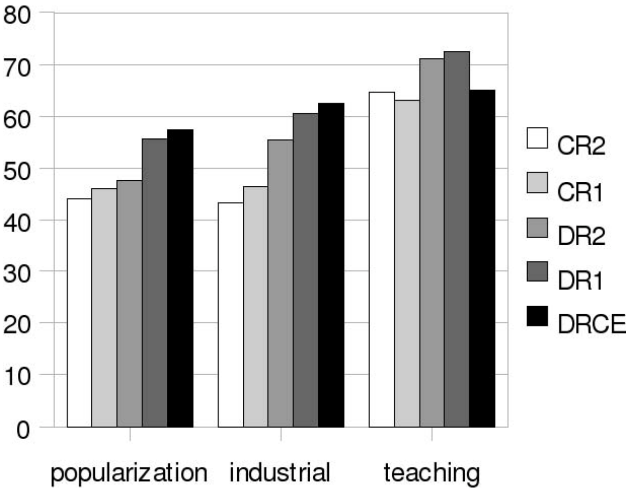

Figure 2: **Evolution of the proportion of scientists active in dissemination as a function of their position. Data correspond to the whole database, i.e. before filtering with bibliometric indicators**

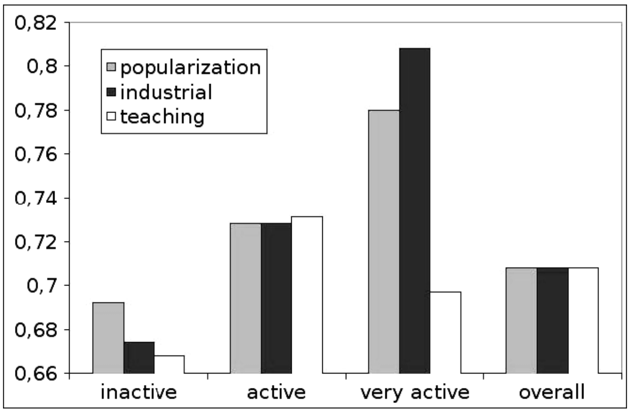

Figure 3: **Average h_y for inactive, active, or very active scientists (see Table 1 for the definitions) in the different dissemination activities. Researchers in the social sciences are excluded because their bibliographic records are not well documented in WoS. Variance tests on the indicators ensured that they were strongly significant (for popularization: *F* = 6.9, p-value = 0.01; for industrial collaborations: *F* = 18.6, p-value = 0.00004. For teaching, active scientists have a significantly higher h_y than the non-active, p-value = 0.0003). However, in contrast to the situation for dissemination, the very active ones have the same h_y as the mean (the small difference is not statistically significant). Our data pointed to an 'optimal' value of roughly 20–30 teaching hours per year, additional hours lowered the value of h_y.**

Scientists active in all wider dissemination activities

It is also interesting to look at the academic records of the scientists active in all three of the wider dissemination areas. They represent roughly 20% of our 3659 database, which is much more than expected if the engagements in the three different dissemination activities (teaching, industrial collaboration and popularization) were uncorrelated (14%). This points to an 'open' attitude, which makes a scientist practicing popularization more prone to teach or establish industrial collaborations. This high percentage is contrary to what one could expect from a 'time consumption' argument, where each of these activities lowers the activity in the others. From an academic point of view, scientists who participate in more than one dissemination activity are more active academically than those who carry out only one of them. The precise values are: scientists active in all three dissemination activities have a h_y of 0.75 against 0.70 for the others (p-value = 0.0001), those active in industrial collaborations and teaching 0.74 against 0.69 (p-value = 2.0 × 10^{-5}), those active in industrial collaborations and popularization 0.74 against 0.70 (p-value = 0.012), those active in popularization and teaching 0.74 against 0.70 (p-value = 0.0008).

Table 3. Differences in scientific activity, as measured by the normalized Hirsch index, for different subpopulations, characterized by the strength of their dissemination activities. To simplify the presentation, we only keep two categories: inactive and active, the latter grouping the 'active' and 'very active' categories of Table 1. We also show the p-values obtained by a standard 'Welch two sample t-test' and the number of scientists in each domain

	Inactive h_y	Active h_y	p-value	Number of scientists
Popularization				
Physical sciences	0.68	0.73	0.036*	669
Life sciences	0.75	0.81	0.0018**	1275
Engineering	0.50	0.52	0.38	504
Chemistry	0.73	0.74	0.54	848
Earth sciences, astrophysics	0.69	0.77	0.037*	363
Industrial collaboration				
Physical sciences	0.65	0.78	$<1\times10^{-6}$***	669
Life sciences	0.69	0.83	$<1\times10^{-6}$***	1275
Engineering	0.47	0.52	0.17	504
Chemistry	0.69	0.75	0.0066**	848
Earth sciences, astrophysics	0.74	0.74	0.96	363
Teaching				
Physical sciences	0.69	0.70	0.77	669
Life sciences	0.67	0.81	$<1\times10^{-6}$***	1275
Engineering	0.47	0.52	0.12	504
Chemistry	0.69	0.76	0.0004***	848
Earth sciences, astrophysics	0.74	0.76	0.58	363

Notes: Standard significance codes are used for the p-values: * for <0.05, ** for <0.01, *** for <0.001

Dissemination activity of the 'best' scientists One can also look at the dissemination performance of the (academically) most active scientists, taken as those whose h increases faster than their career time ($h_y > 1$) (totaling 1/6 of our CNRS researchers). They are more active in popularising (44% of active instead of 37%, p-value = 0.0035), industrial dissemination (56% of active instead of 51%, p-value = 0.035) and teaching (69% of active instead of 60%, p-value = 7.5×10^{-5}. The same correlations are found by discipline, even if, again, the differences are less significant, except for biology and physics.

Dissemination activity of 'those who are not good enough' Finally, one can investigate whether 'those who are not good enough for an academic career' (Royal Society, 2006) are the most active in wider dissemination. Our previous result suggested that this is not the case, this was confirmed by a statistical analysis. Taking as 'not good enough' the 25% of our CNRS scientists with the lowest value for h_y (lower than 0.5), we find that these scientists are also less active in wider dissemination, the precise figures being 39.4% active for popularization instead of 41.4% for the rest of the scientists (p-value = 0.25 i.e. not significant), 52.1% active for industrial collaboration instead of 57.8% (p-value = 0.0025) and 60% active for teaching instead of 67% (p-value = 0.0002). Even stronger differences (all highly significant statistically) are found if the number of publications per career year is used as the bibliometric indicator, which could be more appropriate when comparing scientists of different ages (Jensen *et al.* forthcoming) (for example, 35.7% of the 'not good enough' are active in popularization instead of 42.6% in the rest of the scientists, p-value = 0.00021).

Which scientists are active in wider dissemination?

In the previous section, we have shown that scientists engaged in wider dissemination, be it popularization, teaching or industrial collaborations, are academically more active than other researchers. To be precise, we have shown that if you randomly select a scientist and ask her or him whether she or he is active in dissemination, a positive answer is a sign of higher bibliometric indicators. We now investigate the separate effects of the available characteristics of our scientists on the probability that they are active in wider dissemination. This will help us to interpret the correlations between academic and wider dissemination activities (see next section).

We conducted a statistical analysis in order to single out the individual effects of each one of these characteristics, all other things being equal. For example, for a (hypothetical) average researcher, we analyzed the effect of her or his position, i.e. how much it separately increases (or diminishes) her or his probability of being active in popularization, for example. Since the variable that we investigated is a logical variable (either active or inactive), we have used a standard logit regression model.[1] In this model, the probability of being active is written as $P(y_i = 1) = F(\beta' x_i)$ where β' is the vector of fitted coefficients and x_i the vector of characteristics of scientist i (age, position etc.). The marginal effect of a variation of the variable x_{ik} (where k refers to one of the characteristics) on the probability of being active can be written as $\partial P(y_i = 1)/\partial x_{ik} = \partial F/\partial x_{ik}(\beta' x_i) = \beta_k F'(\beta' x_i)$. In a logit model, $F(z) = e^z/(1 + e^z)$, which leads to $F'(z) = e^z/(1 + e^z)^2 = F(z)(1 - F(z))$. This function reaches its maximum for $z = 0$, which corresponds to an activity probability of 0.5, leading to a proportionnality coefficient of 1/4. Therefore, a simple interpretation of the effect of a scientist's characteristic on her or his probability of being active is as follows: the maximum marginal effect of a characteristic equals the corresponding coefficient divided by a factor 4. For example, the isolated effect of an age increase of one year is a decrease of about 0.027/4 × 100 = 0.6% of the probability of being a popularizer. Being 'CR1' decreases the probability of being active in industrial collaborations by 18% compared to a 'DR2' sharing the same characteristics (age, sex, subdiscipline etc.).

Our results are summarized in Tables 4 and 5. The main influences of scientists' characteristics, all other things being equal, are:

1. Position: as scientists reach higher positions, they become significantly more active in all dissemination activities.
2. Academic record: there is no significant influence except for industrial collaborations. For this activity, scientists with a higher Hirsch index are more active.
3. Age: wider dissemination activities decrease with age.
4. Gender: women are more active in popularization, men in teaching, and there is no significant difference in industrial collaborations.

Results (1) and (3) represent a clear example of the usefulness of a regression study. Since age and position are strongly correlated, a simple study of the evolution of the proportion of active scientists with age is not conclusive. Figure 4 confirms that

Table 4: Binomial regressions to explain dissemination activities for 3659 CNRS scientists (filtered database). 'Active' means at least one action in the three-year period encompassed by our study (2004–2006). For popularization, this represents 1495 scientists (40.9%), for industrial collaborations 2058 scientists (56.2%) and for teaching 2373 scientists (64.9%). These percentages are different from those of Table 1 because social sciences are excluded from the filtered database. The explanatory variables are: sex, age, position, subdiscipline and Hirsch index (*h*) as bibliometric quantifier. The reference levels are: 'Condensed matter: structure' for the subdiscipline and DR2 for the position. The columns give the coefficients of the fit, together with their significance. The position 'DRCE' is almost never significant because it contains less than 100 scientists

		Subdiscipline	Press	Open days	Active in pop.	Active in industrial	Active in teaching
		Intercept	-1.8*	-1.7**	0.71	1.9***	3.1***
		h	0.037**	-0.033*	0.0020	0.019*	0.0067
		age	-0.057***	-0.0010	-0.027***	-0.052***	-0.078***
		CR2	-0.97**	0.21	-0.58**	-1.5***	-1.7***
		CR1	-0.28	0.089	-0.25*	-0.72***	-0.94***
		DR2			Reference		
		DR1	0.21	-0.37	0.24	0.70***	0.31*
		DRCE	0.37	-14	0.26	0.96*	-0.15
		Active in popularization	X	X	X	0.40***	0.39***
		Active in industrial collab.	0.37*	0.25	0.47***	X	0.61***
		Active in teaching	0.44**	0.42**	0.60***	0.40***	X
		Male	0.15	-0.21	-0.19*	-0.08	0.45***
Physical sciences	1	Mathematics	0.31	-1.6**	-0.41	-1.2***	0.96***
	2	Physics, theory and method	1.1	-0.92	-0.37	-0.64*	0.06
	4	Atoms and molecules	1.5**	0.34	0.097	-0.18	0.19
	5	Condensed matter: dynamics	0.5	-0.017	0.15	0.21	0.17
	6	Condensed matter: structure			Reference		
Engineering	7	Information science	1.3*	-0.72	-0.48	1.5***	2.0***
	8	Micro and nano-technologies	1.2*	-0.75	-0.11	2.5***	0.69*
	9	Materials and structure	1.4*	-0.53	-0.32	1.9***	2.4***
	10	Fluids and reactants	1.4*	-0.41	0.032	2.1***	1.0***
Chemistry	11	Super/macromolecular systems	-0.18	-0.04	-0.35	0.92***	0.80**
	12	Molecular architecture	-1.4	-1.1*	-0.91**	0.86**	0.73**
	13	Physical chemistry	-0.077	-0.43	-0.59*	0.011	0.46
	14	Coordination chemistry	-0.50	-0.16	-0.35	1.0***	0.027
	15	Materials chemistry	0.83	-0.8	-0.52*	1.3***	0.65*
	16	Biochemistry	0.28	-0.51	-0.81**	0.97***	0.82**
Earth sciences, astrophysics	17	Solar systems, universe	2.3***	0.56	1.2***	-1.1***	-0.11
	18	Earth and earth plants	1.6**	-0.19	0.63*	-0.37	1.9***
	19	Earth systems: superficial layers	2.3***	-0.58	0.76*	0.17	0.48
	20	Continental surface	1.8**	-0.82	0.72*	1.0**	1.4***
Life sciences	21	Molecular basis of life	0.064	-1.0*	-1.1***	1.1***	1.1***
	22	Genomic organization	-0.065	-1.5**	-1.0***	0.12	1.1***
	23	Cellular biology	-1.6	-0.97*	-1.0***	0.51	1.2***
	24	Cellular interaction	0.31	-1.4**	-0.73**	0.40	1.4***
	25	Physiology	-0.17	-1.9**	-0.69**	0.61*	1.1***
	26	Development, evolution	0.19	-0.92	-0.70**	0.37	1.1***
	27	Behavior, cognition and brain	2.7***	-1.6**	0.56*	0.78**	1.8***
	28	Integrative vegetal biology	0.53	0.063	-0.35	0.57*	0.79**
	29	Biodiversity, evolution	2.1***	-0.13	0.4	0.76*	1.6***
	30	Therapy, pharmacology	1.0	-1.3*	-0.58*	1.1***	0.85**

Notes: Standard significance codes are used for the p-values: * for <0.05, ** for <0.01, *** for <0.001

Table 5. Binomial regressions to explain dissemination activities for 3659 CNRS scientists (filtered database). 'Active in all dissemination activities' means at least one action in each of the activities over the three-year period and 'Inactive' no action in any of the three dissemination activities. The explanatory variables are: sex, age, position, subdiscipline and Hirsch index (*h*) as bibliometric quantifier. The reference levels are: 'Condensed matter: structure' for the subdiscipline and DR2 for the position. The columns give the coefficients of the fit, together with their significance

		Subdiscipline	inactive for all	Active for all
		Intercept	-6.4**	1.5**
		h	-0.01	0.027**
		age	0.10***	-0.071***
		CR2	2.3***	-1.7***
		CR1	1.1***	-0.86***
		DR2	Reference	
		DR1	-0.71**	0.60***
		DRCE	-0.23	0.20
		Male	-0.32**	-0.15
Physical sciences	1	Mathematics	0.19	-0.63
	2	Physics, theory and method	0.77*	-0.32
	4	Atoms and molecules, lasers and optics	-0.02	-0.25
	5	Condensed matter: organization and dynamics	0.19	0.74*
	6	Condensed matter: structure	Reference	
Engineering	7	Information science and technology	-1.9**	1.2***
	8	Micro and nano-technologies, electronics and photonics	-1.9***	1.4***
	9	Materials and structural engineering	-1.7**	1.7***
	10	Fluids and reactants: transport and transfer	-1.5***	1.7***
Chemistry	11	Super/macromolecular systems, properties and functions	-0.79*	0.55
	12	Molecular architecture synthesis	-0.25	0.31
	13	Physical chemistry: molecules and environment	0.31	-0.18
	14	Coordination chemistry: interfaces and procedures	-0.26	0.31
	15	Materials chemistry: nanomaterials and procedures	-0.85*	0.72*
	16	Biochemistry	-0.66	0.45
Earth sciences, astrophysics	17	Solar systems and the universe	-0.06	-0.40
	18	Earth and earth plants	-2.4***	0.62
	19	Earth systems: superficial layers	-1.9**	0.34
	20	Continental surface and interfaces	-1.2*	1.9***
Life sciences	21	Molecular basis and structure of life systems	-0.47	0.41
	22	Genomic organization, expression and evolution	0.03	0.087
	23	Cellular biology: organization and function	-0.39	0.27
	24	Cellular interaction	-0.48	0.26
	25	Molecular and integrative physiology	-0.74*	0.34
	26	Development, evolution, reproduction and aging	-0.43	0.14
	27	Behavior, cognition and brain	-1.7***	1.7***
	28	Integrative vegetal biology	-0.32	0.61
	29	Biodiversity, evolution and biological adaptation	-1.4**	1.6***
	30	Therapy, pharmacology and bioengineering	-0.46	0.80*

Notes: Standard significance codes are used for the p-values: * for <0.05, ** for <0.01, *** for <0.001

popularization activity decreases with age for all positions, but that scientists in higher hierarchical positions are much more active.

It should be noted that there are strong positive correlations between different types of dissemination. As argued previously, this shows that, in practice, different activities do not compete for the scientist's time. Table 4 also shows the specificities of the subdisciplines for the different types of wider dissemination activities. For example, mathematicians are much more active in teaching, and less in industrial collaborations.

Table 5 shows how scientists' characteristics influence the probability of being active in all the dissemination activities. In general, the effects are similar to those seen for single activities, but the effects are stronger. The main difference is the strong effect of academic performance, which is even stronger than for industrial collaborations alone. This further confirms that the different activities (academic and wider dissemination) are not competing but tend to be mutually reinforcing. Table 5 also shows the effects of age, gender etc. on the probability of being inactive in all dissemination activities. These effects are consistent (i.e. opposite) with those seen for the probability of being active, except

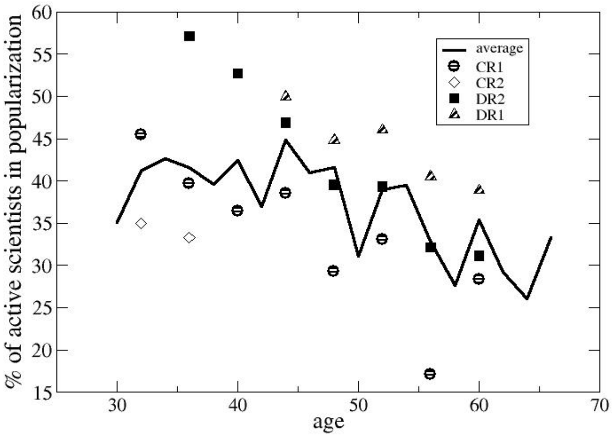

Figure 4. Evolution of the proportion of scientists active in popularization as a function of their age, on average and for different positions. Data correspond to the filtered database, i.e. without social sciences and particle physics, which explains the differences with Figures 1 and 2

for the lack of a significant effect on academic performance.

To interpret the correlations between academic and wider dissemination activities, one has to take into account the fact that our regression models quantify academic achievements in two different ways: the position and the bibliometric indicator, *h*. Since we include both in our regressions, the effect of *h* is considered 'all other things being equal', i.e. only within each position. Therefore, the lack of influence of *h* for the probability of being active in popularization (third column of Table 4) does not contradict our previous findings (e.g. Table 3). Indeed, since positions are strongly correlated with *h* and higher positions are much more active in popularization (Table 4), our regression shows that that popularization activity is more influenced by the hierarchical position than by the bibliometric indicators within each category.[2] The opposite is observed for the probability of participating in 'open day' events (second column of Table 4). Here, the position is not relevant (none significantly affects the participation even if a definite trend exists) but the Hirsch index is. A similar (but in the opposite direction) conclusion can be drawn for popularization in the press (first column of Table 4): position is only slightly relevant (except for the youngest scientists, who rarely participate), but *h* is very important, as is the scientist's age. Briefly, the main influences for the other types of actions are the following: collaboration with industrial partners are strongly (positively) influenced by the position, Hirsch index and (decreasing) age. Instead, popularization through television and conferences or industrial collaborations through patents or licenses only depend on position and age and not bibliometric indicators. Finally, participation in popularization in schools decreases with age but is unaffected by the position or academic performance.

Interpreting our results

What can we learn from this statistical study of dissemination activities? We will examine different hypothesis and compare them with our findings. Our interpretations are centered on popularization practices. We will deal with industrial collaborations and teaching in future work.

- *Hypothesis 1: Dissemination is done by 'those who are not good enough for an academic career'.* If we admit that bibliometric indicators are a good proxy for 'being good enough for an academic career', then our study clearly invalidates this hypothesis. First, randomly chosen, widely disseminating scientists have higher academic indicators than others. Second, all other things being equal, the probability of widely disseminating increases with academic position (Table 4). Furthermore, better academic records increase the probability of being active in industrial collaborations.
- *Hypothesis 2: Dissemination is done by people close to retirement.* Our study has also shown that this hypothesis is incorrect. Figure 1 shows that scientists close to retirement are less active in wide dissemination than average. Our statistical analysis also shows that, as their age increases, scientists become less active in wider dissemination, all other things being equal.
- *Hypothesis 3: Popularization is driven by demand placed upon the scientific elite.* This hypothesis assumes that popularization is driven by an external demand (institutions or journalists, for example). Then, the scientific elite, with higher bibliometric indices, is more visible from outside the scientific community, and is therefore more solicited. Our data supports this interpretation: scientists engaged in the type of popularization actions mostly driven by demand (radio, television, press, and to a lesser extent, conferences) have a higher h_y than average (Table 6). Scientists involved in popularization activities that are mostly driven by the individual scientist, and are symbolically less important (open days, school conferences, web sites etc.) have a slightly lower average h_y than the just-mentioned scientists (Tables 4 and 6).
- *Hypothesis 4: Active personality.* We have repeatedly pointed out that being active in one activity is positively correlated with being active

Table 6. Differences in scientific activity, as measured by the normalized Hirsch index, for different subpopulations, characterized by the type of their popularization activities. The first group (press, radio, public conference) refers to prestigious activities regulated mainly by the outside demand, whereas the second group (school conference, open days, web) gathers less prestigious activities mainly driven by scientists' offer. The p-values give the statistical significativity of the differences. They are obtained by a standard 'Welch two sample t-test'. Note that the differences for the first group are highly significant even if the number of scientists active in those activities is quite low: between 220 (radio/television) and 430 (public conferences)

Type of action	h_y		p-value
	Active	Inactive	
Press	0.82	0.70	1.8×10^{-6} ***
Radio, television	0.81	0.70	5.5×10^{-5} ***
Public conference	0.75	0.70	0.019 *
School conference	0.73	0.71	0.18
Open days	0.68	0.71	0.11
Web sites	0.73	0.71	0.55

Notes: Standard significance codes are used for the p-values: * for <0.05, ** for <0.01, *** for <0.001

in the others. This suggests that the correlations observed could arise from some internal characteristic of the scientists involved, call it 'active personality' or some aspect of intellectual capacity. For example, it could be argued that popularization is intellectually demanding, as it is difficult to explain complex scientific issues in simple terms. Therefore, good popularization demands a deep understanding of the subject, as anyone preparing lectures has experienced. This intellectual capacity would, in turn, generate higher academic records. Alternatively, one could interpret a widely disseminating personality as one keen to and able to 'sell' her or his work, both to journalists and to those colleagues in charge of refereeing papers and citing them. This argument is supported by the fact that scientists active in all wider dissemination activities are also very active academically.

- *Hypothesis 5: Social and cognitive hierarchies*. The observed correlations between position and dissemination activities can also be understood by referring to sociological studies of scientific communities. Shinn (1988) studied a French physics lab for several years, looking for correlations between hierarchical positions and cognitive work. He noticed a clear work division between junior and senior scientists. Junior staff devote most of their time to experiments or 'local' questions. By 'local', Shinn means questions focused on particular points: a single experiment, or a thorough investigation of a very precise subtopic. In contrast, senior scientists devote most of their time to 'general' questions, i.e. how the local results can be inserted into more global theoretical or conceptual frameworks. They also spend much time establishing and maintaining social networks both inside and outside the scientific community. Both these activities are clearly more in line with wider dissemination activities, which demand putting scientific problems into perspective. Moreover, senior scientists generally have a team of junior researchers working with them, who are active even when the seniors are away from the lab, disseminating. One could also argue that the scientific elite is able to transform its symbolic capital (Bourdieu, 1984), gained in the academic arena, into public arenas, thus popularizing not only on issues directly related to their own domain but on virtually any issue. This would lead to a correlation between higher popularization activity and academic records, as for Hypothesis 3. In an old study of popularization practices of CNRS scientists, Boltanski and Maldidier (1970) observed that senior scientists (*Directeur de Recherche*) have the legitimacy to speak to the public in the name of the institution. Scientists in the lowest positions can only express their own point of view, and popularization is mostly seen as a waste of time or a personal hobby.
- *Hypothesis 6: Benefits of dissemination*. This is the reverse causality from Hypotheses 3 and 5. Dissemination activities compel scientists to open up their horizon, to discuss with people having other points of view on their research topics, giving new insights, contacts, which could improve their academic research. Actually, Hypotheses 3, 5 and 6 could act together in a reinforcing way. It seems difficult to argue that this effect dominates, but it could contribute to the observed correlations, mainly in the case of industrial collaborations which strongly correlate with higher academic indicators.

In summary, it is likely that the strong correlations observed between wider dissemination and academic performance result from the cumulative effects of Hypotheses 3–6.

Are dissemination activities good for the career?

It is commonly recognized that scientists engaged in dissemination do not receive much reward, and that their involvement may even be bad for their career (Royal Society, 2006). In France, the CNRS director stated recently the importance of taking into consideration 'scientific culture popularization actions' for the evaluation of researchers: 'one must insist that they give equal importance to scientific work and to activities related to the popularization and dissemination of scientific culture: participations in 'open door' events, or the publication in magazines or other popularization works, in events organized for non-specialized audiences, newspaper articles or TV appearances etc.' (letter sent to CNRS scientists in 2005, our translation). In the document that was supposed to steer its long-term policy, the 'Multi-year action plan' (CNRS, 2004), the CNRS thus declared that: 'If current [evaluation] practice is suitable for the purpose of evaluating academic research, the same cannot be said for interdisciplinary activities and for other facets of scientific work: transfer of scientific knowledge, teaching and popularization. Consequently, the work by CNRS researchers who choose to engage in these activities, which are very necessary for the CNRS, is not adequately acknowledged and researchers are therefore reluctant to proceed in this direction'.

Thanks to our large database, we were able to study statistically the influence of dissemination activities on the promotions of CNRS researchers to senior positions (*Directeur de Recherche*) over the period 2004–2006. Table 7 shows the results of our regression analysis, for all CNRS disciplines and for each discipline separately. It turns out that dissemination activities are not bad for scientists' careers. They are not very good either: the effects are generally weak, but are positive, and rarely significative. The detailed study by discipline shows that the overall positive effect of popularization arises mainly from

Table 7. Binomial regressions to explain promotions to senior positions (from CR1 to DR2) on the 586 candidates and 179 promotions from all scientific disciplines of our filtered database. The last column shows the regressions for the DR2 to DR1 promotion, on 376 candidates and 67 promotions from all scientific disciplines of our filtered database. The explanatory variables are: sex, age, subdiscipline (not shown to simplify since none is significative) and *h* as bibliometric quantifier (except for engineering, where the number of articles accounts much better for the promotions, see Jensen *et al*. (forthcoming)). The columns give the coefficients of the fit for each scientific domain, together with their significance

	All	Physics	ENG	Earth	Chemistry	Life	DR1
(Intercept)	-41.2	-78.2	-71.8*	-35.41	-42.94	3.53	-49.6**
Act pop	0.4	0.01	0.068	-0.82	0.38	0.91*	-0.29
Act indus	0.12	0.88	-1.22	-0.085	0.06	0.14	0.65
Act teach	0.79**	0.76	1.66	1.08	1.06*	0.41	0.33
Male	-0.23	-0.99	0.72	0.5	-0.68	0.23	-0.36
h (or art for ENG)	0.13***	0.26***	0.038*	0.12	0.11*	0.15**	0.106***
Age	1.12***	2.48*	3.2*	1.26	0.96	0.46	1.78**
Age^2	-0.012***	-0.026*	-0.036*	-0.012	-0.0096	-0.0057	-0.017**

Notes: Standard significance codes are used for the p-values: * for <0.05, ** for <0.01, *** for <0.001

its recognition in the life sciences and the positive effect of teaching from chemistry. However, it is interesting to note that all dissemination activities positively influence promotions for most of other disciplines, even if their effects are not significative. Overall, two characteristics have strong effects: academic activity (*h* or the number of papers) and age (the 'optimal' age for becoming DR2 is 46.6 years, for DR1 52.4). For DR1 promotion, there is a small (and positive) effect from industrial collaborations.

Discussion and conclusions

Our statistical study of the correlations between dissemination activities and academic records of more than 3500 CNRS scientists from most disciplines excluding the humanities and social sciences, has allowed us to establish several facts. First, we have clearly shown that scientists engaged in wider dissemination also perform better academically, refuting the idea that wider 'dissemination activities are carried out by those who are not good enough for an academic career' (Royal Society, 2006). We have even shown that some prestigious activities (press, radio and television) are mostly carried out by the scientific 'elite' in academic terms. One can certainly criticize the idea that bibliometric indicators account properly for the academic quality of scientists (Jensen *et al*. forthcoming; Kostoff, 1998; Leydesdorff, 1998; Liu, 1993; Brooks, 1986). However, those who argue that wider dissemination activities are carried out by the 'worst' scientists usually accept this definition of scientific quality. Therefore, our paper should convince them that they are wrong.

That was the easy part of the discussion. The interpretation of our results is otherwise not easy, as there have been few qualitative studies on the perception by scientists of popularization or voluntary teaching practices. Concerning relations with industries, a group at the Catholic University of Leuven (K.U. Leuven, Belgium) examined the academic records of 32 scientist 'inventors' at their university (Van Looy, 2006). Their data suggest a 'reinforcing or positive spillover effect on scientific performance from engaging in technology development efforts', which is consistent with our findings in a much larger sample. A recent study has investigated the factors that predict scientists' intentions to participate in public engagement (Poliakoff and Webb, 2007). Thanks to a questionnaire distributed to academic staff and postgraduates, it was found that the main reasons why scientists decided not to participate in public engagement activities are the following: they had not participated in the past (a result consistent with our former finding (Jensen and Croissant, 2007)), they have a negative attitude toward participation (it is seen as 'pointless' or 'unenjoyable'), they feel they lack the skills and finally that they do not believe that their colleagues participate in such activities, which is interpreted as an indicator of the relative irrelevance of this activity. Notably, the lack of time or career recognition are not seen as important determinants of participation. Clearly, more qualitative studies on the relations of the scientific milieu and dissemination practices are needed. Here, we limit our discussion to three main issues:

First, what have we learnt about the relationship of scientists to popularization? Our study suggests that popularization is mostly an activity of the (academically speaking) scientific 'elite'. Our finding agrees with data from the Royal Society survey (Royal Society, 2006), which showed that higher positions popularize more, the differences being even larger than in our database: 86% of senior staff were involved, while a mere 14% of the junior staff joined in. The following Royal Society report comments on the difference in involvement of senior and junior staff: 'The seniority finding is borne out by the qualitative research which found that young researchers keen to climb the research career ladder were focused on research and publishing and/or felt that they needed more experience before they could engage with those outside their research community'. We may add (Hypothesis 5 above) that senior activities are more in line with dissemination that those carried out by junior staff. The question that our findings raise is then: why does a significant fraction of the scientific community feel that 'only bad scientists' popularize? Is it a problem of jealousy for colleagues that manage to present their results to a wide audience? Is that because creating knowledge is judged more important than widely disseminating it, as has been suggested by Shinn (1988)? This would imply that many scientists are still prisoners of the 'diffusion model' (Weigold, 2001), which ignores that to disseminate knowledge, one has to recreate it, an altogether creative and difficult endeavour. Qualitative interviews indicate that many reasons push scientists to engage in popularization. In private discussions, popularizers acknowledge that one of the main reasons is the pleasure of interacting with the public, of going out of the lab (Pérez *et al.*, 2008). For the Royal Society study (Royal Society, 2006) i.e. in a more official environnment, the strongest justification for popularization is 'informing the public'. We can wonder whether scientists are still prisoners of the so-called deficit model (Weigold, 2001). This is an old model for scholars of the science studies field, dating back to 1960. It insists on the teaching of elementary scientific facts and methods to the public. Listening to the public seems important to only a few percent of the scientists interviewed in the UK (Royal Society, 2006). However, this idea should be one of the strongest with a more 'generous' vision of the public in mind (Lévy-Leblond, 1992; Wagner, 2007). Scientists also seem to ignore the numerous criticisms of the deficit model: the relation between the knowledge of scientific facts and its appreciation is empirically unsolved, and the knowledge of the 'facts' of science taken out of their context is more alienating than it is informative. It is also important to establish links in the other direction, where scientists learn from society (Irwin and Wynne, 1996; Jurdant, 1993; Bensaude-Vincent, 2001). Much of the culture of the scientific milieu seems far from these ideas at the moment.

Second, what do we learn about the relationship between science and society? Our study has shown that, even in the institution hosting the most fundamental sciences, roughly half of the scientists are in close contact with society, i.e. they popularize or look for funding outside the academic sphere. This could worry some 'fundamentalists' who think that science can only work by developing its own questions, protected from the emergency and the deformation congenital to the social and economics worlds. However, our result will not surprise scholars in science studies, as they know that the 'ivory tower' of science never existed. Scientists have always been engaged with society, on which they depend for funding (e.g. Biagioli, 1993; Pestre, 2003; Latour, 1988). Even the most fundamental physical theories such as relativity (Galison, 2004) and quantum mechanics (Hoddeson *et al.*, 1992) have been inspired by applications.

Finally, another contradiction between our study and common views among scientists is the idea that wide 'dissemination activities are negative for the career'. For example, 20% of scientists of the Royal Society survey (Royal Society, 2006) answered that scientists who engage in popularization are viewed less well by their peers. Here, we have shown that promotion is mainly determined by academic performance, wide dissemination activities being marginal, counting only in specific disciplines (chemistry for voluntary teaching, life sciences for popularization). However, there is no negative effect. How can we explain the common opposite idea that pervades some of the scientific community?

We started our paper by proclaming that many prestigious institutions claim that dissemination activities are priorities. We have shown that these activities are carried out by academically active scientists, that receive no reward for their engagement. We feel that the institutions now have a duty to invent ways of evaluating and rewarding the scientists who are active in widely disseminating their work.

Appendix 1. A summary of popularization activities of CNRS scientists

To draw up their personal annual report, CNRS researchers must specify the type of any popularization activities that they have performed. Table 8 shows a distribution of types of activities according to the different scientific departments of the CNRS for the 2006 data. The categories are chosen by the scientists themselves. Most category names in Table 8 are self-explanatory. 'Associations' refer to popularization actions taken to help associations understand the scientific aspects of their activity (think of patients or astronomical associations). 'Schools' refers to actions taking place in schools. 'Web' to popularization sites on the web.

It is interesting to analyze the representation of certain disciplines for each type of activity. For instance the relatively high representation of social sciences researchers in radio/television and, to a lesser extent, in activities involving associations, the press and conferences. Not surprisingly, these researchers are by far under-represented in 'open door' events. On the other hand, their weak presence in schools is food for thought for the community. Nuclear physics, chemistry and engineering departments are relatively highly represented in 'open door' activities, which are relatively scarce in the life sciences. These departments are rather absent from engagement with the press, radio or non-professional publishing.

(*continued*)

Appendix 1 (*continued*)

Table 8 Distribution of popularization activities undertaken by scientists in various departments at CNRS

	Chemistry	Nuclear	Earth	Life	Social	Engineering	Physics	Info tech
Other	0.14	0.11	0.06	0.10	0.05	0.10	0.10	0.10
Conference	0.18	0.24	0.28	0.19	0.30	0.20	0.24	0.23
Exhibition	0.09	0.08	0.06	0.05	0.06	0.11	0.11	0.09
Associations	0.02	0.03	0.05	0.05	0.05	0.04	0.04	0.02
Schools	0.14	0.14	0.09	0.14	0.02	0.13	0.11	0.10
Books/CD Rom	0.03	0.02	0.04	0.03	0.04	0.03	0.04	0.05
Open door	0.16	0.09	0.08	0.09	0.01	0.13	0.12	0.13
Press	0.13	0.14	0.15	0.18	0.19	0.13	0.13	0.14
Radio/television	0.06	0.06	0.14	0.14	0.22	0.08	0.07	0.06
Web	0.06	0.08	0.05	0.03	0.05	0.05	0.05	0.08

Appendix 2. Obtaining reliable bibliometric indicators for the CNRS scientists

We detail our procedure to obtain a large but reliable sample (around 3500 records) of bibliometric indicators (number of publications, citations and *h* index). The difficulty lies in the proper identification of the publications of each scientist. Two opposite dangers arise. The first one consists in including extra publications because the request is not precise enough. For example, if only surname and name initials are indicated to WoS, the obtained list may contain papers from homonyms. The second one consists in missing some papers. This can happen if scientists change initials from time to time, or if the surname is that of a woman who changed her name on marriage. But this can also happen when one tries to be more precise to correct for the first danger, by adding other characteristics such as scientific discipline or French institutions for CNRS scientists. The problem is that both the records and the WoS classifications are far from ideal: the scientific field can be confusing for interdisciplinary research, the limitation to French institutions incorrect for people starting their career in foreign labs etc.

Basically, our strategy consists in guessing if there are homonyms (see below how we manage to obtain a good idea about this). If we think there are no homonyms, then we count all papers, for any supplementary information (and the resulting selection) can lead to some records being missed. If we guess that there are homonyms, then we carefully select papers by scientific domain and belonging to French institutions. After all the bibliometric records have been obtained in this way, we filter our results to eliminate ‘suspect’ records by two criteria: average number of publications per year over the person’s research career, and age at the first publication.

Evaluate the possibility that there are homonyms

For this, compute the ratio of the number of papers found for the exact spelling (for example JENSEN P.) and all the variants proposed by WoS (JENSEN P.*, meaning P.A., P.B. etc.). If this ratio is large (in our study, larger than 0.8), then the studied surname is probably not very common and the author might be the single scientist publishing. To obtain a more robust guess, we used the scientist’s age. We looked at the total number of papers and compared it to a ‘maximum’ normal rate of publishing, taken to be six papers a year. If the publishing rate was smaller than our threshold, this was a further indication that there was a single scientist behind all the records. Actually, our strategy can be misleading only when there are only homonyms with the same initial and all the homonyms have published very few papers.

Obtain the bibliometric records

No homonyms

If we guess that there is a single scientist behind the publications obtained for the surname and initials (which happens for about 75% of the names), we record the citation analysis corresponding to all associated papers.

Homonyms

If we estimate that there are homonyms, we try to eliminate them by using the supplementary data that we have. We refine the search by scientific field (‘subject category’ in WoS terms, but one can select only one) and by only selecting French institutions.[3]

Eliminate suspect records

Finally, once all the data has been gathered according to the preceding steps, we eliminate ‘suspect’ results by two criteria related to the scientist’s age. For a record to be accepted, the age of the scientist on first publication has to be between 21 and 30 years, and the average number of publications per year over their career, between 0.4 and 6. After this filtering process, we end up with 3659 records out of the 6900 initial scientists, i.e. an acceptance rate of 53%.

Can we understand why half of the records are lost? First of all, let us detail how the different filters eliminate records. Deleting scientists who published their first paper after 30 years old eliminates 1347 ‘suspect’ names, which are probably related to errors or missing papers in the WoS database, to married women for whom we miss the first papers published under their maiden name and to

(*continued*)

Appendix 2 (*continued*)

people who started their career in non-French institutions and had homonyms. Deleting scientists who published their first paper before 21 years old eliminates 1235 additional 'suspect' names, which are probably related to errors in the WoS database, to scientists with older homonyms which we could not discriminate. Deleting scientists whose record contained less than 0.4 papers per year on average leads to the elimination of 121 names. These wrong records can be explained by the method missing some publications, as in the case 'first publication after 30 years old'. Deleting scientists whose record contained more than 6 papers per year on average leads to the elimination of a further 178 names. These doubtful records can be explained by the presence of homonyms we could not discriminate between. Finally, to make our database more robust, we decided to eliminate records suspected of containing homonyms even after selection of discipline and institution. This was done by eliminating the 359 scientists for which the number of papers kept after selection was smaller than 20% of the total number of papers for the same surname and initials. In those cases, we did not trust our selection criteria sufficiently to keep such a fragile record.

A robust bibliometric database

In summary, our method leads to a reliable database of around 3500 scientists from all 'hard' scientific fields. It discriminates against married women who have changed their surname. It also suffers from the unavoidable wrong WoS records.[4] We stress that the main drawback to eliminating half of the records is the resulting difficulty in obtaining good statistics. But at least we are pretty confident about the robustness of the filtered database.

Our filtering criteria were based on homonym detection, age of first publication and publication rate. The first criteria correlates only with scientist's surnames, therefore we can expect that it introduces no bias except for married women. Actually, there is a lower proportion of women after filtering: 24.9% women in the 3659 selection, against 29.6% in the 6900 database. This is consistent with the preferential elimination of married women who changed surnames and have an incomplete bibliographical record.

The two other criteria could discriminate scientific disciplines with lower publication rates or that are underrepresented in WoS. For example, more scientists from the engineering department have been eliminated in the filtering. The mean age is somewhat lower in the filtered database (46.4 years) to be compared to 46.8 in the whole dataset, probably because the records from older scientists have a higher probability of containing errors.

However, overall, the filtered database is very similar to the initial one. For example, the percentage of candidates for senior positions is 16.0% in the 3659 selection, against 16.4% in the 6900 database, and the percentages actually promoted are, respectively, 4.9% and 5.0%. The proportions of scientists from each position is also similar: none of the small differences between the filtered and unfiltered values are statistically significant.

As noted previously, the robustness of our filtered database is validated by the significantly better indicators found for scientists in higher positions. An even stronger test (because the effect is subtler) resides in testing the correlations of the scientist's age at his or her first publication with several variables: age, position, subdiscipline and gender. We find a progressive decrease in the age of first publication when a scientist has a higher position (all things being equal, for example scientist's age), an effect that is intuitively appealing but certainly small. The fact that we can recover such a subtle effect is a good indication of the robustness of our procedure. We also recovered the intuitive effect of the scientist's age (older scientists have begun their career later). The gender effect (men publish their first paper two months later than women, all other things being equal) is more difficult to interpret, since it mixes many effects: our discrimination (in the filtering procedure) of married women, the unknown effects of marriage and children on scientists' careers etc. Finally, a word of caution: our database is robust in a statistical sense, and allows us to characterize the academic records of different scientists groups (by discipline, position etc.). Bibliometric data alone should not be used to compare individuals.

Notes

1. The statistical analysis was carried out with the open software 'R'. Available at <http://www.r-project.org/>, last accessed on 22 July 2008.
2. If positions are omittted from the regression, *h* becomes strongly significant.
3. Unfortunately, WoS allows the selection to be made only on the institutions of all coauthors as a whole. So we might retain articles of homonyms that have coauthored a paper with a French scientist.
4. For a noticeable fraction of scientists, WoS records only start in the 1990s, even if there are much older publications, which can be found by Google Scholar and other similar routes.

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