Towards indicators for 'opening up' science and technology policy

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Introduction

Recent years have seen much critical debate over the simplistic use of scientometric tools for formal or informal appraisal of science and technology (S&T) organisations (e.g. in university rankings) or individuals (e.g. the h-index) (Roessner, 2000; Van Raan, 2004; Weingart, 2005). As a reaction to these critiques, efforts have been made to improve the robustness of measurements by broadening the range of inputs considered in scientometric evaluations. Examples include the inclusion of books and national or regional journals (Martin et al. 2010), or more recently 'altmetrics' (i.e. metrics based on alternative data sources, see Priem et al., 2010). In doing so, the S&T indicator and policy communities have reverted to an early conventional wisdom that scientometrics should rely on multiple sources of data that may provide 'converging partial indicators' (Martin and Irvine, 1983).

While this 'broadening out' of the range of data used as 'inputs' in scientometric appraisal is, in our view, commendable (Stirling, 2003), we propose in this paper that a second dimension also needs to be considered. This relates to the extent to which the 'outputs' of appraisal 'open up' contrasting conceptualisations of the phenomena under scrutiny and consequently allow for more considered and rigorous attention to alternative policy options, both by decision makers and within wider policy debate (Stirling, 2005; Stirling et al., 2007, pp. 54-58; Leach et al., 2010 pp. 102-107). We use a recent comparative study on the performance and interdisciplinarity of six organisational units (Rafols et al, 2011) to illustrate the difference between increasing the range of inputs ('broadening out') and enhancing the diversity of outputs to policy decision making ('opening out'). In this way, policy appraisal can inform decision making in a more rigorous 'plural and conditional' fashion – acknowledging the way in which divergent normative assumptions and metrics can yield contrasting understandings of both the phenomena under scrutiny, and of appropriate policy responses (Stirling, 2008).

Conceptual framework: 'Opening up' versus 'broadening out' in policy appraisal

Many S&T indicators have been developed over the past 50 years as means to reveal the 'strengths' and 'weaknesses' of a given country's 'capacity' and 'performance' in science and technology (Godin, 2003). Developments by the OECD and US National Science Board (NSB), were derived from 'a pure accounting framework based on the anticipated economic benefits of science' (Godin, 2007, p. 1388) and hence with a tendency to take an essentialist understanding of scientific excellence and production, influenced by economic concepts such as 'efficiency' and 'effectiveness' (Narin, 1987). Initial scientometric studies were careful to

Comment [ss1]: "Scientometrics" is the study of measuring and analysing scientific research. Oftentimes, it is based on bibliometrics; quantitative methods using publication record.

Comment [ss2]: H-index is a popular bibliometric measurement of scientific performance. You don't have to know how it is computed to under this paper. If you are interested, see http://www.en.wikipedia.org/wiki/H-index

Comment [ss3]: Typical scientometric measurements are based on publication record; for example, how many papers you published (publication count), how many times your papers were cited (citation count).
A basic assumption of the authors is that such simplistic measurements can be misleading especially when they are used for policy decisions.

By the way, citation count is often regarded as (kind of) quality measurement for the following reason. When your paper is cited by someone else's paper, it implies that your paper provides scientific basis for the someone's research. Thus, when your paper is cited many times, it appears that your paper greatly contributes to the progress of science. The weakness of this argument is that papers may be cited for various reasons, not necessarily as a scientific basis.

declare methodological limitations, for example stating explicitly that citations were proxies and 'partial and imperfect' measures of impact rather than quality (Martin and Irvine, 1983). But whether cautious or not, the emphasis of scientometric studies has traditionally lain in producing a 'good' measure of a given concept such as 'scientific excellence', rather than in providing contrasting perspectives on what the meaning of 'excellence' is.

In recent years, various parallel developments have begun to challenge this scientometric *status-quo*. First, the pervasive diffusion of simplistic (and very possibly damaging) scientometric measures such as the h-index at various levels of management has renewed the debate over abuse and misuse of indicators (Weingart, 2005). Second, traditional scientometrics is challenged by alternative data sources, like databases from hitherto excluded countries (e.g. Brazil's Scielo), and new web-based indicators such as publication download frequency or popularity in 2.0 websites like *academia.eu* (Priem et al., 2010). Third, new tools have emerged for data visualisation (e.g. Hans Rosling's *Gapminder*), for large network analysis (e.g. Rosvall and Bergstrom, 2008) and, for science mapping (Börner, 2010), which are radically easing the presentation of complex multidimensional quantitative information to non-experts.

Comment [ss4]: A popular database used for scientometric analyses is Web of Science, as is used in this study.
One of the problems in using this database is that its coverage of non-English publications is low. As a result, the performance of scientists in non-English speaking countries (such as Japan) can be underestimated.
Knowing such a limitation, some databases attempt to offer more exhaustive publication data.

Each of these trends is pushing S&T policy towards use of indicators based on more diverse data inputs. These broader portfolios of inputs can in principle make scientometric analyses more robust. However, we contend here that this improved 'breadth' of inputs need not necessarily translate into a more plural and conditional policy process. 'Opening up' is not just about 'more' indicators, nor is it only a matter of 'positioning' or contextualising (Lepori, 2006). It's about the design and use of indicators aimed explicitly at providing plural policy understandings and options. For S&T policy to be 'opened up', indicators used in appraisal need to be re-conceived as 'debatable devices, enabling collective learning' (Barré, 2010, p. 227).

In this way, we distinguish two dimensions in any process of policy appraisal, as illustrated in Figure 1. The first dimension, 'breadth' refers to the depth, extent and scope with which appraisal includes different types of knowledge that can describe the phenomena under scrutiny (Leach et al., 2010, p. 104). The second dimension, 'openness', refers to the degree to which the outputs of appraisal provide plural and conditional interpretations of the phenomena – and thus allow contrasting policy options to be rigorously debated. Unlike analytical tools that 'close down' appraisal by establishing an absolute ranking of 'best' choices, 'opening up' tools allow decision-makers to contrast how under different assumptions the analysis may result in different rankings of options.

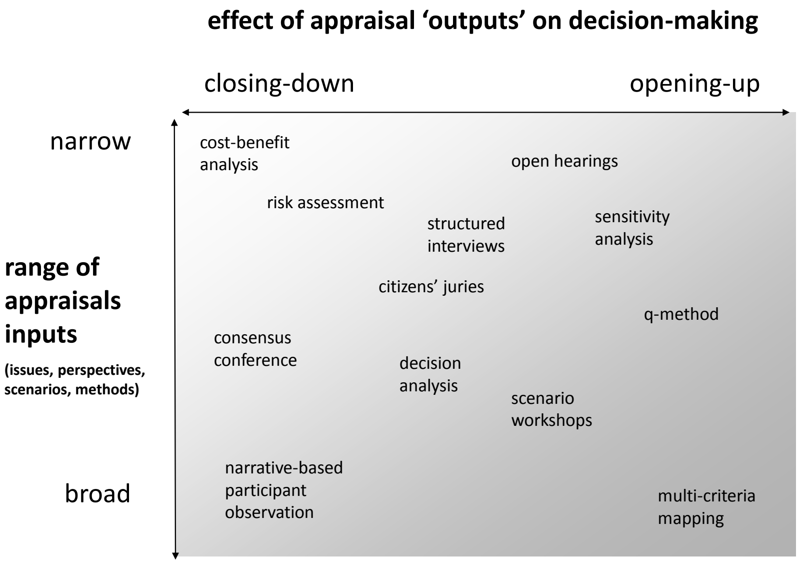


Figure 1. Characteristics of appraisal methods. Source: Stirling et al. (2007, p. 57)

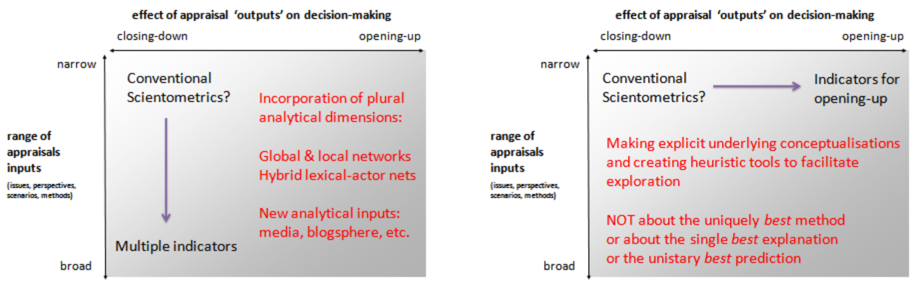


Figure 2. Difference between 'broadening out' the range of inputs used in indicators (left) and 'opening up' decision making.

Conventional scientometric appraisal is rather narrow: both in the breadth of inputs and the openness of outputs (as illustrated in Figure 2). As with cost-benefit analysis, this narrowness results from measuring performance only in one or two dimensions (e.g. production and efficiency, or number of publications and citations) and focusing disproportionately on artificially singular selections of allegedly 'best possible' methodological choices with which to handle empirical data (like normalisation routines or aggregation procedures) – even where equally reasonable alternatives yield disparate output rankings.

Some of the analytical tools in S&T indicators can be relatively broad in terms of the range of inputs. For example, the Shanghai ranking of universities takes into account six different

Comment [ss5]: The Shanghai ranking is one of the university ranking systems frequently appearing in the media.
By way of example, U Tokyo is ranked 21st in 2013.

inputs, and the European Innovation Scoreboard includes a total of 25 indicators. However, both tools create a composite index that uses simple weightings to aggregate multiple dimensions into a single scalar. These are broad in inputs but narrow in outputs (as illustrated in the left side of Figure 2). Such scalar scores 'close down' debates on performance by univocally establishing which university is 'best' or which country is 'most' innovative. Such composite indicators have been shown to be potentially misleading as 'the scope for manipulation of scoreboards by selection, weighing and aggregation is great' (Grupp and Moggee, 2004, p. 1382).

An obvious way to handle plural input dimensions is to use multidimensional representations, such as 'spider' charts (Grupp and Schubert, 2010) –preferably after conceptually and mathematically grounded reduction of dimensions. But in scientometric (and even more so, in bibliometric) analysis, the range of inputs on a given property (productivity or citation impact) is often limited by the nature of data sources. In such cases, can quantitative studies capture and convey diverse outcomes under different analytical assumptions? Our answer is yes. Even when data sources are relatively narrow, there is still scope for opening up (on the right hand side of Figure 2). Even with narrow inputs, tools can be developed that help decision makers scrutinize how different conceptualisations and associated mathematical operationalisations may yield contrasting results (even of exactly the same data). By investigating how different assumptions lead to different methods and rankings, the analyst can provide 'plural and conditional' advice – and policy makers can be more reflective and explicit about the normative aspects of their choices.

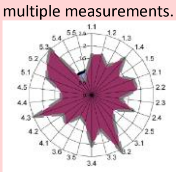
Opening up measures of interdisciplinarity and performance

Here we will explore and illustrate the process of 'opening up', by reviewing a recent bibliometric comparison of performance and interdisciplinarity in six academic organisations (Rafols et al., 2011). Both 'performance' and 'interdisciplinarity' are complex concepts that can only partially be captured by bibliometric indicators. Indicators in question were derived from only two data sources: generic journal attributes and the references contained in each publication. [1] Yet in spite of this narrowness of inputs, we show it is possible to conceive of different conceptualisations of interdisciplinarity and performance, and make multiple operationalisations of some of them.

Two conceptualisations of interdisciplinarity are shown in Figure 3. One the one hand, we can understand interdisciplinarity as disciplinary *diversity*. Thus diversity measures of the distribution of publications (or references) of a unit across disparate subject categories (as illustrated by the spread of nodes over the map of science) captures the degree to which a unit covers different disciplinary approaches. On the other hand, we can conceptualise interdisciplinarity as the degree of *coherence* in their network of categories where they publish. This aims to capture the degree of cross-fertilisation between disciplines, which

[1] These data are treated using complementary contextual information such as the classification of journals into disciplinary subject category, and the overall citation patterns across journals in all the web of science.

Comment [ss6]: This type of chart, showing multiple measurements.



Comment [ss7]: In this section, the authors present, as an example, their previous study that created multiple measurements from scientometric data.
Especially, they focus on "interdisciplinary" as one aspect of the measurements (shown in Figure 3).
And, the other aspect is "performance," which is a rather traditional measurement (Figure 4).

Comment [ss8]: As a case study, the authors compare 6 university departments in the UK.
As mentioned later more specifically, they compared 2 fields: "innovation studies" vs. "business management" (3 departments for each).
Research subjects of these 2 departments look similar, but the authors found a certain difference specifically in the extent of interdisciplinarity.

Comment [ss9]: In this study, authors use "Subject Category," which is an attribute of journals.
Simply put, Subject Category indicates scientific field (e.g., biology, medicine, economics) of a journal.
Each journal is assigned one or a few Subject Categories. Thus, by looking at the list of journals where each organization published its papers, we can roughly understand on what scientific fields the organization is working.
This data is used in computing "diversity" (explained in the next paragraph).

Comment [ss10]: Scientific papers always have a list of references. The database offers this information: i.e., it tells which papers cited which papers.
This is used in computing "coherence" (explained in the next paragraph).

Comment [ss11]: In Figure 3, each node (vertex) represents one field (Subject Category) and each line (edge) represents citation relationship between 2 fields.
Grey nodes and lines represent all publication data in 2009 (thus, they are the global average), and coloured ones are for one organization, ISSTI (Institute for the study of science, technology and innovation).

would be shown by the extent to which the references of publications criss-cross the map of science (as illustrated by the green lines, which show cases of cross-citation 5-fold above expectation). In the analysis it was found that the most interdisciplinary unit in terms of diversity was not the most coherent –hence there is good reason to differentiate these conceptualisations. Nevertheless, a comparison between three Innovation Studies (IS) units and three Business and Management units (BM) units showed that under any of the various conceptualisations and operationalisations IS units were more interdisciplinary than BM units. Thus, at this larger scale, the contribution of the opening-up effort was to provide more robust evidence of the difference between IS and BM.

Comment [ss12]: As mentioned above, by using the Reference data, we can tell what papers are cited by each organization' papers. In addition, by using the Subject Category (=field) data, we can tell what fields the cited and citing papers belong to. Taking together, we can see links ("cross-fertilization") between different fields.
Now, the strength of the links differ from one organization to another. The authors first computed the average strength of the links for all pairs of fields (subject categories) using the whole publication data published in 2009. Then, the authors compare this average with links of a particular organization. If a link is stronger than the average by five times, the authors highlighted it by a green line in Figure 3.

Comment [ss13]: The reason they computed two measurements (diversity and coherence) in the first place was to offer multi-dimensional information for decision making. But, it turned out that the conclusion the authors can draw from the two measurements are the same.
Then, one might want to argue that only one measurement is enough and the second measurement is redundant. True, but when two measurements give the same conclusion, decision makers would have greater confidence. This is the contribution of this particular case study. But, if the same approach is used for other contexts, the conclusions from two measurements could be different.

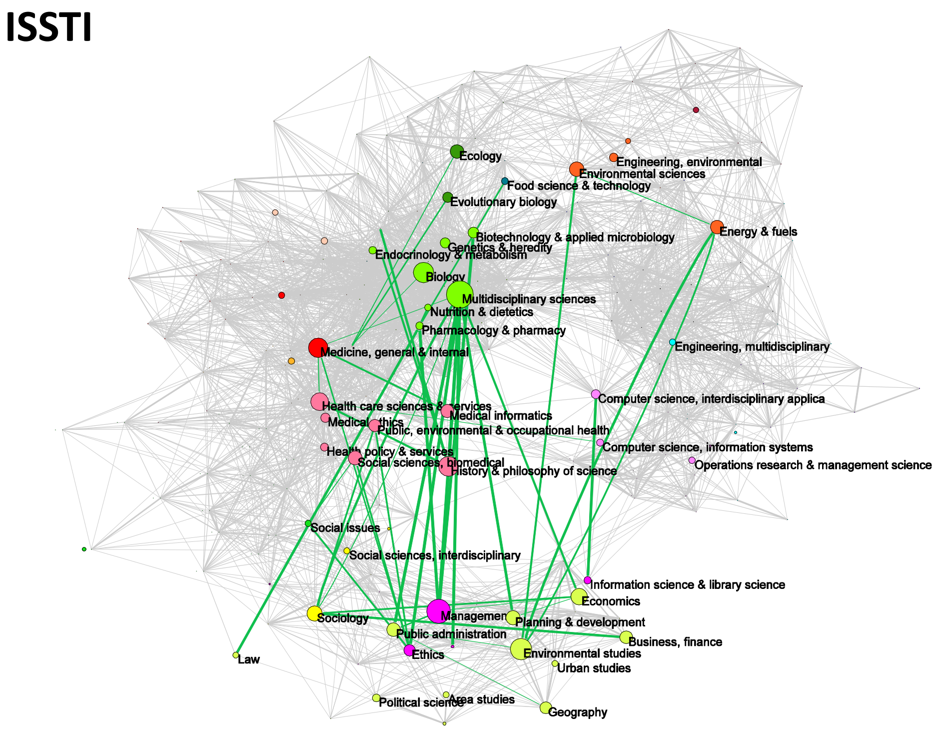


Figure 3. Overlay of number of references on Web of Subject Categories (source) by of the Institute for the Studies of Science Technology and Innovation (ISSTI, University of Edinburgh) on the global map of science. Each node represents a sub-discipline (Subject Category), and node size the number of references. Green links indicate 5-fold above expectation referencing (or citing) between Subject Categories by ISSTI. Grey lines indicate a certain level of similarity between Subject Categories. The degree of superposition in the grey background illustrates the degree of similarity between different areas of science for all 2009 Web of Science data. Diversity of references (as reflected in the spread of nodes over map) and referencing across disparate Subject Categories (the amount of cross-linking) are interpreted as signs of interdisciplinarity. Source: Rafols et al. (2011)

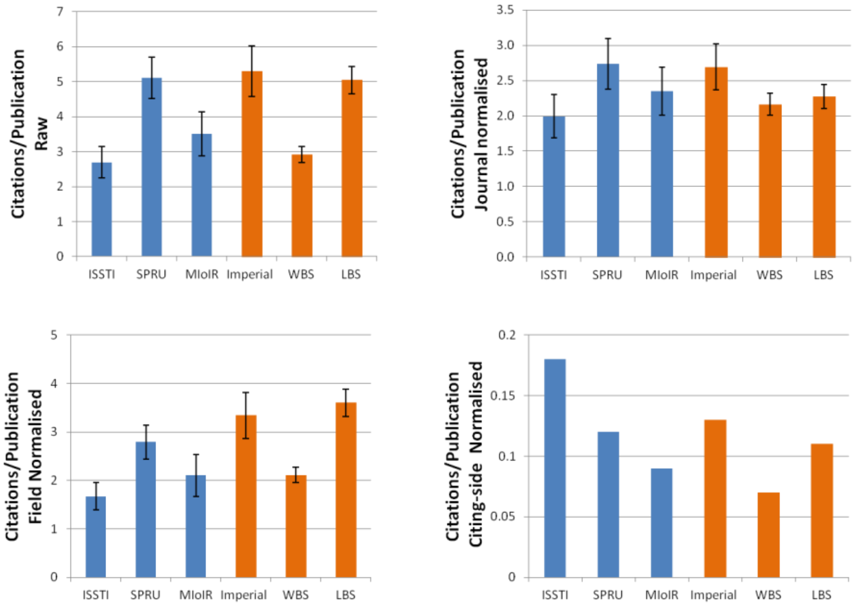


Figure 4. Example of opening-up by using different normalisations to a measure of the average number of citations per publication in a given organisation. Source: Rafols et al. (2011).

Conclusions and policy implications

This paper aims to illustrate that even analytical tools as narrow and apparently rigid as scientometric indicators leave room for policy usage that is more explicit about the dependence of analytic outputs on normative assumptions. We have argued that this 'opening up' is distinct (and complementary) to the 'broadening out' of the range of data inputs.

Indicators in S&T policy and management (as well as in other social spheres) have not only become pervasive as measurement tools, but constitute obvious 'technologies for governance' (Davis et al., 2011). Indicators play a performative role, incentivising and thus 'guiding' scientists towards particular understandings of 'good' performance. 'Statistical measures tend to replace political debate with technical expertise' (Merry, 2011, p. S83). Under these circumstances, it becomes imperative to bring out into more open debate the crucial normative choices underlying indicators (Barre, 2010). In short, both broader and more plural forms of S&T indicators and visualisation tools are needed, in order to facilitate the 'opening up' of more rigorous and accountable policy appraisal.

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