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Report in Focus

INFORMING RESEARCH CHOICES: INDICATORS AND JUDGMENT

The challenge of determining what areas of research to fund permeates science policy discussions and decisions. Governments around the world invest substantial public resources in supporting discovery research in the natural sciences and engineering (NSE). Discovery research in NSE disciplines is a key driver in the creation of many public goods. Scientific advances can help catalyze innovation, foster economic prosperity, improve public health, enable better protection of the environment, and strengthen national security and defence. In Canada the Natural Sciences and Engineering Research Council (NSERC) spends approximately one billion dollars a year on scientific research. Over one-third of that goes directly to support discovery research through its flagship Discovery Grants Program (DGP).[1]

In times of increasing fiscal pressures and spending accountability, public funders of research often struggle to justify their funding decisions – both to the scientific community and the wider public. A 2008 international review of Canada's DGP[2] found it to be highly effective in meeting its goals. This perception is widely shared by the research community, however concerns have been periodically raised that NSERC's allocation of funding across research fields is overly dependent on historical funding patterns.

Funding organizations like NSERC are increasingly looking to science assessment tools and quantitative science indicators for guidance in informing funding decisions. New indicators continue to emerge with technological and methodological advances. These metrics, together with an emerging "science of science policy," can potentially improve the overall effectiveness and transparency of resource allocation, and monitoring of research investment performance. But the growing array of choices can also make it difficult to know which assessment methods and indicators are most appropriate in a given context.

Since funding decisions directly affect the income and careers of researchers, assessment systems linked to those decisions will invariably have an impact on researcher behaviour. Past experiences with science assessment initiatives have sometimes led to unintended, and undesirable, impacts on the research community. For example, correlations have been observed between the use of indicators of research volume in a funding formula and subsequent increases in research output. The potentially negative aspect of this impact is that when funding is explicitly linked to research output, researchers may be tempted to produce a higher *quantity* of publications at the expense of *quality*. In addition, poorly constructed or misused indicators have created skepticism among many scientists and researchers about their value and utility.

How should funding organizations allocate their budgets across areas of research? And how can the performance of those investments be monitored or assessed over time? These are core questions of science policy.

As a result, the issues surrounding national science assessment initiatives have become increasingly prominent. In the United Kingdom and Australia, debates about national research assessment have been highly publicized and contentious in recent years. Other countries are also in the process of developing new approaches to assessing and benchmarking scientific performance. Consequently, there is a growing demand among research funding organizations for clear guidelines on effective science assessment strategies and indicators. As new technologies and analytical techniques continue to reshape science measurement and evaluation, policy-makers and research funders strive to ensure their assessment systems and funding allocation processes reflect the latest advances and best available knowledge.

"Quantitative indicators are best interpreted by scientific experts with a deep and nuanced understanding of the research funding contexts in question, and the scientific issues, problems, questions, and opportunities at stake."

– Rita Colwell, Chair, Expert Panel on Science Performance and Research Funding

Responding to the Question

As part of NSERC's ongoing efforts to ensure responsiveness of the DGP funding allocations to the evolving scientific landscape, in 2010 the federal Minister of Industry, on behalf of NSERC, posed the following question to the Council of Canadian Academies (the Council):

What do the scientific evidence and the approaches used by other funding agencies globally have to offer, in terms of performance indicators and related best practices in the context of research in the natural sciences and engineering, carried out at universities, colleges, and polytechnics?

In response to the charge, the Council convened a multidisciplinary panel of 16 Canadian and international experts. This Expert Panel was chaired by Dr. Rita Colwell, Distinguished University Professor at the University of Maryland. The Panel relied on two principal lines of evidence. A literature review was conducted, which surveyed a wide range of peer-reviewed articles and related studies on research evaluation, funding allocation, quantitative indicators, deliberative approaches, international practices, and behavioural impacts. In addition, in order to develop a more detailed knowledge of science assessment practices in selected countries, the Panel developed 10 international case studies on countries that are emerging or current leaders in science and technology, leaders in science assessment, or of particular relevance to Canada.

The Panel's focus was science performance at the national level of research fields in the natural sciences and engineering and the indicators and methodologies most relevant to discovery research.

MAIN FINDINGS

Many science indicators and assessment approaches are sufficiently robust to assess science performance in the NSE at the level of nationally aggregated fields.

Many types of quantitative indicators can be useful in assessing the overall scientific impact of research in a field at the national level, and in characterizing research trends or national research capacity in certain assessment contexts. For example, bibliometric indicators based on weighted publication counts can be useful in assessment of research output at the level of a research field, and citation-based indicators – when appropriately normalized and based on a sufficiently long citation window – can be useful in assessing the overall scientific impact of research.

Quantitative indicators should inform, rather than replace, expert judgment in science assessment for research funding allocation.

Quantitative indicators should not be used to support research funding allocation without expert judgment. A review of the recent experience of selected countries and research funding organizations lends support for strategies combining quantitative indicators and expert judgment. For example, the new U.K. Research Excellence Framework will retain core reliance on peer review, but allow for use of quantitative indicators. In Australia, a recently adopted national research assessment system relies on a model of expert judgment informed by quantitative indicators. Many countries – including the United States, Finland, and the Netherlands – have employed science assessment strategies combining indicators and expert judgment in various contexts.

International "best practices" offer limited insight into science indicator use and assessment strategies.

Construction and application of indicators are context dependent. Whether an indicator is informative or reliable depends as much on the context as on its nature and construction. No single indicator, set of indicators, or assessment strategy offers an ideal solution in research assessment contexts for NSE discovery research. The individual circumstances of the assessment and the research funding context must be considered. The assessment must reflect proximal goals (in terms of desired output or results) and the ultimate objectives of the funding program or organization.

Mapping research funding allocation directly to quantitative indicators is far too simplistic, and is not a realistic strategy.

Indicators may reveal useful information, but funding allocation decisions are complex. Neither the existing body of evidence nor the experience of international funding processes justifies a simplistic funding allocation or application of a specific indicator. Funding agencies may choose to allocate resources to an area of research weakness to bolster performance, or alternatively, direct resources away from areas of research weakness and towards strengths. These choices are driven by the strategy of a funding agency and program. In addition, there is no compelling reason for certainty that past successes will lead to future successes or past failures to future failures. Science indicators – essentially a measure of past performance – may not provide a reliable guide to future prospects.

Methodological Guidelines for Assessing NSE Research

Science assessment strategies can be divided into two major types: those based on deliberation and expert judgment, and those based on quantitative data and analysis. While deliberative approaches remain the dominant method of science evaluation in most contexts (e.g., peer review of scientific papers and grant applications), reliance on quantitative data and indicators is increasingly prevalent in many types of research assessment.

NSE research funding allocation decisions at the level of nationally aggregated research fields require sets of indicators that capture information on the following:

- **research quality** – a complex, multidimensional attribute that takes into account factors such as originality, rigour, and scientific impact but not the broader socio-economic impacts of research.
- **research trends** – trends related to evolution of scientific research such as emerging or declining fields of study, changing research foci, and new patterns of collaboration.
- **research capacity** – the overall capacity for undertaking or performing scientific research in a field or region, as determined by, for example, human capacity and physical infrastructure.

For each of these assessment types, the Panel developed a taxonomy of potential indicators, and assessed their validity with respect to the assessment objective. The Panel concluded that quantitative indicators should always be evaluated by informed expert review because accurate interpretation of data from available indicators may require detailed contextual knowledge of a field.

SCIENCE INDICATORS EXPLAINED

Common types of quantitative science indicators are:

Funding Measures: Different types of metrics are constructed based on patterns or trends in research funding. Some examples include: the number of grant applications (by research field or topic), amounts of funding granted, average grant size, the diversity of funding sources, and measures of the stability of funding overtime.

Students: The number of students in a research field or program may be used as an outcome measure related to the goal of training new researchers or developing labour market skills. Students are also a measure of research capacity at the graduate level and fluctuations in student enrolment rates provide important information on research trends.

Publications: Counts of scientific publications, such as articles in peer-reviewed journals, are one of the most common and widely-used science indicators. Publication counts can be computed at many levels (e.g., individual researchers, research groups, institutions, and entire research fields), and are the basis for many advanced bibliometric measures.

Citations: Citations in scientific papers are a useful measure of impact, as research which reveals important or influential findings tends to be highly cited over time. Citation counts are most useful when normalized by field of research, as different areas of science vary in their citation practices and average levels of citation.

Measures of Esteem: Academic honours, awards, and prestigious appointments are other indicators of scientific accomplishment. In some cases, these types of honours can be quantified (e.g., counts of Nobel prizes or laureates) to lead to new types of metrics. However, due to the inherent heterogeneity of these types of academic honours, they rarely can be used to make comparisons across different fields of research.

Webometrics: With the growing use of the internet as a venue for both publishing and accessing scientific research, metrics based on online activity (e.g., paper downloads or views, html links) are increasingly being explored for use in science assessments. Today, these metrics are experimental and not widely used in large-scale research assessments.

Assessments of Research Quality

Indicators associated with monitoring research quality often relate to different aspects of quality or timeframes. As a result, the strongest approach relies on a balanced combination of deliberative methods and quantitative indicators. As a measure of the scientific impact of research, indicators based on relative, field-normalized citations (e.g., average relative citations) are the best available metrics.

GUIDING PRINCIPLES FOR THE USE OF SCIENCE INDICATORS

Context matters: Effective use of indicators or assessment strategies is context dependent. Any approach should take into account national S&T objectives as well as the goals and priorities of the organization and funding program.

Do no harm: Attempts to link funding allocation directly to specific indicators have the potential to lead to unintended consequences with negative impacts on the research community. Promising strategies identified by the Panel to mitigate this risk include relying on a balanced set of indicators and including expert judgment in the assessment process.

Transparency is critical: Science assessment initiatives are most effective when transparent to the scientific community. Transparency should include both the assessment methods or indicators and the method or process by which the indicators or assessments inform or influence funding decisions.

The judgment of scientific experts remains invaluable: Many quantitative indicators are capable of providing useful information in the assessment of discovery research. However, in the context of informing funding allocation, quantitative indicators are best interpreted by scientific experts with detailed knowledge and experience in the relevant fields of research.

Assessments of Research Trends

The best approach relies on a combination of assessment strategies and indicators to create a composite perspective on emerging research trends across fields. Indicators should include one or more metrics from each of the following types: trends in grant applications, bibliometric methods, and trends in student population.

Assessments of Research Capacity

The best approach relies on multiple, diverse indicators to create a composite of underlying features that determine capacity in a field. Indicators should include one or more metrics from each of the following types: funding, infrastructure, numbers of researchers and students, networks and collaborations, and field characteristics (i.e., average research team size, average size and duration of research grants, material and equipment intensity of research, cost of research; and dependence of research on access to a facility).

Endnotes

1 NSERC (Natural Sciences and Engineering Research Council). (2008). *The Report of the International Review of the Discovery Grants Program*. Ottawa (ON): NSERC.

2 NSERC (Natural Sciences and Engineering Research Council). (2012). NSERC– Facts and Figures Retrieved March 7th, 2012, from http://www.nserc-crsng.gc.ca/_doc/FactsFigures-TableauxDetailles/2010-2011Tables_e.pdf

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