Research Evaluation, 17(1), March 2008, pages 33–44
DOI: 10.3152/095820208X291176; http://www.ingentaconnect.com/content/beech/reev

New perspectives and challenges for the design and production of S&T indicators

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This paper discusses recent changes in the production of science, technology and innovation indicators, linked to wider changes in the research and innovation system, but also to the transition from a centralised to a distributed intelligence system. The emerging needs require a change of rationale from an input/output to a positioning indicators framework, focusing on flows and linkages between actors in the innovation system. Further, we look at changes in the production systems for indicators and at structural limitations which don't allow addressing the double challenge of developing innovation in indicators and of consolidating their production. We conclude with some proposals of measures at the European level to address these challenges.

IN RECENT YEARS, quantitative indicators for science and technology (S&T) have witnessed an extraordinary development, pushed up by the emergence of new customers and demands, but also by technological and methodological developments which have opened new fields. S&T indicators are increasingly used by policy-makers for decision and are relevant for public debates concerning research policy; some examples are the widespread use of indicators for the evaluation of research programs, as recognized by the European Commission in preparing the evaluation of the seventh Framework Program (FP7) (Georghiou and Larédo, 2006; Larédo, 2004) and the discussions raised by ranking exercises of universities (Van Raan, 2005). The content of the recent *Handbook of Quantitative Science and Technology Research* is another example of this broadening of the field (Moed *et al*, 2004).

As a result of this movement, indicators which emerged in the 1960s, based on national statistical offices collecting data on the one hand and the Organization for Economic Cooperation and Development (OECD) coordinating the methodological work and producing indicators on the other hand (Godin, 2005b; Sirilli, 2006), are no longer the unique reference. New indicators domains, new demands and new customers gave the floor to new players, including independent indicators producers (such as the Observatoire des Sciences et Techniques in France), specialized research institutes (e.g. CWTS in Leiden or ISI-Fraunhofer), semi-official bodies (e.g. the Institute for Prospective Technological Studies of the European Commission) and large indicators projects (e.g. ERAWATCH and the Innovation Trendchart at the European level), but also many research teams which are nowadays responsible for a large part of the production of indicators, especially in domains e.g. human resources, mobility, web indicators and bibliometrics. Technological evolution, which has reduced the barriers to access and the costs of handling data, strongly contributed to this.

In this context, the first aim of this paper, which is based on the methodological work undertaken in recent years in the framework of the European network of excellence on research and innovation policies (PRIME), is to provide a more analytical and systematic view of these changes, of their driving forces and of their impact on the organization of the production of indicators.

This analysis however is only a first step to address the future of the S&T indicators in research

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 0958-2029/08/010033-12 US$08.00

and innovation policies. What we would want to engage with is a reflection about today's organization of the indicators production systems and markets — including its customers and their requirements, the procurement procedures, the organization and available competences of the producers — and about their ability to provide the indicators needed for appropriate S&T policies at the European level.

We will argue in the following that two functions are needed for a dynamic of innovation in the field of S&T indicators and are thus critical to provide an answer to this issue. The first is the capability to design new indicators (*experimental design function*); the second is the capability to transfer effectively those indicators which stand up the early phases of their development to a systematic and long-term production setting (*capitalization function*). We thus advocate that the set-up of suitable institutional arrangements and regulations is essential for the functioning of what has become in the last years a true market for knowledge-intensive services. In conclusion, we open the discussion about some possible actions.

The shaping of a new demand context: the driving forces

In the last decades, the increase and the diversification of S&T indicators has been largely driven by a parallel increase in the complexity of the S&T system and of its governance, leading the policy-makers to search for a better design for their decisions (the so-called "evidence-based policies"; Campbell, 2002). We briefly discuss below these trends and their impacts, and we conclude by introducing the *positioning indicators* rationale, as a suitable conceptual framework for the future production of indicators.

Changing realities and their representations

As illustrated by many studies, a set of profound changes in the S&T system has taken place during the last decades: these include the expansion of the system and the differentiation of its components and actors, while the emergence of a dense network of interactions and complementarities between them becomes critical for the performance of the system as a whole.

First, the size of the S&T system has greatly increased since the Second World War, even if it is difficult to measure the pace of growth because of the lack of coherent statistical series. For instance, US R&D expenditures have increased about ten times in real terms between 1953 and 2004 (source: National Science Foundation R&D statistics), and a similar level of increase for public funding has been shown for Switzerland (Lepori, 2006b) and Germany (Grupp *et al*, 2004). Then, this quantitative expansion has been a key drive for differentiation, since it allowed the continuous addition of new functions, instruments and actors, a pattern which has been demonstrated in the analysis of the evolution of public funding systems (Benner and Sandström, 2000; Lepori *et al*, 2007).

Second, many studies show that linkages and complementarities between the S&T actors — for example between public research organizations and private companies — are becoming critical for knowledge production and for innovation. For example, recent studies showed that various emerging and high-growth fields in science, such as computer science, biotechnology and life sciences, materials sciences and nanotechnology, are characterized by high degrees of diversity and of complementarities, both at the cognitive and institutional level, requiring active cooperation forms between different disciplines and actors (Bonaccorsi, 2005). At a system level, models such as Mode 2 (Gibbons *et al*, 1994), national systems of innovation (Lundvall, 1989; Nelson, 1992) or Triple Helix (Meyer *et al*, 2003, Etzkowitz and Leydesdorff, 2000) all point to an increasing relevance of the interactions between sectors for the development of science and for innovation.

Third, the spatial organization of the system has become more complex, especially in Europe. The long-lasting national organization of the systems of research and innovation is now embedded in a multiplicity of interconnected spatial levels of organization and governance arrangements. For example, multinational corporations act now as "global actors" across the national innovation systems (Kuhlmann, 2001; Meyer-Kramer and Reger, 1999). At the same time, the emergence of the European Union as a relevant actor for S&T and innovation policies (Caracostas and Muldur, 2001) has led to a complex multilevel governance setting, where individual actors tend to develop at the same time national, European and even global strategies (Kuhlmann, 2001; Borras, 2004). Finally, regions have also emerged as relevant actors in science, technology and innovation policy even in non-federal countries, largely as a consequence of European policies (Charles *et al*, 2004; Uyarra *et al*, 2007).

Changing actor spaces: towards multilevel decision-making and distributed intelligence systems

These changes have concerned both the functioning and the governance of the innovation system. Namely, we assisted the transition towards what has been called a system with *distributed intelligence* (Kuhlmann *et al*, 1999), where decisions are no longer assumed by an individual actor — the national state — and then top-down implemented, but increasingly involve negotiations between multiple actors, including national and European authorities, intermediary organizations and performers (see for example the Open Method of Coordination introduced to achieve a greater coherence in RTD policies at different geographical levels; Borras and Jacobson, 2004). Then, the actors are placed in a complex environment, where they must act on their own as strategists. Of course, this leads to higher information requirements than in a centralized system.

To some extent, the situation is not new: science policy studies have extensively documented the continuously growing need for widespread delegation from the policy-makers to the representatives of the scientific community, which has induced the set-up of so-called “intermediary organizations” to mediate between the state and science (Braun, 2006; Van der Meulen and Rip, 1998). However, while former mediation processes were organized only at the national level of policy-making, they now turned to become inherently multilevel since the decision-making competences are continuously negotiated across different spatial and political levels (European, national, regional, local). This creates room and options for the actors to develop their own strategies, and to position themselves in these multiple spaces of action.

Among these new ‘strategic’ actors, we witnessed in the last years the emergence of the S&T performers themselves; this is the case of large companies, especially the multinational ones, but happened also in the public sector where public research organizations and higher education institutions clearly tend to position themselves as autonomous actors in the international, European and national research landscape (Bonaccorsi and Daraio, 2007). In many European countries, public policies have actively promoted this process by giving stronger autonomy and responsibility to them, while orientating the role of the state to the supervision of the whole system (Maassen, 2003). Thus the S&T performers are now politically legitimate - and even required - to produce and receive sufficient information (including indicators on their *own* position) to define and monitor their strategies.

The multiplication of demands: the arising of ‘new’ S&T indicators

We discuss the implication of these trends for the production of indicators at two levels. At a phenomenological level, we certainly witness the multiplication and differentiation of the demand for indicators and thus a considerable broadening and differentiation of the field, concerning the *level of analysis*, the *type of indicators*, the *customers* and *their uses.* At a conceptual level, we think that these developments are pushing for a deep change of the *underlying rationale* for the conception and the production of indicators.

First, the new governance setting implies a *multiplication of the possible levels of aggregation* for the analysis. Besides classical indicators at national and regional levels, indicators related to S&T performers are now required by them for their strategy-making and -monitoring, then by those who need to assess the performance of the institutions, be they partners, clients, board members, financing bodies, citizens, policy-makers or political decision-makers. The recent multiplication of rankings of S&T institutions is a case in point (Van Raan, 2005). Other emerging levels of analysis include the organizational unit — for example the university — but also the disciplinary subunits such as departments, as well as the positioning of individual laboratories. Needless to say, the conception of the indicators, the methodological problems for their development and the available data sources are deeply different at each level, as it is well-known in bibliometrics.

In this context, the requirement for comparability becomes increasingly relevant. Yet, alongside the well-established comparisons between countries by national-level indicators, which was a major aim of the methodological work at OECD level in the 1960s and 1970s, there is a demand for indicators providing reliable comparisons at different levels of aggregation, such as individual universities in different countries. The difficulty of this exercise, faced with heterogeneity in the underlying data sources but also with more fundamental differences between individual units, as well as the national systems in which universities are embedded, has been a major concern in PRIME higher education projects such as AQUAMETH (Bonaccorsi *et al*, 2007).

A second trend has been the *differentiation of the needs and the uses of indicators*, which implies also a considerable broadening of the indicators categories. Benoît Godin demonstrated that the underlying rationale of the first wave of S&T indicators developed in the 1960s has been basically to measure the national effort in research (as measured by the R&D expenditures and human resources) and to relate it to economic development (Godin, 2005a). The first edition of the *Frascati Manual* called for two broad categories of indicators, namely input indicators (funding, expenditures, human resources) and output indicators (scientific publications, Van Raan, 2004; technological products, innovation; Schmoch, 2004). These indicators still constitute the bulk of what we would call the classical S&T indicators, as for example presented in the last *Handbook on Quantitative Science and Technology Indicators* (Moed *et al*, 2004). However, the changes in the systems of innovation are bringing to the forefront the relationships and fluxes of information between actors, and this has opened a wide field for the development of indicators: relevant examples are bibliometric indicators on the organization of scientific activity, such as science maps and network analysis through citations or copublications (Noyons, 2004; Glänzel and Schubert, 2004), especially concerning interdisciplinary fields (Merkx and Van den Besselaar, 2008), science-technology linkages indicators (Tijssen, 2004), as well as indicators concerning brain drain and, in general, careers and fluxes of human resources (Auriol, 2006; Da Costa *et al*, 2006); and the so-called Triple-Helix Indicators are another example at a more systemic level (Meyer *et al*, 2003).

This tendency is apparent also in fields which are traditionally well-covered by classical S&T indicators, as demonstrated by the PRIME work on the analysis of public project funding, where a completely new set of indicators focused on allocation mechanisms rather than on R&D expenditures has been developed (Lepori *et al*, 2007).

Finally, a related tendency is the *multiplication and diversification of the customers* for S&T indicators. If the innovation systems are evolving as described then the European Commission, the national states, the funding agencies, the research performers, all developing their own trajectory and strategy, will need indicators, to evaluate their positioning, to define their strategic decision-making processes and to support their interests.

This brings of course a potential for conflicts, since different actors' goals influence also the type and definition of the indicators produced: data on universities requested by state officers to distribute funds are not the same as those used by the institution itself either for public communication, strategic decisions or internal management. The idea of generic indicators, which has been the underlying paradigm of official statistics, gives place to *customized but interoperable indicators*, reflecting the specificities, the needs and the (policy) goals of each actor or actor group. Hence, the indicators themselves are becoming part of the political discussion and power struggle, and the objects of criticism and discussion to an extent unknown in the old world of national "statistical" indicators (Barré, 2001, 2004).

A new rationale: positioning indicators

We believe that these developments require a deep change in the conceptual framework underlying the production of S&T indicators. We owe to the historical work of Benoît Godin on OECD statistics the recognition that the Frascati system was essentially based on a specific conceptual model, namely the production function as stated by economics (Godin, 2005a). This has led to an input/output rationale, in which the actors are described as 'black boxes' whereas the most important factors are their inputs and outputs and it is believed that an optimal production function can be identified to evaluate the efficiency of individual actors *at different levels of aggregation*. Moreover, the system is based on a strong belief in the possibility of a universal metrics to measure inputs, namely level of spending: thus, one currency unit spent in R&D is considered to be basically the same, irrespective of how this money has been allocated, of the context (except for correcting for different price levels) and of the nature of the performing organizations. If these assumptions are correct, the problem of aggregation can be solved by adding separately inputs and outputs and then estimating the correct production function at each level.

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The new rationale for S&T indicators — which we will call the *positioning indicators* rationale — is based on the new insights gained by the economics of science and by political analysis in the last three decades. First, the *position* of the actors — their identity, relationships, complementarities and immaterial assets — are as important as formal inputs and outputs for their performance. The role of science, technology and innovation indicators is thus to describe each singular entity in terms of its specific characteristics, as of its competition and cooperation with other entities. In turn, this calls for a broader set of indicators including all kinds of measures of linkages and immaterial fluxes and stocks, alongside the classical input and output indicators.

Second, the benchmark with a universal production function — to optimize internal production processes to achieve efficiency — is replaced by the idea of helping individual actors to position themselves in a complex and fragmented institutional space, where local effects are relevant and strategic choices are determinant for the production. Thus, as exemplified by work on universities (Bonaccorsi and Daraio, 2007) and on laboratories (Larédo and Mustar, 2000), rankings and efficiency scores can be replaced by multidimensional maps comparing actors along irreducible dimensions and aiming to characterize their 'positioning' and relative trajectories in the innovation system.

In this context, indicators are needed to support the strategic decisions of the actors — conceived as autonomous and strategic agents — and to help to improve the autonomous coordination of the system rather than to provide to the national state the information to centrally control and steer the system. Indicators here have to be designed as appropriable to feed the collective debate and mutual understanding. This means that they must be kept transparent and customizable for this purpose, while openness concerning theoretical and political presuppositions used for their design, methodology and limitations are crucial for their shared use.

Admittedly, these ideas are not new and most of today's developments of S&T indicators are based on at least some of them. However, their systematic presentation is proposed in order to explore the organizational and institutional conditions for the production of such ‘positioning indicators’, a subject to which we will devote the second part of the paper.

The new supply context: towards a multiple production space

These trends also impact the organization of the indicator production system itself. Godin (2005b) has remarked that the measurement of science and technology is no longer a resort of official statistics only, but a system composed of multiple participants, including S&T departments at the government level, specialized agencies on S&T indicators, transnational organizations such as the Organization for Economic Cooperation and Development and the European Union, research institutes and, in some cases, private companies.

This differentiation process has been driven by the combination of the different factors discussed above. First, the new demands for indicators and the differentiation of the indicator domains imply a *wider scope of competences* needed and thus open new niches for different organizations, partially also related to specific fields of research (as in the case of bibliometric indicators or of innovation indicators, closely linked to science studies and to economics of innovation respectively), as well to specific data sources and technical requirements.

Second, the differentiation of the markets and of the customers pushes up the emergence of a *public procurement space* for indicators design and production. This has become a widespread practice at the European level, where indicators production is now mainly attributed through competitive procedures, such as tenders or even framework program projects as in FP7, but is present also to some extent at national level in fields such as bibliometrics (where few countries have national production capacity) or production of national indicators reports. Of course, this breaks to a large extent the monopoly of statistical offices or international organizations, which for reasons of competences, internal organization and even formal rules do not easily access this market.

Third, *technological development* in information technologies has strongly reduced the costs of data handling and analysis, but also the barriers for access and collection of data at national and international levels. Where data and indicators are not covered by statistical secrecy, online access has become the rule (even though by paying fees, such as for Thomson Scientific and Derwent), including national and international statistical databases such as MSTI, EUROSTAT-Chronos, bibliometrics and international patent databases. Moreover, for the production of a number of indicators, Internet access to documents reduces the costs of collecting the data, two typical cases being the funding reports largely available online (Lepori *et al*, 2007) and CVs, which can nowadays also be retrieved from websites (Probst and Lepori, 2007). A further simplification has been the availability of simple-use software, such as Microsoft Excel or Access, which require far less informatics competence than database software both for data management and for analysis (including queries, statistical functions, etc). It is important to notice that these technical developments have a deep impact on the phase of experimental development of indicators, which usually involves limited amount of data and statistical competences; while, on the contrary, coding, maintaining correctly and documenting a large database, such as those used in bibliometrics or in patent analysis, still requires specialized competences in data management. Wider access thus entails some risks of decreasing quality of exploitation for lack of methodological competence.

The current organization of indicators production at the European level

The joint emergence of a demand for positioning indicators and of new opportunities for indicators production, has already complicated the indicators production scene.

A detailed view of the organization of indicators production is provided by a survey performed by the PRIME project European Network of Indicator Producers. Despite its limitation to ten European countries, it shows clearly that the indicator producers are strongly differentiated according to the categories of indicators considered and their data sources, both for historical and technical reasons (Esterle and Theves, 2005). Namely, we can distinguish five broad categories.

The first group of producers concentrate on data of the ‘Frascati type’, that is, data of input (expenditure and human resources) collected according to the *Frascati Manual* (OECD, 2002). This type thus relates to typical OECD products, and the data are obtained by means of national surveys whose results are communicated to OECD. In other words, these data have a quasi-obligatory status and their production is mainly due to the need of international comparisons. All countries except Norway, entrust their collection to the national statistical office or, in two cases (France and Portugal) to a ministerial department. Norway is displaying an original system since data are shared between the national office of statistics (industrial sector) and a public institute of research, NIFU-STEP (public sector).

A second group of producers is related to a multitude of data on research funding and human resources that do not enter within the framework of the national surveys, but which are produced for example by ministries or funding agencies for their reporting duties or for the preparation of policy documents, such as the German report on technological performance (Federal Ministry of Research and Education, 2001) or for evaluation purposes, such as the Italian rector’s conference data or the data produced in the UK Research Assessment Exercise. Thus, the existence of such structured data bases reflects a voluntary investment in tools for strategic monitoring and, actually, it is well-known that these data are much more used for decision-making than the Frascati-type data (Godin, 2005b). Accordingly, we can see a large variety of data producers, including statistical offices, ministries, funding agencies, research operators (universities, research organizations), and research institutes such as NIFU-STEP in Norway. The experience of the PRIME projects on public project funding and on higher education showed that the use of these sources is the only way to overcome the limitations of existing statistical data to produce indicators, but it raises a number of methodological issues because of the poor coherency and systematization across time and space. It is not by chance that in the FP7 a specific topic is devoted to the development of methodologies for the exploitation of these non-statistical sources.

The third group includes the innovation indicators produced by the community innovation survey according to the *Oslo Manual* (CIS; European Commission and Eurostat, 2004; OCDE, 1997). The majority of the European states entrusts it to their statistical office. Two countries (Portugal and France) have it realized by ministerial structure (OCES in Portugal, and SESSI, a dedicated unit of the ministry for industry in France). Lastly, in two countries, Switzerland and Germany, specialized research institutes are responsible for the innovation survey (respectively KOF — Institute for Business Cycle Research, and ZEW — Center for European Economic Research). These two countries thus constitute an exception by delegating to research organizations a survey of national range. The case of Germany is coherent with the realization of national reports delegated to research institutes.

The fourth group refers to bibliometric indicators on scientific publications as a tool for the characterization and evaluation of scientific production (Van Raan, 2004). For these indicators, we consider the organizations able to access the International Science Citation Index Expanded (SCI) base of reference. Since the SCI database is made available under an expensive agreement with the private company which produces it, we consider that its use reflects the will of an actor to provide itself with tools to produce indicators of research performance and also to develop a capacity of interpretation of these indicators.

Only some countries in Europe developed capacities of production of bibliometric indicators: Belgium/Flanders, France, Germany, Norway, Spain, UK. In these cases, the competence is held by institutes and in no case by the national offices of statistics, with the specific case of the UK where bibliometric indicators are developed by a private company. Moreover, Norway has developed a national publication database for the purposes of allocation of research funding. Thus, it seems that the costs of acquisition of the database and of its use are promoting a strong international concentration with a handful of organization offering these services on contract basis; this pattern is also reproduced at the European level, with CWTS having a large European framework contract for the production of these indicators.

The last group concerns the data on patents (Narin, 1994; Schmoch, 2004). The levels of analysis are quite different according to whether one considers the national patents or the European or American patents, even triadic families of patents. The corresponding databases are initially held by the offices of patents; the database of triadic families of patents is a product of OECD. In all the countries of the sample, the national office of patents holds the corresponding patent database. The great majority readily uses indicators of OECD on the international patents (European, US, Japanese or on the triadic families of patents). Two exceptions must be noted, France and Germany. In France, a non-governmental public organization, the OST (Observatory of Sciences and Technologies), maintains a copy of the French and European patent databases and has the capacity to build indicators with these bases. In Germany, a research institute, Fraunhofer-ISI, possesses the tools to perform on-line searchers on patent databases for producing indicators (that is, predefined classification files). Fraunhofer has also a framework contract with the European Commission for the production of these indicators at the European level.

Finally, the importance of S&T indicators has led to the emergence of national reports trying to integrate different indicator categories and to produce a summary view of the S&T performance of the considered unit. In the old national paradigm this had led to the benchmarking reports between national states produced by the OECD (OECD, 2003) and more recently by the European Commission (European Commission, 2002); summaries of S&T national statistics are also published by various structures in a number of countries. However, some countries are also producing more complex reports, which aim to go beyond statistics to provide detailed analysis of S&T systems by combining different types of indicators and levels of analysis; for example, the report published every two years by the French OST (Esterle and Filliatreau, 2004; Filliatreau, 2006) includes both international comparisons, indicators at the level of the whole country and detailed regional figures. Ttypically these reports are produced either by independent agencies or by consortia of research institutes as in Austria (Bundesministerium für Bildung, Wissenschaft und Kultur, 2007) and in Germany (Federal Ministry of Research and Education, 2001).

A similar case is the Report on European S&T Indicators (REIST) issued by the European Commission in 2003 and produced by a consortium of research institutes throughout Europe, where positioning indicators at different institutional levels, based on *ad hoc* treatment of data can be found (European Commission, 2003). The experience of this report is exemplary of the limitations of the today's situation since most of the indicators were produced by *ad hoc* data treatment, a process that is quite time-consuming and difficult to reproduce without the set-up of a dedicated organization (such as OST in France).

The role of academics: the conception of new designs for indicators

Another relevant feature of today's indicators production scene is that a large number of research teams and organizations has entered the field more or less episodically. Thus, while the Frascati domain is characterized by a clear-cut division between the production of indicators by statistical offices and the OECD on one side and their use in academic work on the other side, in other domains there is a much stronger interaction between research and the design and production of indicators. A typical case is bibliometrics, where alongside the 'industrial' production of indicators based on ISI databases there is a large scope of research either using the same databases (for example for science-mapping; Leydesdorff and Cozzens, 1993) or experimenting with other sources (such as Google Scholar, Jacso, 2005, or data collected from surveys or CVs; Gaughan and Bozeman, 2002; Dietz and Bozeman, 2005). In this domain we find the whole spectrum of institutional arrangements between units with a prevalent function of service (OST), mixed units with strong service but also academic work (CWTS) and pure research units in universities.

Research institutes are the dominant actors in domains where the definition and methodology of S&T indicators is not yet institutionalized and thus indicators are largely produced case by case and in experimental way, not only for academic purposes, but also for the use by policy actors. A typical case are human resources and careers indicators, where despite on-going efforts by the OECD to introduce a common practice by statistical offices (Auriol, 2006), most of the work is performed by research institutes through *ad hoc* surveys (Da Costa *et al*, 2006). At the end of the spectrum we find domains which are today largely outside of the political interest and where most of the work is done for academic purposes, such as web indicators (Thelwall, 2004; Katz and Cothey, 2006).

Thus, indicators design and methodological development itself have achieved the dignity of an academic activity, with the possibility of publishing in peer-reviewed journals (for example *Research Evaluation* and *Scientometrics*) and a number of international conferences. Just to give some examples, we could mention here the International Conference on S&T Indicators organized by CWTS and University of Leuven, the OECD Blue Sky conferences, the PRIME Indicators conference series, as well as conferences on the subject organized by institutes such as ISI-Fraunhofer, and the Science Policy Research Unit (SPRU).

Research is fundamental to the development of the needed new indicators because of its innovative character, the link with conceptual development and theory, and finally the possibility of performing experiments

Clearly, research is fundamental to the development of the needed new indicators because of its innovative character, the link with conceptual development and theory, and finally the possibility of performing experiments. However, the PRIME experiences with public project funding and higher education indicators illustrate that these experiments, if successful, inevitably raise the issue of the robustness and consolidation of the methodology and collected data, that is, what we call below the transition from experimental development to the large-scale and systematic production of indicators.

The S&T indicators production system

Producing indicators includes five main functions (Barré, 2006):

- the analysis of the user needs and the conception of indicators,
- the development of methodology and techniques,
- data collection and indicators production,
- the storage and maintenance of the indicators and, finally,
- their interpretation and use.

In this respect, at present the production of S&T indicators is made according to different organizational and business models. The producers of Frascati indicators display what we could call a *vertically integrated model*, where all five functions are realized in the same institutional setting and are closely integrated; thus, data collection is performed through specific surveys designed on the basis of the Frascati methodology and of the needed indicators, while the same actors are involved throughout the whole process. OECD assumes a coordinating role, with the direct involvement of the national statistical offices through the NESTI group (Sirilli, 2006).

By contrast, publications and, to some extent, patents indicators display a *data-driven model*: there is basically a single source of data which has not been originally designed for indicators purposes. The produced indicators are largely defined on top by the available data sources, rather than by the user needs, as is exemplified by the use of ISI data for assessing research performance of universities despite the well-known problems of coverage in the social sciences and humanities field (Hicks, 2006; Nederhof, 2006). Moreover, the existence of a single data source, whose handling requires specific competences and experience, contributes to promote a strong international concentration of the production itself, with a few players selling these services throughout Europe. Alongside, a large experimental domain has developed, essentially driven by academic interests, which uses, case by case, different sources, but which has rarely entered into the 'official' market of policy indicators. It remains to be seen to what extent the emergence of new data sources such as the Open Archives system, Scopus or Google Scholar, as well as subject-specific databases such as Medline, will change the situation.

Finally, other domains such as human resources, non-ISI bibliometrics and Web indicators display what we call a *customer-driven model*, where indicators are built according to specific demands of customers (and mostly *ad hoc* funding), largely by combining existing data sources of disparate origin (the case of human resources flows being very typical in this respect; Da Costa *et al*, 2006); accordingly, this model is characterized by a large variety of actors and by a diverse methodology, with limited consolidation and standardization and with limited presence of statistical officers or professional indicator producers.

Addressing the new challenges

The preceding discussion leads to the conclusion that the production of relevant S&T indicators is also a question of how the system of production is organized and regulated. In very general terms, we argue that, to answer suitably user's needs from a long-term perspective, an indicator production system should rely on two main processes.

The first is the process of *experimental design*, needed to conceive new (or improved) indicators, to design a suitable methodology for their production (by identifying relevant data sources and their handling), to produce them at least on a small scale (for example for a limited sample of units or period of time) to prove their ability to answer research and policy questions. The experimental design process ensures that S&T indicators will evolve in close relation both to new theoretical insights concerning science and technology and to the new needs of the actors.

The second is the process of the *capitalization* needed to build a systematic and long-term production of robust indicators using a standardized methodology. Capitalization is critical for reducing the costs of production, but also for expanding the use of these indicators, since it means establishing standards and quality-validated indicators (a critical factor in the success of the OECD indicators).

The two processes are synergistic and, together, allow for a dynamics of innovation in the S&T indicators field: capitalization has to be built on design, as it was the case for the developments leading to the *Frascati Manual* in the 1960s, while design has to build on the existing stock of data and indicators. Thus, the process of experimental design concerning higher education indicators and project funding indicators in PRIME was based on careful exploitation and integration of existing data sources, including Frascati survey data and national higher education statistics where available (Lepori *et al*, 2007; Bonaccorsi *et al*, 2007).

However, they require different competences and cultures: experimental design being better accommodated in an academic setting, where performing experiments by a trial-and-error method is normal, while capitalization requires a culture nearer to the statistical units and a long-term setting for maintaining both data and methodological competences.

The actual system: a limited ability to enter an innovation dynamics

Looking at the three main industrial–organizational models identified in the previous section, it is apparent that they are able to answer differently the challenge of the articulation between experimental design and capitalization, that is, to enter an innovation dynamics.

Thus, the vertically integrated model allows the production of coherent indicators with a long-term perspective and accumulation of methodological competence, thanks to the progressive revisions of methodology. However, it has proved to have great difficulty in renewing the indicators because of its closure concerning the use of specific *ad hoc* data and the institutional setting of the producers involved. We could say that capitalization has taken primacy at the expense of design — which is essentially the same as in the 1960s —concerning both the data and indicator structure and the institutional setting (Lepori, 2006a). Unfortunately, the drawback has been an increasing loss of relevance of these indicators for policy analysis (Irvine *et al*, 1990).

The data-driven model scores better in this respect, since there is generally more room, in this case, for exchange with users, while at the same time the producers take advantage of a sound data source allowing long-term analysis. However, it displays a typical case of *technological irreversibility*: the large initial investment in the core database, the cumulative advantage of accumulation of data and methodologies and, finally, the constitution of stable coalitions of interests between data producer, indicators producers and users make it difficult to allow for the emergence of alternative methodologies even in domains where there are signs that these would provide better indicators, such as survey-based publication data in social sciences and humanities (Archambault and Vignola Gagné, 2004; Moed *et al*, 2002). These methodologies have been largely confined to small-scale experiments or to academic research, but have not entered the market of the large indicator production contracts by public authorities.

Finally, the customer-driven model is very attractive in terms of its responsiveness and ability to combine different data sources to answer to new needs; but the drawback is that accumulation of competences has been very limited and thus it entails a risk of never getting to the systematic development of stable — or even eventually used — indicators; moreover, exactly because of this fragmented nature, it is not certain that methodological quality is always present.

If none of the discussed models is completely satisfactory, each of them teaches us some lessons on the conditions for the functioning of the S&T indicators production system and on the needed regulations of it. We argue that one should consider today's S&T indicators production as a *market for knowledge-based services*, characterized by a variety of customers and service providers which are to some extent in competition. The preceding discussion makes clear that a differentiated and competitive system, with different types of actors covering different competences, functions and domains, is better suited to answer to the new needs than a centralized system, such as the one adopted for Frascati indicators, exactly because of the distributed nature of today's innovation systems.

However, there are two features of markets for knowledge services that require intervention if they have to function correctly and develop new products suiting customers' needs (Foray, 2006), namely promoting linkages, collaborative relationships and information flows between actors on the one hand, while ensuring open and fair competition between producers on the other.

Promoting linkages and consolidating new indicators domains

First, given the importance of *complementarities* between competences and actors, we argue that innovation concerning positioning indicators is strongly dependent on the *quality of the linkages, collaborative relationships and information flows between actors*. The experience of innovative districts points to the value of this approach to promote innovation in knowledge-intensive domains such as S&T indicators. Examples of these linkages are the following:

- *Vertical linkages and collaborations between actors fulfilling different functions*, for example between academics engaged in exploratory work and organizations charged with large-scale production; this is needed because the complementary competences present at these levels are needed for the production of S&T indicators.
- *Horizontal exchange of experiences and interoperability between different producers*, for example concerning the methodology and the collected data, thus avoiding the possibility in today's fragmented procurement market of building on previous work for the development of indicators in the same area.
- *Exchange of experiences and information between producers and users* to ensure an effective transfer of user needs in the indicators development and production, as well as promoting awareness by users of new developments but also methodological limitations of indicators.

There are a number of reasons why we cannot assume that these linkages will be developed to the extent required by the actors themselves: these include cultural differences and understanding problems — for example between academics, service providers and users; institutional barriers — for example between the public administration and the statistical offices and universities; but also conflicting interests and objectives and the wish by some actors to keep their rent-seeking positions. We face here a typical case of collective trap: while in the aggregate establishing cooperation and linkages would benefit to all actors in the field, without organized collective actions this will not take place and thus, if each actor pursues autonomously its own interest, globally sub-optimal solutions are likely to emerge.

Thus, besides regulating the market and promoting competition, we think it necessary to consider whether, at least in some domains, there is a general public interest in consolidating and structuring the indicators production system. Among the actions in this direction we indicate the definition of standards for interoperability (for example for data-sharing), the provision of suitable infrastructure to support and maintain distributed data sets, the circulation of information and systematic documentation of competences and experiences and the promotion of stable communication and exchange spaces and of collaboration forms.

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This would clearly require the setting up of suitable institutional forms, such as instruments for funding collaborative projects including users, indicators producers and academics — beyond the public procurement formula, which usually leaves limited space to experimental design; and the creation of stable networking spaces — beyond the existing ones, which are largely organized around a single community, for example academics or statisticians.

With all its limitations, the experience of PRIME — in promoting experimental indicators projects, bridging experimental design with user needs and a specific conference series oriented towards exchange between communities — points to the value for the development of indicators of the networking across cultural and institutional borders. However, the whole issue, which has not yet been answered, is how to stabilize and broaden these experiments to create stable institutional spaces for these collaborations, which include a wider community than PRIME. Here, public action at the European level with the participation of all relevant actors is clearly required.

Regulating the indicators market

Second, we argue that, as in most knowledge-intensive markets, competition will not work correctly without careful regulation, avoiding the creation of *monopoly and rent-seeking positions* by some actors (for example keeping crucial data sources inaccessible). This is needed for a number of reasons:

- Technological irreversibility and scale-effects in the production (once a product has been introduced it requires a large effort to replace it);
- The existence of critical resources which put their owner in a strong position (such as ownership of primary data) and, more important;
- Information asymmetry between producers and users, meaning that users will find it difficult to evaluate and compare the quality of the delivered indicators and to choose the best producer.

We hereby identify at least three priority major tasks which need to be fulfilled by this regulation. A first task is to regulate the access to *statistical data sources*. This means that in principle the data sources at the micro level should be accessible to all indicator producers at fair conditions; this could include deontological and methodological requirements, a fair price for data access and related services. The enlarged access supposes the softening of the statistical secrecy rules, of course under some non-disclosure agreement to avoid diffusion of confidential data. A parallel measure would be to introduce an *accreditation practice* for trusted indicator producers, which engage themselves to comply with common standards and codes of conducts and thus can be safely entitled to access these sources.

A second task is to promote separation between the *data producers*, the *indicators producers* and the *indicator users*, since there is evidence that innovation will better emerge if these actors are independent and cooperate, because they require different competences, while there is competition at the interfaces. This does not exclude alliances and forms of integration, but one should avoid the creation of closed vertically integrated systems.

A third, closely related task, is to *regulate the procurement market* for S&T indicators, by defining rules and conditions for access and use of the indicators (linked for example to an European accreditation protocol for indicator producers). On the one hand, this could help to reduce artificial access barriers and thus reinforce competition, not only at the European but also at the national level; on the other hand, it would help to consolidate the procurement market — avoiding different rules for the same type of service — and improve the quality of the demand.

There is no doubt that given the nature of S&T indicators these issues need to be ruled at the European rather than at the national level; the development of the Frascati system displays exactly the value of having a supranational agency not only for ensuring comparability but also for establishing a set of common rules. Moreover, given the specialized nature of the indicators production system these rules should be developed and enforced by a body composed by people competent in the field itself rather than directly by the public administration, for reasons of competence, but also of trust by the producers in the regulating body.

A suitable form could be to delegate these regulating tasks to an *independent European agency*, whose main function would be to define the playing field for the competition and interaction between (different types) of service providers and with the customers, and to intervene in case of abuse and misconduct. In this respect, one could take stock of the experience done in deregulating other public markets such as electric utilities, telecommunications or media, where this organizational form has become very widespread (Gilardi, 2006). This agency could also to some extent take up some of the networking and communication functions discussed in the previous section. However, we are aware that other coordination forms could be equally effective and thus we consider the theme of how to institutionalize the cooperation and the regulation of the indicators system as essentially open to discussion.

Concluding remarks

To conclude this paper, it is useful to review the main arguments we have proposed and the conclusion to which they lead for the organization of the indicator production system. We showed that the evolution of the research and innovation system has profoundly changed the needs but also the practice of indicators production.

We no longer live in the simple world where a rather small number of indicators were produced by national statistical offices under the supervision of the OECD. The whole system has become much more differentiated concerning the categories of indicators, the levels of aggregation and the customers. As a result of this widening market, the category of indicator producers has become quite differentiated, ranging form statistical offices to specialized units in the public administration, to independent bodies, specialized institutes and academic research units.

However, and this is our main reason for concern, in this decentralized and multi-actor production system the quality of the produced indicators, the responsiveness of the system to new user needs and the efficiency of the production critically depend on consolidation of the production space. We have thus identified two critical issues in this respect: promoting communication and exchange between the involved actors to allow for capitalization on previous experiences and for innovative design; and carefully regulating the market to avoid rent-seeking and to promote competition, leaving a fair opportunity also to new entrants in this market.

We think it urgent that these issues are collectively discussed in our community and that we develop shared visions on how institutionalize the missing functions in the indicators system, beyond the individual interests and objectives of each of us (which are clearly legitimate and must be recognized explicitly). Otherwise it is the quality and the role of S&T indicators in the design of S&T policies, and the legitimacy of our community itself, that will suffer.

Acknowledgements

This paper is a result of conceptual work that has been developed by the authors during the last three years in the framework of the indicator activities of the Network of Excellence on Policies for Research and Innovation in a Move towards the European Research Area (PRIME). It takes largely stock of the experiences of PRIME projects related to indicators such as the European Network of Indicator Producers, the ENIP project funding activity, as well as projects concerned with indicators higher education institutions (AQUAMETH, CHINC, Observatory of European Universities).

Earlier drafts were presented at the PRIME annual conference in Paris (February 2006) and Pisa (January 2007), as well at the first PRIME indicators conference in Lugano (November 2006). It owes a great deal to discussions and intellectual contributions from a number of colleagues in this network, among whom we would like to mention at least Benoît Godin, Laurence Esterle, Philippe Larédo and Jean Theves.

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Research Evaluation is published every March, June, September and December, by Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, UK; email page@scipol.co.uk; telephone +44 1483 824871.
Production assistant: Trisha Dale
ISSN 0958-2029; eISSN 1471-5449
It is in the Social Science Citation Index, Google Scholar, SCOPUS, CrossRef, etc.

Website www.ingentaconnect.com/content/beech/reev

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