Efficiency, Effectiveness and Impact of Research and Innovation: a framework for the analysis

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Introduction, motivation and policy relevance

The main objective of this paper is to provide a framework for the assessment of the research activity and its impacts. This is a difficult task. First of all, because of the heterogeneity, partial overlapping and fragmentation of the different streams of literature. Secondly, due to the need of applying a systemic approach to account for the complexity of the research activity and its complementarities and interrelationships with teaching, third mission activities and other relevant dimensions of performance, including the inputs.

This work originated from Daraio (2015) which pointed out the unavailability of a best evidence on the "efficiency, effectiveness and impact of research and innovation" due to the lack of a suitable framework for a comprehensive analysis.

Two recent policy initiatives witness the need and call for the proposal of a general framework for assessing research and its impact. We refer to the STAR metrics in US and to the EC (2014) "Expert Group to support the development of tailor-made impact assessment methodologies for ERA" in Europe.

We discuss in the following the main dimensions of our framework which are: 1. Theory, 2. Methods, 3. Data.

Research and innovation in the theory

In theory, the following streams of literature have considered research and innovation as the main link of Science and Society interplay:

• *Economics of science and technology* as an emerging field, which draws on the fields of economics, public policy, sociology and management (Audretsch et al., 2002).

• *Growth theory* (Aghion & Howitt, 2009), within which «the residual» is considered as technology advance over time (Solow, 1957); or as our ignorance (Abramovitz, 1956). The old growth theory (Nelson & Phelps, 1966) considers as additional inputs investments in R&D and education while the new growth theory (Romer, 1986; 1994) emphasizes the influence of other factors such as technologies or efficiencies, spill-overs and incentive of agents.

• *Quantitative science and technology research*, organized as quantitative studies of science system, of technology system and of science-technology interface. The focus here is -though not exclusively- on scholarly publications and patents, it embraces bibliometrics, scientometrics (Moed, Glanzel & Schmoch, 2004) and informetrics (Egghe & Rousseau, 1990), more recently starting to consider also other non-scholarly and societal «altmetrics» dimensions (Cronin & Sugimoto, 2014).

• *Economics of innovation*, which is at the core of several different economic fields, including macroeconomics, industrial organization (strategies and interactions of innovative firms), public finance, policies for encouraging private sector innovation, and economic development (innovation systems and technology transfer) (Hall & Rosenberg, 2010).

• *Science of Science policy* (Fealing et al., 2011; National Academy of Science, 2014; Lane, 2011, 2014).

• *Science and Society interplay* (Etzkowitz & Leydesdorff, 2000; Aghion et al., 2009; Helbing & Carbone, 2012).

A neglected aspect within these streams of work is the building block of education. From the economics of education (Johnes & Johnes, 2004; Hanushek et al., 2011) we know that education is an investment in human capital analogous to an investment in physical capital. The missing link with previous streams of literature is people. People in fact carry out research and innovation activities; attend schools and higher education institutions, acquiring competences and skills. Here another link could be added with Dosi (2014).

Methods for the assessment of Research

The assessment of the performance of an activity can be carried out on its output, on its outcome (indirect output), on its productivity (partial or total factor productivity), on its efficiency, on its effectiveness, on its impact.

From a methodological point of view, a distinction between productivity and efficiency has to be done. Productivity is the ratio of the output/input. Efficiency, in the broad sense, is defined as the distance with respect to the frontier of the best performers (Daraio & Simar, 2007). The econometrics of production functions is different than that of production frontiers as the main objective of their analysis differs: production

functions look at average behaviour whilst production frontiers analyse best performers behaviour (Bonaccorsi & Daraio, 2004). Obviously, assessing the impact on the average performance is different than assessing the impact on the best performance. This distinction has been considered also recently in the theory of growth and in the managerial literature. From a methodological perspective, different approaches, both parametric and nonparametric (Badin, Daraio & Simar, 2012; Daraio & Simar, 2014) have been proposed.
On the other hand, classical methods of impact assessment (Bozeman & Melkers, 1993; Khandker et al., 2010) proved inadequate to the checklist of "sensitivity auditing" (Saltelli & Guimarães Pereira; Saltelli & Funtowicz, 2014).

Important role of data

The data dimension is characterized by a kind of "data paradox". On the one hand, we are in a "big data" world, with open data and open repositories that are exponentially increasing. On the other hand, in empirical applications «data constraints» are almost the same as those described in Griliches (1989, 1994).
We believe that a great improvement could come by the adoption of an Ontology-Based-Data-Management (OBDM) Approach (Calvanese et al. 2010; Lenzerini, 2011; Poggi et al., 2008) to integrate the heterogeneous sources of data on which the empirical analysis has to be carried out.

A framework for the analysis

A general framework to investigate and empirically assess the research activity and its impacts is derived integrating existing approaches according to three dimensions. The main building blocks of these dimensions are reported in Figure 1.

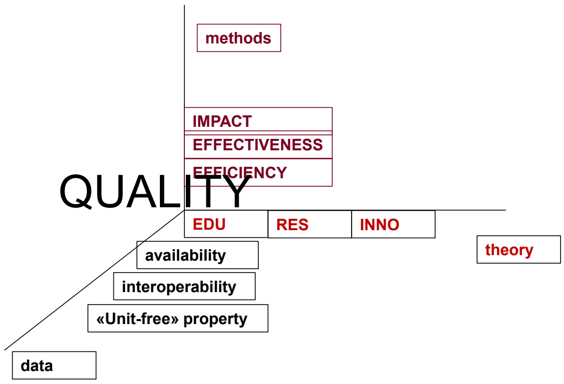

Figure 1. A framework for the analysis of research assessment and its impacts.

We propose "quality" as the overarching concept, which links together all the three dimensions. Quality should be declined along the three dimensions and by each building block. In theory, in education, a lot of progresses have been done. Much more work is needed for research and innovation. If we include quality indicators in the analysis we can move from efficiency to effectiveness. Moreover, it is the quality of education, research and innovation, which has an "impact" on the growth and development of the society. Finally, it is on the data dimension that the quality issues are of primary importance in all the three main building blocks proposed.
If we are not able to conceptualize and formalize in an unambiguous way the different meanings of «quality» for each building block proposed, we will not be able to make a real step forward in the empirical evaluation of the Efficiency, Effectiveness and Impact of Education, Research and Innovation. Third mission indicators (see Bornmann, 2013 for a survey) have a crucial role in this respect. It is indeed the role played by third mission indicators formally conceptualized as a measure of quality of higher education/research institutions, which can be used to investigate the Science-Society interplay.
For the conceptualization and formalization of the «quality» dimensions we suggest to adopt a very different approach based on: 1. Knowledge infrastructure (Edwards et al., 2013); 2. Convergence as «the coming together of insights and approaches from originally distinct fields», which «provides power to think beyond usual paradigms and to approach issues informed by many perspectives instead of few» (National Research Council, 2014).
We need to develop a knowledge infrastructure to model research and innovation and all the activities related to their (economical and societal) impacts in a systemic way. To advance towards an "open science" we have to build a common platform that has to be able to show us which data is relevant for assessing the model we selected for the analysis. In this way, the data could be analysed under different perspectives while sharing the same common conceptual characterization.

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[1] The full list of references can be found at the author website.