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Investigating the interplay between fundamentals of national research systems: Performance, investments and international collaborations

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ABSTRACT

We discuss, at the macro-level of nations, the contribution of research funding and rate of international collaboration to research performance, with important implications for the "science of science policy". In particular, we cross-correlate suitable measures of these quantities with a scientometric-based assessment of scientific success, studying both the average performance of nations and their temporal dynamics in the space defined by these variables during the last decade. We find significant differences among nations in terms of efficiency in turning (financial) input into bibliometrically measurable output, and we confirm that growth of international collaboration positively correlate with scientific success—with significant benefits brought by EU integration policies. Various geo-cultural clusters of nations naturally emerge from our analysis. We critically discuss the factors that potentially determine the observed patterns.

1. Introduction

The science of science policy is emerging as an interdisciplinary field that aims at developing theoretical models and studying empirical evidence for the performance of scientific communities and individual researchers (Fealing et al., 2011). This scientific activity can then help to develop policies for improving Research and Development (R&D) funding allocation and strategical decision making. Within the field, a critical issue has been that of identifying suitable quantities to characterize the research systems at the level of nations, in terms of scientific impact, development and competitiveness.

Indeed, many metrics to evaluate the impact of scientific research have been proposed in the literature, but few have proven to be satisfactory—see Waltman (2015) for a recent overview of the field. The traditional approach, based on shares of citations or documents (May, 1997; King, 2004), in fact, suffers from several drawbacks. First, the number of published papers gives no clear information about the quality of the research they contain. Second, the number of published documents grows steadily in time, whereas, citation statistics are highly biased for recent papers that had not enough time to attract citations (Medo et al., 2011), and thus need to be normalized properly for a time dynamical analysis. Third, the number of citations or documents is an extensive measure that naturally correlates with size, thus requiring additional normalization in order to compare, e.g., different national research systems. The latter problem applies also to more refined methods like the H-index (Hirsch, 2005) and its variants. Other approaches (Smith et al., 2014) measure scientific performance of individual

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papers by comparing the total number of citations a paper has accrued to those of other publications of the same journal volume. Still, methods based on publication venues suffer from all the exogenous and endogenous factors that enter in the effective publication mechanism and that can follow different criteria than the real quality of the scientific work.

Metrics that take care of the skewness of citation distributions (by considering only highly cited publications) (Aksnes and Sivertsen, 2004) have found wide application in the field, however how to determine whether a publication is counted as highly cited or not is still an open issue (Waltman and Schreiber, 2013) which can hinder a comparison of different studies (Bornmann et al., 2013). In order to avoid all the problems mentioned above, and to obtain a proper normalization of bibliometric data, we follow the general ideas of Waltman et al. (2011) and measure scientific performance of individual nations as their ratio of citation shares to publication shares (see Section 2). The reason is that whenever a nation receives a larger share of citations compared to the fraction of papers it publishes, it is producing science that has a greater impact than the world average. Interestingly, most national research systems have been characterized, during the last years, by a remarkable increase of the number of international scientific collaborations (Leydesdorff and Wagner, 2008; Leydesdorff et al., 2013). This phenomenon has been studied and analyzed especially in the context of the European Union, where it appears to be a particularly strong clue of successful EU integration policies—see Glänzel and Schlemmer (2007), Huang et al. (2011); and Chessa et al. (2013) for a contrary view. However, also developing nations have increased their rates of collaboration with foreign, already developed nations, and empirical evidence suggests that this strategy is at the core of their successful entrance in the scientific community (Wagner et al., 2001). As noted by Persson (2010), it is necessary to point out that the presence of a possible cause–effect relationship between scientific success and international collaborations is still an open issue. Notably, simple but commonly adopted measures of scientific performance (productivity, citation performance and journal placement) are known to be positively correlated with the rate of internationalization of the scientific community of a nation (Katz and Hicks, 1997; Abramo et al., 2011; Kato and Ando, 2013; Smith et al., 2014). In particular, it has been shown that the most successful teams are characterized by a moderate level of cultural diversity (Barjak and Robinson, 2008).

Of course, any study of national scientific performance cannot neglect the role played by the availability of financial resources—namely, R&D funding. Yet, assessing efficiency at the research system level is a complex research question. In a recent paper, Pan et al. (2012) have shown that the research impact of a nation grows linearly with the amount of national R&D funding, pointing out also the presence of a peculiar effect: in order to be effective, public investments should exceed a certain threshold. As pointed out by Leydesdorff and Wagner (2009), there is a great difference in national ability to transform financial input into bibliometric output. The situation becomes even more complicated when looking at scales smaller than nations. For instance, according to the analyses performed by Sandström et al. (2014) comparing the change in scientific output with the change of funding, there is no evidence that the amount of institutional funding correlates with competitiveness, overall performance, and top performance of universities at the national level. Fortin and Currie (2013) instead focused on individual researchers, showing that impact is positively, but only weakly, related to funding, and in general is a decelerating function of funding itself. These conclusions, together with the multi-facet structure of the R&D funding scheme (Leydesdorff and Wagner, 2009), stress the need of a systematic approach to funding-based analysis.

Notably, as we show at the end of this paper, a complex structure of geo-cultural clusters naturally emerges from this kind of studies. As originally pointed out by Frame and Carpenter (1979), international co-authorships are clearly biased by extra-scientific factors such as geography, politics and language. Also Luukkonen et al. (1992) reached similar conclusions, suggesting the presence of cultural *centers* on which other nations hinge. In summary, three fundamental aspects naturally emerge as prominent features for a systematic analysis of nations scientific production: internationalization, funding, success, and, as a further resulting output, the presence of geographic and cultural communities. In this work we precisely address the issue of how the complex interaction between these fundamentals shape the scientific production of nations. Our paper is organized as follows. In Section 2 we describe our datasets and define the variables we are going to use in our analysis. In Section 3 we present our main results, namely, a static and dynamic analysis for the scientific performance of nations as a function of both level of internationalization and fundings to various types of research institutions. The concluding Section 4 summarizes our findings and discusses future perspectives.

2. Materials and methods

In this section we define the different metrics we rely upon to characterize national research systems, and describe the databases used to build them.

2.1. OECD data and R&D funding

We collect data on national expenditure in scientific research and development from the Organization for Economic Cooperation and Development (OECD, www.oecd.org). Data refer to $N_f = 37$ developed nations and to years 2000–2012. All expenditures are expressed in terms of current purchasing power parity (in millions of US dollars). The overall national expenditure indicator, known as GERD (Gross Expenditure on R&D), is divided into three main components: BERD (Business