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Are there any frontiers of research performance? Efficiency measurement of funded research projects with the Bayesian stochastic frontier analysis for count data

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ABSTRACT

In recent years, scientometrics has devoted increasing attention to the question of measurement of productivity and efficiency in research. In econometrics, the question is usually examined using data envelopment analysis. Alternatively, in this paper we propose using a statistical approach, Bayesian stochastic frontier analysis (B-SFA), that explicitly considers the stochastic nature of (count) data. The Austrian Science Fund (FWF) made data available to us from their peer review process (ex-ante peer evaluation of proposals, final research product reports) and bibliometric data. The data analysis was done for a subsample of N = 1,046 FWF-funded projects (in Life Science and Medicine, Formal and Physical Sciences). For two outcome variables, a general latent research product dimension (CFACTOR) and the total number of publications (P), technical efficiency values (TE) were estimated for each project using the SFA production functions. The TE values for CFACTOR and P were on average 0.86 and 0.27, as compared with a maximum TE value of 1.0. With regard to CFACTOR, female PIs, younger PIs, and projects with longer durations have slightly higher TE than male PIs, older PIs, and projects with shorter durations. A simulation study showed the statistical behavior of the procedure under different sampling conditions.

1. Introduction

In recent years, scientometrics has devoted increasing attention to the question of measurement of productivity and efficiency in research, as shown for example by a special section of the *Journal of Informetrics* (Volume 10, Issue 2) published in 2016. The use of the concepts of productivity and efficiency favors economic approaches, which relate research output to input (e.g., the amount of funding). For instance, Abramo and D'Angelo (2014), who are proponents of this perspective, try to define and measure research productivity within a microeconomic theory of production framework and utilize a numerical nonparametric approach, data envelopment analysis (DEA). In econometrics, DEA is considered to be a standard method of efficiency analysis (Liu, Lu, Lu, & Lin, 2013a; Liu, Lu, Lu, & Lin, 2013b), and it also has numerous applications in research on higher education (e.g., Bessent, Bessent, Charnes, Cooper, & Thorogood, 1983; Sinuanystern, Mehrez, & Barboy, 1994). In the 2016 special section of *Journal of Informetrics*, several contributions discuss Abramo and D'Angelo's (2016, p. 646)

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proposition "to switch" from size-independent indicators based on the ratio to publications, such as crown indicators (e.g., mean normalized citation score), "to rankings by research efficiency." The issues of productivity and efficiency are discussed mainly in the context of performance-based university research funding. That approach demands, in addition to the ex-ante evaluation of research projects, also their ex-post evaluation. This raises explicitly the questions of the effectiveness and efficiency of research funding (Hicks, 2012; Rabovsky, 2014a, 2014b).

The use of nonparametric methods of productivity and efficiency analysis like DEA requires deterministic indicators (Glänzel, 2010, p. 314). Any kind of random noise or stochastic component is not considered. Alternatively, in this paper we propose a statistical approach for analysis of productivity and efficiency, stochastic frontier analysis (SFA), and apply it to the input and output data of projects funded by the Austrian Science Fund (FWF) as an example.

The next section below looks at the foundations of SFA as opposed to ordinary regression analysis and DEA. The following sections then outline the research questions and formulate the hypotheses, describe the data, and provide methodological-statistical details. The paper concludes with a presentation of the results and a discussion of the findings.

2. Regression, DEA, and stochastic frontier

Economic productivity and efficiency analyses are based largely on four elements: Decision making units (DMUs), outputs, inputs und a function that describes the transformation of input into output formally (mathematically), the production function. For research funding organisations are the funded projects the DMUs, which owing to the financial input, especially the grant sum, and the intellectual capital of a proposal (Falzagic, 2005) produce research output (e.g., journal article, book, conference contribution, PhD). The intellectual capital of a project is rated by the reviewers in the ex-ante evaluation of the proposals.

From the perspective of data analysis, in a productivity and efficiency analysis, as compared with the classical approach of statistical regression, it is not primarily about prediction. The aim is not to predict the research output of a DMU on average but instead to determine the maximum expected research outputs of the DMU with the given input (Archibald & Feldman, 2008), for example the maximum possible number of publications given a certain grant sum. The basis is the transformation of a set of research inputs or production factors into a set of research outputs. The set of maximum expected research outputs for a set of given research inputs defines the production function, or the *frontier* of production. Technical efficiency (TE) characterizes "the relationship between observed production and some ideal, or potential production" (Greene, 2008, p. 100), which is the maximum feasible output for an input as it is represented by the estimated production function. Productivity is defined "as the ratio of output y (what we produce) over input x (the resource we use: Productivity = y/x)" (Faire, Grosskopf, & Margaritis, 2008, p. 522).

In econometrics, DEA is the standard method of analysis of TE; it is also already being used frequently in research on higher education and in scientometrics (e.g., Abbott & Doucouliagos, 2003; Abramo, Cicero, & D'Angelo, 2011; Abramo & D'Angelo, 2014; Athanassopoulos & Shale, 1997; Charnes, Cooper, & Rhodes, 1978; Johnes, 2004, p. 625; Johnes, 2006; Liu et al., 2013a): "DEA involves the use of linear programming methods to construct a non-parametric piece-wise surface (or frontier) over the data. Efficiency measures are then calculated relative to this surface" (Coelli, Rao, O'Donnell, & Battese, 2005, p. 162). Here, the level of analysis is mostly the entire institution or certain scientific disciplines of an institution, which, however, makes direct assignment of funding resources to research output difficult. In the end it is the individual research project in which the assignment of input to output takes place. In this connection, Abramo and D'Angelo (2014) point to the necessity for a two-step procedure "first measuring the productivity of the individual researchers in their field, and then appropriately aggregating the data" (p. 1132). Whereas in Abramo and D'Angelo (2016) the DMUs are researchers, in our case they are the research projects.

As compared with other methods of production efficiency, especially the statistical approach of stochastic frontier analysis (SFA) (Coelli et al., 2005; Greene, 2008; Johnes, 2004; Kumbhakar, Wang, & Horncastle, 2015; Parmeter, 2014), DEA, as a numerical nonparametric technique, is preferred for the following reasons (Abramo et al., 2011, pp. 231&232; Abramo & D'Angelo, 2014, p. 1133; Bonaccorsi & Daraio, 2004; Chen, Delmas, & Lieberman, 2015): First, with DEA, complex production functions with multiple outputs and inputs can be analyzed and described with a single efficiency indicator. Second, with DEA, no specific functional connection in the form of a production function has to be defined (e.g., the Cobb-Douglas production function). Third, benchmark best practices can be identified directly; "in other words, comparisons are to real production units that are used as references for best practices" (Abramo & D'Angelo, 2014, p. 1133). Last but not least, the numerical technique produces robust solutions for the desired production efficiency.

SFA has the following advantages over these undoubtedly strong arguments for DEA: First, SFA takes account of random measurement errors. The research output of DMUs, such as number of publications or citations, are not fixed values but are affected by many random factors (e.g., periodic updates of bibliographic data bases, random fluctuations of universities' performances). The research output and impact of DMUs fluctuates to a certain extent by chance. Second, for the measurement of productivity and efficiency it is crucial what factors actually determine the measured values. In DEA this is a two-stage procedure: The productivity efficiency values calculated in the first stage of DEA are regressed statistically on predictors by ordinary least-squares regression (OLS) in a second step (e.g., Johnson & Kuosmanen, 2012; Ramalho, Ramalho, & Henriques, 2010). This procedure has limitations, however, as ". . . second-stage OLS estimation is consistent only under very peculiar and unusual assumptions on the data-generating process that limit its applicability" (Simar & Wilson, 2011, p. 205). In SFA, the efficiency values and the regression parameters are estimated unbiased in one step (Wang & Schmidt, 2002). Third, by