

Research efficiency in relation to investment

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It is well known that productivity -expressed as production per unit effort- is a better comparative measure than bulk production, which largely relies on internal peculiarities of production agents. In science, however, many success measures still consider production instead of productivity. A common appraisal of scientific production is the number of papers published (P), especially in journals with recognized impact indices, usually the *Impact Factor Index (IFI)* of the *ISI-WOK Journal Citation Reports (JCR)*. Beyond discussions on the suitability of this procedure, P is an absolute measure that should be balanced against other parameters to properly calculate productivity or production efficiency (E).

An index that would make sense for basic or fundamental research units is P in relation to investment (I), which could be expressed in the number of papers published (or *IFI* points scored) per unit money invested per unit time ($E = P/It$). In this way, it can be computed the productivity of any research unit (a researcher, a project, a department, a university, an institute, etc).

The interpretation of E is not straightforward and would be taken as indicative of anomalous situations useful to implement or revise investment policies. For example, a research unit with high funding but lower E than other with a lower budget would be requested to increase its production or decrease its budget. Conversely, the salary of a scientist (or the budget of a research unit) with similar E than other who receives higher funding could be considered worth to be increased. In this sense, it is noteworthy that some

Nobel prizes have been obtained with comparatively low investment (Ioannidis, 2011). On the contrary, in some cases, scientists or research units participate in high number of national and international projects and receive high funding, but this is not necessarily reflected in the number of papers in *JCR* journals or the *IFI* points obtained.

Regional and worldwide comparisons among countries are also possible but, in this case, E -values should be interpreted with care due to obvious economic inequality. However, these indices can also help finding unexpected disequilibria among regions. For example, a classification of countries or world regions based on E -values would produce eventual surprises, in terms of research efficiency in relation to investment. Indeed, countries with higher budgets for science should not necessarily be the more efficient, while others with lower investment would be comparatively more productive. This would lead to revise national policies of investment in science.

The parameters of the E -equations can be selected according to the evaluation target. For example, patents or other similar outcomes can be used instead of papers, in the case of technological units. For applied research units, direct (or short-term) and indirect (or long-term) social benefits could be also used but this includes many other complex variables, which are beyond the scope of this letter. Similarly, I could be replaced by any other variable expressing scientific endowment. Combinations and differential weighing of the involved variables leading to little more complicated equations are also possible.

It should be emphasized that *E*-values are by no means quality measures; they only record the efficiency of investment in science and should not be used to evaluate research quality, but only to optimize investment policies. These simple indices would be also useful to show tax payers and administrators the efficiency of public and private investment in science. A proposal like this cannot be analyzed only on the grounds of theoretical arguments. Rather, it should be tested using empirical data from a variety

of situations, in order to decide about its suitability, or to suggest eventual improvements. Therefore, it would be useful to start doing statistics with these and similar productivity indices at all levels, and be prepared for amazing results.

REFERENCE

Ioannidis, J. P. A. 2011. More time for research: Fund people not projects. *Nature* 477: 529-531.