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INNOVATIONS IN RESEARCH METHODOLOGY

Measurement of research and development activity in Poland from the perspective of science, technology and innovation statistics

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Authors' Contribution:
- **A** Study Design
- **B** Data Collection
- **C** Statistical Analysis
- **D** Manuscript Preparation
- **E** Funds Collection

Received: 19 September 2022; **Accepted:** 25 November 2022; **Published online:** 27 December 2022

AoBID: 16093

Abstract

This scientific essay introduces readers to science, technology, and innovation (STI) statistics. It discusses the Frascati Manual, Canberra Manual, OECD Patent Statistics Manual, Oslo Manual, as well as manuals from Bogota, Santiago, Lisboa, Antigua, Valencia, and Lima. These manuals provide guidance on harmonizing and standardizing methodologies, guaranteeing both the validity of statistical data and their international comparability. They offer information for R&D policy evaluation and support innovation strategies. The essay emphasizes the importance of measurement in monitoring scientific, technological, and innovative progress at the national and international levels. The authors point out the limitations and challenges related to the interpretation and use of indicators, such as focusing on data quantity at the expense of research quality, differences in data collection methods, and the lack of unambiguous indicators defined for specific institutions or countries. They also highlight the need to complement R&D indicators with other tools to ensure a better understanding of R&D and innovation activities. The purpose of this essay is to expand readers' understanding of the importance of measuring STI activities.

Keywords: bibliometrics • Canberra Manual • Frascati Manual • OECD Patent Statistics Manual • Oslo Manual • R&D • STI

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: Not required

Provenance & peer review: Not commissioned; externally peer reviewed

Source of support: Departmental sources

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Frascati Manual – an international standard defining the scope and methodology for measuring R&D activities. It defines research and development activities and provides guidelines for collecting and interpreting data on R&D expenditure, personnel, and performance [5].

Canberra Manual – international methodological recommendations for measuring human resources in science and technology, as well as methods for analyzing its structure and changes [13].

Oslo Manual – international methodological recommendations for collecting, presenting, and interpreting data on innovation [14].

OECD Patent Statistics Manual – a compendium of knowledge essential for developing statistics on patent activities [15].

STI indicators – international tools for measuring, analyzing, and comparing activities in research and development and innovation systems, encompassing aspects such as technology transfer, research commercialization, new product and service creation, business innovation, utilization of information and communication technologies, etc. [5].

R&D indicators – primarily focusing on measuring research and development activities, including expenditure on R&D, R&D personnel, innovation expenditure, the number of patent applications, technology transfer, etc. [5].

INTRODUCTION

The specificity of this work is also reflected in its editorial structure. Therefore, we forgo the traditional introduction based on a set of sentences informing about the essence of the researched (theoretical or empirical) issue, and instead, we directly introduce the international standards for measuring scientific, technical, and innovative activities. We believe this to be the optimal approach to achieve the cognitive goal of this scientific essay: an expanded understanding of the significance of measuring scientific, technical, and innovative activities.

INTERNATIONAL STANDARDS FOR MEASURING SCIENTIFIC, TECHNICAL, AND INNOVATIVE ACTIVITIES

Indicators for measuring scientific, technical, and innovative activities, encompassing R&D statistics, government budget appropriations or outlays for R&D (GBAORD), innovation statistics, and human resources in science and technology, are based on concepts and principles specified in manuals such as Frascati, Canberra, Oslo, OECD Patent Statistics Manual, Bogota, Santiago, Lisbon, Antigua, Valencia, Lima.

These manuals provide descriptions of these indicators, as well as methods for their measurement and analysis. They are essential tools for institutions involved in scientific and development research, enabling them to monitor progress in this area and compare results across different countries and institutions. However, these indicators are not the sole tools for measuring and analyzing R&D activities and may be complemented by other instruments, depending on research needs and objectives.

We present a brief description of these manuals:

1. **Frascati Manual** – developed by the Organisation for Economic Co-operation and Development (OECD) and published in 1963. Currently, it is the most recognized international standard defining the scope and methodology for measuring R&D activities, extensively used by the Central Statistical Office. It defines research and development activities and provides guidelines for collecting and interpreting data on R&D expenditure, personnel, and outputs [1].

2. **Canberra Manual** – developed by OECD, Eurostat, and UNESCO, published in 1978 as a tool for measuring R&D activities in the public sector. It identifies three categories of R&D expenditure: basic research, applied research, and experimental development. The manual also defines researcher categories such as scientists, engineers, and technicians. Measurement methods include indicators such as the number of scientific publications, patents, and R&D expenditure as a percentage of gross domestic product [2].

3. **Oslo Manual** – developed by OECD and published in 1992 as a tool for measuring innovation in enterprises. It provides guidelines for collecting and analyzing data on innovative activities, including product, process, and organizational innovations, covering a wide range of industries [3].

4. **OECD Patent Statistics Manual** – developed by OECD and published in 1994. It is a comprehensive compendium of knowledge essential for harmonizing patent statistics as one of the tools for measuring inventive activity, a crucial element of innovative activities [4].

5. **Bogota Manual** – a manual developed by the Latin American Economic System (SELA) to measure innovation in the region. It provides guidelines for collecting and analyzing data on innovative activities and is used by policymakers, researchers, and innovation practitioners.

6. **Santiago Manual** – a manual developed by the Economic Commission for Latin America and the Caribbean (UNECLAC) to measure innovation and technological change. It provides guidelines for collecting and analyzing data on innovation, technology, and industrial performance.

7. **Lisbon Manual** – a manual developed by OECD to measure the economic impact of knowledge-based sectors. It provides guidelines for collecting data on high-tech sectors and their contribution to the economy.

8. **Antigua Manual** – a manual developed by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) to measure science, technology, and innovation. It provides guidelines for collecting and analyzing

data on research and development activities, innovation, and human resources in science and technology.

9. **Valencia Manual** – a manual developed by the Inter-American Development Bank to measure innovation in the Latin American and Caribbean region. It provides guidelines for collecting and analyzing data on innovation and is used by policymakers, researchers, and innovation practitioners.

10. **Lima Manual** – a manual developed by the Economic Commission for Latin America and the Caribbean (UNECLAC) to measure research and development activities in the region. It provides guidelines for collecting and analyzing data on R&D expenditure, personnel, outputs, as well as technology transfer and innovation.

The above manuals constitute important frameworks for assessing and comparing research and innovative activities at the national and international levels, with Frascati Manual [1], Canberra Manual [2], Oslo Manual [3], and OECD Patent Statistics Manual [4], collectively known as the **Frascati Family Manuals**, being the most significant international methodological standards in the field of science, technology, and innovation (STI). It should be emphasized that these manuals do not define specific indicators but rather establish principles and guidelines for measuring, classifying, and analyzing data, including R&D and innovation (R&D&I) activities. Specific indicators for a particular institution or country are often developed by experts in research and development analysis, frequently utilizing the principles and guidelines set forth in these manuals.

All the mentioned manuals provide guidelines for harmonizing and standardizing methodologies, ensuring both the validity of statistical data and their international comparability. They offer valuable information for research and development policy evaluation and support innovation strategies.

LIMITATIONS OF SCIENCE, TECHNOLOGY, AND INNOVATION STATISTICS

Statistics of science, technology, and innovation (STI) have emerged and developed in response to the need for monitoring and evaluating progress in these fields and making effective policy and strategic decisions. Several factors have contributed to the birth and growth of STI statistics, resulting from changes in the development factors of highly developed countries and the structure of their economies:

- "The need to monitor scientific and technological progress. Governments, research institutions, and other entities require statistical information to assess the effectiveness of their actions, identify trends and areas needing improvement, and make decisions regarding resource allocation.

- The increasing significance of science and technology for socio-economic development. Countries have recognized that investments in R&D&I significantly impact competitiveness, innovation, and sustainable development. STI statistics have become a tool for assessing and monitoring these processes.

- Globalization and increased international cooperation in STI necessitated tools for comparability between countries. STI statistics provide indicators and data that allow for comparing results and achievements across different countries and identifying best practices.

- The introduction and reform of national and international science and innovation policies require monitoring and evaluating the effects of these policies. STI statistics provide indicators and data that enable the assessment of policy effectiveness and resource allocation decisions, as well as the evaluation of the effectiveness of public interventions" [5].

Metrics for science, technology, and innovation, being internationally recognized tools for measurement, analysis, and comparison, support understanding and evolution in R&D&I activities. These measures undergo evolution, with an increasing number of factors influencing a country's level of development. Interpretation of metrics also changes over time. Additionally, priorities in science policy of individual countries evolve. Hence, there are several reasons contributing to the limitations of STI metrics:

- Adopted theoretical assumptions determine what data is collected, categorized, and how classifications are applied, as well as what relationships are studied.

- Data analysis depends on changing interpretative frameworks.
- Each metric describes only one aspect of the phenomenon under study. For example, a metric for:
  - inputs does not reveal information about the effects,
  - publications does not account for expertise, prototypes, or know-how,
  - patents does not cover innovations in fields where patents are not used.
- Despite standardization, countries may apply different definitions and methods of data collection.
- Different bodies within the public administration may have varying interpretations of R&D activities. For example, in Poland, the Central Statistical Office, the National Revenue Administration, and the Ministry of Education and Science may have different interpretations.
- Many important issues are only visible at lower levels of data aggregation.

There are several significant barriers that hinder the effective use of STI metrics:

- The research, development, and innovation system is incredibly complex, while statistics have their limitations and can only answer certain questions concerning this system.
- The effective use of metrics requires a good understanding of statistical methods, which is often lacking among those using statistics, making proper utilization difficult and leading to erroneous data interpretations and decision-making.
- While STI metrics are useful, there are still gaps in theoretical knowledge concerning the relationship between these indicators and the reality they aim to describe. A full understanding of the context and dynamics of these relationships is lacking, which makes it challenging to fully utilize metrics in formulating science policy.

MEASURING RESEARCH AND DEVELOPMENT ACTIVITIES IN POLAND

Research and Development (R&D) Statistics is one of the branches of Science, Technology, and Innovation (STI) statistics, alongside statistics related to government budget appropriations or outlays for R&D (GBAORD), innovation, and human resources in science and technology. Due to editorial limitations, the most commonly used R&D indicators in Poland, which are significant for monitoring the country's scientific policy, disciplinary development, and allocation of resources in the science and higher education sectors, are presented. The reference point for these indicators is the national regulations concerning the evaluation of scientific activity, promotion procedures, and employee assessments, which include bibliometric indicators:

- the number of scientific articles, with special emphasis on highly ranked journals;
- the number of citations of scientific articles;
- the number of points based on Impact Factor;
- the number of ministerial points;
- the value of the Hirsch index;
- the number of scientific monographs, with special emphasis on highly ranked publications;
- the number of projects acquired through competitive competitions, with a specific focus on projects funded by the European Research Council (measured in the evaluation of scientific activity).

The use of bibliometric indicators is also motivated by the following reasons:

1. The fact that researchers in the field of science are primarily interested in obtaining Impact Factor points and accumulating citations, which reflects a well-established practice in the scientific and academic community.
2. A widespread opinion that the evaluation of scientific activity is mainly focused on points obtained from publications. However, the highest scientific categories (A+, A) are awarded

to entities that conduct activities across all assessed criteria (K1 – the level of scientific activity in the field of R&D, K2 – financial effects of R&D, K3 – the impact of scientific activity on society and the economy).

3. A lack of analytical tools in the hands of management in scientific institutions to assess the scientific potential of individual employees, scientific disciplines, and entire organizational units.

4. Different levels of substantive and legal knowledge, which is best illustrated by the scale of appeals during successive evaluation processes (29.1% of appeals in 2013 [6], 39% in 2017 [7], and estimated 50% in 2022).

5. Asymmetry of information caused by incomplete managerial information available to the management of scientific institutions and limited data on the scientific effectiveness of employees, which contributes to making scientific policies and decisions based on subjective perceptions rather than facts.

6. Low data quality manifested by excessive (unnecessary, inadequate) data or lack of appropriate data due to the lack of defined scope for collected information, errors resulting from the lack of verification, and repetitive data (multiplication).

7. Chaotic reporting processes due to assigning responsibilities to individuals unrelated to scientific information and blurring of accountability for reporting (multiple sources, multiple individuals), resulting in inconsistent data, lack of validation, and control.

The persisting practice of focusing on bibliometric indicators has led to the emergence of the phenomenon of pointosis (*punktoza*) [8], known worldwide as publish or perish. In both cases, researchers prioritize publishing, driven by high scores or bibliometric indicators assigned to scientific journals. Depending on updates to international rankings (e.g., Web of Science, Scopus) or currently applicable lists of journals in a given country, the demand for particular titles may rise or fall. In this pursuit, other significant indicators for science, technology, and innovation statistics, as defined in the Frascati Family Manuals, are overlooked. These indicators include:

- contextual indicators, such as science and investment policies,
- science indicators,
- technology indicators,
- research funding indicators,
- patent indicators,
- innovation indicators,
- research and development talent indicators,
- education and staff promotion indicators,
- mobility indicators,
- scientific culture and engagement indicators,
- university-industry collaboration indicators,
- entrepreneurship indicators,
- social impact indicators.

It is essential to apply various indicators and evaluation methods, as each can contribute to supplementing knowledge and enabling adequate utilization. The awareness that indicators are tools, not goals in themselves [9, 10], fulfills the fundamental criterion of self-control. The authors of "The Metric Tide: Report of the Independent Review of the Role of Metrics in Research Assessment and Management" recommend using diverse metrics and methods, adhering to principles of Robustness, Humility, Transparency, Diversity, and Reflexivity [11].

CONCLUSIONS

B+R indicators can be interpreted and utilized in various ways. It is worth noting that, due to the needs of research and development evaluation policies as well as supporting innovation strategies, science, technology, and innovation statistics serve the purpose of making effective policy and strategic decisions. Therefore, considering the multitude of operational goals of individual institutions and the creativity of individual researchers (creators), it would be a mistake to ignore the principle of daring (yet rational) use of diverse indicators. Furthermore, it is essential to consider both quantitative and qualitative dimensions to achieve a fuller understanding of R&D activities and their impact on the development of science and technology, as well as their effects on society and the economy. This vision aligns with the complex legislative interventions undertaken in the science and higher education sector in Poland concerning innovation and the social responsibility of science [12]. Although this essay is dedicated to a universal theme, citing Poland as an example is justified for at least two reasons. Firstly, Poland is a country that has successfully undergone a long process of socio-political transformation since 1989. Secondly, global civilizational changes do not bypass any democratic state, and the factor of research and development, despite being an area of dynamic competitiveness, includes elements of necessary international cooperation.

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Cite this article as: Rek M, Barczyński BJ. Measurement of research and development activity in Poland from the perspective of science, technology and innovation statistics. Arch Budo Sci Martial Art Extreme Sport 2022; 18: 95-100