The importance of research & development and innovation measurement for scientific institutions in a historical perspective

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Abstract

The essay presents a historical overview of indicators for the science, technology, and innovation (STI), which serve as international tools for measuring, analysing, and comparing scientists, scientific institutions, and countries. The development of STI statistics is discussed as a derivative of changes occurring in the development factors of economically advanced countries and the structure of their economies. The importance of developing science, technology, and innovation statistics as tools for measurement, analysis, monitoring, and their influence on shaping scientific policies is emphasized. Changes in the interpretation and significance of STI indicators and their role in monitoring progress and effectiveness of scientific policies from the 1950s to the second decade of the 21st century are discussed. The significance of STI indicators as a fundamental measurement tool used by international and national organizations is highlighted. The need for employing various indicators and evaluation methods that complement each other to gain a more comprehensive understanding of STI phenomena is emphasized. The objective of the paper is to enhance knowledge regarding the importance of measuring research and development activities and innovation from the perspective of the economization of the broadly understood field of science.

Key words: Frascati Manual • measurement of achievements • R&D expenditures • R&D statistics • RDI • STI

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Government budget appropriations or outlays for R&D – is the process of allocating expenditures on research and development to specific sectors and fields of science, allowing for specific description, which fields require greater investment and attention to achieve progress and development [12].

Economization of science – also commercialization of scientific research, means real building of economic capital by shaping close relations between science and economy [13].

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

Science, Technology & Innovation (STI) indicators – are international tools for measurement, analysis, and comparison that support the understanding and evolution of research and development activities and innovation systems, including other aspects such as technology transfer, commercialization of research results, creation of new products and services, business innovativeness, utilization of information and communication technologies, etc.

Research & Development (R&D) indicators – mainly focus on measuring research & development and innovation activities, including: expenditures on research and development, R&D personnel, innovation expenses, the number of filed patents, technology transfer, etc.

INTRODUCTION

The ongoing technological race extends beyond economic boundaries and encompasses political, geostrategic, and security issues. There is an increasing need for substantial resources dedicated to scientific research and development, while available resources and capital have significantly diminished. One of the fundamental challenges faced by scientific entities is the social and economic relevance of science and research. Modern institutions are expected to demonstrate greater effectiveness and efficiency in scientific and research activities, along with the capacity for change, understood as a sustainable model for managing their capital and resources.

The measurement of research and development activities has played a crucial role for scientific entities for years. Understanding the significance and role of such measurement is essential for scientists, research institutions, and public administration. Scientific research and development are integral to social progress, including innovation, and the outcomes of these activities have significant socio-economic impact.

This essay explores the subject of measuring research and development activities for the benefit of scientific entities in a historical perspective. It presents a synthetic overview of the evolution of expenditures on R&D (see glossary) and statistics of science, technology, and innovation, from the perspective of the development of key STI indicators (see glossary), from the 1950s to the second decade of the 21st century.

The aim of the work is extended knowledge of the importance of measuring research and development activities and innovation, from the perspective of the economization of the broadly understood scientific phenomenon [1, 2].

DEVELOPMENT AND SIGNIFICANCE OF SCIENCE, TECHNOLOGY AND INNOVATION STATISTICS

Science, technology, and innovation (STI) indicators are international tools for measurement, analysis, and comparison that support understanding and evolution of research and development activities and innovation systems. These measures undergo evolution, with an increasing number of factors determining the level of a country's development. The interpretation of indicators also changes over time, and the priorities of individual countries' science policies also shift.

The development of science policies alongside STI statistics is a derivative of changes occurring in the development factors of economically advanced countries and the structure of their economies. Starting from the times of the industrial revolution, Europe held a significant advantage. The creation of a global economy at the beginning of the 20th century made Europe a catalyst for economic growth worldwide, with Great Britain, Germany, and France being recognized as major powers, followed by the United States. However, the balance shifted with the outbreak of World War I, moving the world's industrial and trade centre from Europe to North America.

Between World War I and World War II, many countries focused on rebuilding and modernizing their economies. The development of industry, transportation, and communication was crucial, requiring innovation, capital inflow, and the application of modern technologies. The importance of science and technology as drivers of economic development increased. Many countries began establishing scientific institutions, universities, and research centres to promote scientific and technological development. Considerable technological progress occurred during World War II, with significant investments and resource concentration dedicated to research, technology, and military strategies. While morally a tragedy, the war acted as an economic catalyst that presented numerous challenges to the scientific community. Many governments realized the crucial role of science and technology for national security and progress, which led to a direction set for scientific advancements in the post-war years, sparking a scientific-technical revolution that lasted for decades.

In the 1950s, R&D expenditures were relatively low, with most countries focused on rebuilding their economies and infrastructure destroyed during World War II. Only two superpowers, the United States and the USSR, had the necessary human and financial resources. A breakthrough moment came with the launch of the first satellite, Sputnik, by the USSR in 1957. This event triggered a rapid increase in R&D spending during the 1960s, particularly in the United States and Western Europe. This period witnessed intensive development of new technologies such as electronics, space flights, and satellite communication, which required significantly higher R&D investments. Additionally, many countries began recognizing R&D as a crucial factor in economic development and made efforts to increase investments in this area. In 1963, two fundamental works were published: Derek J. de Solla Price's book 'Little Science – Big Science' [3], and the 'Frascati Manual' released by the OECD [4].

Both 'Little Science – Big Science' and the 'Frascati Manual' introduced the topic of measuring and assessing the quality of science. Derek J. Solla Price [3] described a method for measuring the effectiveness of research and development through the analysis of scientific publications and citations. Meanwhile, the 'Frascati Manual' defined standards for measuring scientific activities, enabling comparisons of results and progress in science [4]. It has since become one of the most important standards used by countries worldwide for monitoring and comparing their scientific activities.

The development of science, technology, and innovation statistics observed since the memorable year 1963 reflects the diversity of roles it played in state policies, in managing science in the public and private sectors, and in the higher education sector. Measuring research plays a crucial role in shaping science policies and serves as a source of knowledge for government administration in evaluating policy effectiveness.

The 1970s were characterized by the growing significance of science, technology, and innovation as factors for economic development and competitiveness. There was an increased government support for scientific research and technological development, resulting in a revolution in science management, making it more rationalized, with grant-awarding agencies shifting from dividing funds to professional management. STI statistics played a crucial role as instruments aimed at monitoring progress in these areas and evaluating science policies' effectiveness.

From the 1980s, new economic concepts (evolutionary economics, new growth theory, innovation systems concepts) influenced the development of science, technology, and innovation statistics. The concept of innovation systems was introduced for the first time. There emerged a need to measure efficiency, effectiveness, and accountability of public administration, leading to the emergence of the New Public Management [5].

The 1990s brought globalization and the development of a knowledge-based economy, resulting in greater emphasis on competitiveness, innovation, technology transfer, particularly in sectors such as information and telecommunications technology, financial services, biotechnology, and pharmaceuticals. Programs and initiatives promoting inter-sectoral and international cooperation in research and development and innovation (RDI) were established. The importance of STI statistics grew as tools for monitoring policy effects and decision-making.

The first decade of the 21st century was marked by sustainable development and solving global problems in a changing environment. Global research cooperation increased, demanding better integration and harmonization of STI statistics to facilitate monitoring of progress and evaluation of cooperation effectiveness. Simultaneously, rapid technological development required the development of shared methodological frameworks and indicators to enable data comparability between countries.

The second decade of the 21st century brought increased engagement in science, technology, and innovation policies as tools for achieving sustainable development, digital transformation, and social innovations in a changing environment. The significance of sectors based on digital technologies, artificial intelligence, biotechnology, and nanotechnology grew. Emphasis was placed on stimulating public-private partnerships and inter-sectoral and international cooperation to promote innovation and technology transfer. The importance of measuring and monitoring the effects of science, technology, and innovation policies significantly increased, leading to the development of more advanced STI statistics and innovation efficiency indicators.

DEVELOPMENT OF KEY SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS

The measurement of scientific activity, enabling comparisons of results and progress in science, is a gradual and lengthy process that becomes increasingly complex over time, requiring consideration of a growing number of factors, indicators, and evaluation methods. Expenditures on research and development are crucial for innovation progress, influencing economic development, shaping prosperity, and building geostrategic position. “Innovation processes occur in a specific system of connections involving networks of businesses, research institutions, non-governmental organizations, as well as government, public administration, and civic initiatives” [6]. Both research and development and innovations are at the heart of economic research interests for scientists, scientific entities, financial institutions, countries, and international organizations such as OECD, Eurostat, UNESCO, which measure STI indicators.

Table 1 presents the development of research and development expenditures along with statistics on innovation activities from the 1950s to the second decade of the 21st century.

Table 1. Development of key S+T+I indicators in successive decades.

Span	Expenditures for B+R activities	Statistics
The 1950s of the 20th century	Relatively low expenditures on R&D	Limited statistics on innovative activity
The 1960s of the 20th century.	Rapid increase in expenditures on R&D, especially in the United States and Western Europe	OECD has developed the first standards for the measurement and classification of R&D activities, providing guidelines for collecting and interpreting data on R&D expenditures, personnel measurement, and R&D outcomes
The 1970s of the 20th century	Expenditures on R&D started to grow even more dynamically as many countries realized the significance of innovation as a key driver of economic growth	Statistics related to innovative activity have become more detailed, including patent statistics and the balance of payments in the field of technology
The 1980s of the 20th century	Many countries, especially the highly developed ones, started investing more and more in R&D activities. Structural changes in the global economy contributed to changes in the allocation of R&D expenditures	More detailed statistics on innovative activity have been developed, including high-tech products, bibliometrics, patents, human resources, research on innovation activity, and also the balance of payments in the field of technology
The 1990s of the 20th century	Expenditures on R&D remain at a high level, with some countries increasing their investments to compete in the knowledge-based global economy. The shift in the nature of R&D spending from basic research to applied research is driven by the growing interest in the applicability of research	Statistics on innovative activity have become even more detailed, encompassing product, process, and organizational innovations
The 21st century’s first decade	Expenditures on R&D continue to grow, focusing on innovations and the implementation of new technologies	Statistics on innovative activity also included indicators related to information and communication technologies, biotechnology, nanotechnology, as well as productivity and budgetary support for innovation activities
The 21st century’s second decade	Expenditures on R&D have remained at a high level, driven by technological advancements and the increasing importance of innovation in modern economies	Innovation statistics are increasingly complex and encompassing GBAORD disaggregation, as well as issues such as investments in intangible assets, commercialization of scientific research, internationalization and globalization, knowledge-based economy, intellectual capital, venture capital, tax incentives, digital revolution

Source: Own source.

SCIENCE, TECHNOLOGY AND INNOVATION STATISTICS – PERSPECTIVES FOR THE FUTURE

STI indicators, due to their well-established practice of application by multinational organizations such as OECD, UNESCO, Eurostat, are a fundamental measurement tool used for many years, including in Poland by the Central Statistical Office. They are utilized in making effective policy and strategic decisions.

Currently, STI indicators play a crucial role due to the following reasons:

- The need for monitoring scientific and technological progress. Governments, research institutions, and other entities require statistical information to assess the effectiveness of their actions, identify trends and areas for improvement, and make decisions regarding resource and funding allocation.
- The increasing significance of science and technology for socio-economic development. Countries recognize that investments in RDI have a significant impact on competitiveness, innovation, and sustainable development. STI statistics have become tools for assessing and monitoring these processes.
- Globalization and increased international cooperation allow for comparability between countries using digital tools. STI statistics provide indicators and data that enable comparisons of results and achievements among different countries and the identification of best practices.
- The introduction of reforms in science and innovation policies at both national and international levels requires monitoring and evaluating the effects of these policies. STI statistics offer indicators and data that allow for the assessment of policy effectiveness and resource allocation decisions, as well as the evaluation of the effectiveness of public interventions.

Most commonly used are bibliometric or scientometric measures by scientific and higher education institutions – for example, the Physical Education Academies in Poland [7]. It has not been observed that these institutions equally often use measures of innovation, talent, scientific culture, engagement, university-industry cooperation, entrepreneurship, training, and mobility. It is essential to use various indicators and evaluation methods, as each of them can contribute to complementing knowledge and allowing for a more comprehensive understanding. Therefore, the awareness that indicators are only tools, not goals in themselves [8, 9], meets the basic criterion of self-control [10]. Hence, by using diverse metrics and methods, one should be guided by the principles proposed by the authors of 'The Metric Tide: Report of the Independent Review of the Role of Metrics in Research Assessment and Management' [11]:

1. **Robustness** means that indicators should be based on the best available data in terms of accuracy and scope. It is important to use credible and reliable data sources, avoid errors and distortions. Indicators should be based on solid scientific and research foundations that provide reliable results.
2. **Humility** means that quantitative assessment should support qualitative assessment and expert knowledge. Science and higher education indicators should not replace expert subjective assessment but rather complement it. It is essential to consider various perspectives and contexts in the assessment process.
3. **Transparency** plays a crucial role in ensuring fairness and credibility of assessments. Data collection and analysis processes should be open and transparent to enable those being assessed to verify and validate the results. This builds trust and enables participants in the science and higher education system to have a better understanding of the assessment process.
4. **Diversity** is essential to consider the diversity in different scientific fields. Each field has its specific goals, methods, and outcomes, so it is essential to consider this diversity in creating indicators and assessments. The use of diverse indicators allows for considering various aspects of achievements and effectiveness in individual fields.
5. **Reflexivity** is crucial as indicators can have systemic effects. This means that when introducing indicators, one should be aware of

their impact on the science and higher education system and the possibility of their update and adaptation in response to changing conditions and needs. Reflexivity provides flexibility and enables the adjustment of indicators to a changing environment.

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