Emergence of new branches of statistics (Science, technology and innovation statistics)

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Statistical information and its analysis are key factors in any kind of decision-making process. In response to modern society's increasing demand for information, new branches of statistics must be developed in order to provide decision-makers with detailed and timely information. One of the relatively young branches of statistics, only one century old, is the branch of science, technology and innovation (STI) statistics.

This paper focuses on the emergence and development of science, technology and innovation (STI) statistics that has resulted in internationally harmonised norms, classification and comparable time series.

STI indicator development is an ongoing process. In the 21st century, it is critical to improve measures for the internationalisation of STI in order to provide new tools for policymaking and evaluation. This process requires additional internationally comparable databanks as well as a better understanding of currently unmeasured factors in the STI internationalisation process. The first section of this paper gives a short overview of the background leading up to the emergence of STI statistics. The second section focuses on the new epoch: the post-war period when demand, actors and speed of development in STI statistics changed significantly. These changes resulted from the recognition of the importance of scientific policy, which created the need for research and development indicators. The third section gives a detailed account of international comparability, an area which gained importance as competition between nations as well as the internationalisation of research and development (R&D) activities both created a strong demand for internationally comparable indicators. The OECD played an important role in this process that lead to the creation of the Frascati Family manuals and internationally comparable time-series. The adoption of OECD standards in a transition economy, namely in Hungary, is described in the fourth section, while the final section gives some concluding notes.

Keywords: science, technology and innovation statistics, Frascati Family manuals, transition economies

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1. Background

As modern society's demand for information increases, new branches of statistics must be developed in order to provide decision-makers with detailed and timely information. Statistical information and its analysis are key factors in any kind of decision-making processes. It was because of the needs of states to collect data on their people and economies, and to administer these data that modern statistics emerged in the 18th century.

One of the relatively young branches of statistics is the branch of *science, technology and innovation* (STI) statistics. Dramatic changes in the socio-economic environment resulted in the need for systematic information on research and development activities, and on the output of scientific efforts.

During the era of the second industrial revolution, in the late 19th century, the role of science and research activities had significantly transformed the economic life of forerunner countries. The emergence of industrial research and development (R&D) transformed the mode of operations for innovative work and the attitude toward the cost and benefit of scientific work. In the majority of industries, links between science and technological innovations grew closer, as this era was marked by changes in various areas: great inventions, organisational innovations, and the expansion of educated people.

One of the important organisational innovations was the creation of industrial laboratories. At the same time, the growing need for an educated workforce affected the education system, including colleges and universities. The growing role of profit-oriented funders in science and the increasing cost of research made investors in science much more interested in the input, output, and outcome of research and development activities. *All of these changes created a demand for STI statistics that has developed gradually over the last century.* Scientists themselves also became interested in S&T statistics.

The history of STI indicators reaches back more than just 100 years. As identified by Benoit Godin (2007), an historian of STI indicators, the first systematic STI publication was American Men of Science, compiled regularly by the American James McKeen Cattell and published between 1906 and 1944. Cattell had edited the still prestigious Science journal for decades. This journal published short scientific CVs on the authors and accumulated thousands of CVs. Cattell exploited the information on authors thus gathered in order to create a repertory of American scientists. Its first publication contained demographic, geographic and scientific performance indicators on 4000 American scientists. This publication provided information on the relative strength of individual scientific fields per geographic region, and on who are the most successful scientists by fields and age cohorts.[2]

There were *various users* of this series of publications: for example, universities considering whether to appoint an applicant to a tenured position. Researchers used it when seeking collaboration partners in their own or another field of science, as did various clients to know which science is strong in a given region or which region is strong in a particular science.

One of the first attempts to focus on R&D activity from the *policy point of view* was in the 1930s. It was at that time that policymakers first appeared among the users, even if only from a distance. There was an attempt to measure input and output of research and development activities in the Soviet Union's centralised planned economy, where everything was approached as important macroeconomic growth factors. Lundvall and Borrás (2005 p 604) mentioned in Western Europe, 'according to Chritopher Freeman science policy was recognised as a policy area through the pioneering work by Bernal (1939) Bernal was a pioneer in measuring the R&D effort at the nationa level in England.' 'In the 1930s Bernal made the first attempt to measure the effort made in science by relating R&D expenditure to the national income of the UK.' (616)[3]

Until the end of World War II, there were only few countries that prepared S&T statistics, the majority of which existed merely as research products and focused on researchers as the most important assets of science. Demand for S&T statistics and the involvement of stakeholders changed in the early post-war years.

The shift in the concept of S&T statistics is usually linked to the Vannevar Bush report (1945, Science, The Endless Frontier) prepared by V. Bush as the first presidential advisor to President Roosevelt right after World War II. He proposed to create a peacetime government research and development agency. In 1950, the National Science Foundation was created in the US. This organisation made the first systematic collection of data employing surveys and administrative data and analysis of data and indicators.

In the early post-war years, S&T policy became an immanent and independent part of governmental policies. (The emergence of science policy was influenced by the experiences of World War II and by the start of the Cold War.) When the

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[2] Similar data sources were available for at least few fields of science in several other countries. (For example: a biologist compiled data on biologic researchers in Belgium in the mid-19th century.) This publication remained as a matter of special interest. French experts prepared a repertory based on a systematic datasheet on S&T personnel but did not exploit this source statistically to support S&T policymaking. They employed only for identifying relevant knowledgeable people for military purposes.

[3] Bernal J. D. (crystallography and molecular biology) worked on these indicators following his visit to the Soviet Union. He focused on social function of science, attempts to measure progress in science by relating R&D expenditure to the national income in Great Britain.

importance of science policy as a new policy area was recognised (Bernal 1939, Bush 1945) the need for R&D indicators for policymaking came into the spotlight. (Lundvall-Borrás 2005 pp. 599-631) The post-war era opened a new epoch in STI statistics.

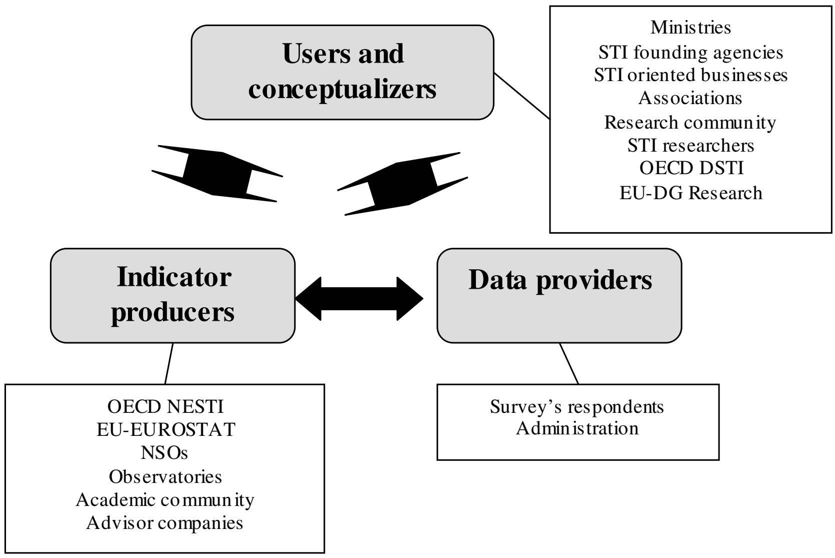
2. New epoch in STI statistics: changing demand, actors and development in STI statistic

The main difference between pre- and post-war S&T statistics was in their *conceptual framework*, as the issues covered by STI statistics and the actors producing the statistics changed significantly after the war. The measurement concept for RDI became economic in character. The result is a collection of economic indicators that are compatible with other economic datasets. (Many dimensions of RDI activities remained out of the measurable field.)

Conceptual foundations are crucial in the development of STI statistics even if they are rarely considered when indicators are used, as S&T (and innovation) statistics always rest on some kind – explicit or implicit – of conceptual foundation. In the 1950s, the conceptualisation and construction of STI indicators, as well as the collection and analysis of internationally comparable STI data and indicators, started. In the 1950s, British researchers developed the conceptual framework, definitions and classifications for measuring R&D. One of the main problems was to define research in a way that allows to measure research activities in different fields of science in a comparable way. During the preparation of the 'Green Book' for government R&D policy, the House of Lords discussed a study that backed up a unified definition of R&D for national policy. This study presented more than 40 definitions of research that was used previously in ad hoc measures. (Lord Rothschild 1972)

STI statistic work is an interactive process and the statistic is a joint product of various actors in the process. Figure 1 shows the schema of actors and their relations.

Figure 1. Actors and Linkages in Preparing Indicators



Source: own creation

The following lists some breakthrough concepts that led new streams of STI indicators. These examples illustrate that research community was also an important initiator of and actor in the development of STI indicators.

- *Polanyi's concept* on the codified and tacit dimensions of knowledge is a great challenge to measure diffusion of knowledge. Developments of scientometrics and patent indicators are a good illustration of designing indicators to measure codified knowledge. Indicators for measuring the diffusion of tacit knowledge are still in the blue-sky or development stages. Pilot indicators on the mobility of science and technology personnel are promising indicators in this field.
- *Rosenberg and Kline's work* (1986) relates to the conceptual foundation of innovation indicators. That work had an explicit effect on the OECD's (Organisation for Economic Co-operation and Development) Innovation Manual (Oslo Manual 1992, 1997, 2005). As Smith summarised (2005, p. 150), the chain-link innovation model (Rosenberg and Kline 1986) has important implications for indicator developments: (a) innovation indicators should pick up small-scale changes that originated from the learning process and that may lead to important technological and economic outcomes; (b) innovation input indicators should cover non-R&D input (design, engineering developments, experimentation, training,

exploration of markets for new products. Measuring the networking dimension of innovations is still in the blue-sky stage.

3. Demand of Users

Demand of users has always had a crucial impact on the measuring, disaggregation and frequency of data collection. Beside the conceptual development, the emergence of new policy issues played an important role in broadening the STI statistical field. Both important scientific studies on STI-policy related issues and new policy challenges (European sclerosis, emergence of new technologies, globalisation, global warming, and ageing population) have created a demand for more fact-based analysis on science, technological development and on the innovation process. Heightened demand for S&T statistics also increased the involvement of stakeholders.

In the 1980s, policymakers had no reliable relevant indicators to support them in better understanding the changing world and to back up strategy-making. However, there was a recognition in international policy circles that technological development and innovation are crucial factors influencing economic growth, efficiency and employment.

Since the 1990s, the demand for indicators has been increasing. Policymakers as well as economic actors seek an accurate portrayal of the relationship between technological development and economic performance. This increasing demand has lead to the development of information that allows for the identification of the economic importance of high-tech industries, in particular the role of information and communication technology, their contribution to national performance in global competition. Detailed information on R&D personnel, on R&D expenditures, and on the effects of public investment in R&D is becoming important for policymakers. Other stakeholders such as leading industrialists are becoming more and more interested in S&T statistical information to back up their strategic decisions, since R&D investments play an important role in competition. The academic community also showed an interest in some types of information.

A good example of demand-led indicator development is the appearance of innovation indicators. The emergence of innovation in scientific work and as policy issue was another breakthrough in the second half of the 20th century in the development of this new branch of statistics. Beside science and technology policy, innovation policy also emerged in the 1950s and 1960s and created a new demand for statistics. Gradually developed indicators and more detailed disaggregation by large and small businesses and by manufacturing and technology intensive service sectors improved our knowledge on the innovation process, and provided support for further development of concepts and measures. (Smith 2005)

Innovation statistics gained further impetus in the 1990s. Several deployments have affected the innovation systems of world leading economies, such as the globalisation of STI. (OECD 1997) This also created a new demand for indicators. Decision-makers are now seeking information on issues that were not even of peripheral interest to them a decade ago. They need information on different RDI and competition performances by global regions; globalisation of RDI; cross-border RDI collaborations; cross-border mobility of highly skilled workers, and its impact on flow of knowledge. In recent years, new indicators have emerged on innovation input and output combined with economic data. Economy-wide measures have some degree of international comparability. Beside sectoral disaggregation, improving data coverage allows for regional disaggregation as well.

These mutual developments of quantitative information, scientific advance and policy needs have initiated a new track for STI indicator developments in the second half of the 20th century and are also the locomotives for 21st century RDI statistics.

4. Key producers and developers

The key producers of R&D statistics changed significantly after World War II. The first systematic collection of data was carried out in the US by NSF. Since its establishment in 1950, the National Science Foundation has been organising surveys and analyses of data and indicators. Other regions of the world also developed their national STI statistics. Nowadays the leading role rests on official statisticians (institutions vary by national settings). Scientists and hobby indicator developers are being gradually replaced by statisticians.

In several countries, STI observatories and STI platforms are important producers of indicators and analytical reports. Researchers have remained important and visible figures in designing indicators, in developing academic databanks, carrying feasibility studies, and in identifying emerging needs.

Beside official statistics, individuals or research teams have developed important classes of indicators with related databases as research tools. *Even spot data and short time series can help to put old questions of science in a new light.*

As was illustrated by this little detour through conceptual work, policy needs and indicator development, conceptualisers, users, indicator producers and data providers are crucial actors in the development of STI statistics and their interactions have an important influence on the availability and quality of information.

5. International comparability

Competition among nations, the internationalisation of R&D activities and the diffusion of international collaboration have all served to create a stronger demand for the international comparison of relevant indicators. Thus, the search for the international comparability of STI indicators is an important chapter in the development of this branch of statistics. The differences between countries in their knowledge producing and accumulating capabilities, the role of these capabilities, and their impact on economic competitiveness can only be analysed using internationally comparable indicators.

The collection and analysis of internationally comparable STI indicators and data started in the 1950s along with the conceptualisation and construction of STI indicators. The exchange of knowledge between nations and active collaboration between countries were crucial in the international harmonisation procedure. (Sirilli 2005, 2006) Work on international comparability started in the 1950s at the predecessor of OECD.[4] 'The OECD played not a single but a unique role among international organisations in STI policy and conceptual debates, in the development of instruments used for measuring and producing an internationally comparable databank and indicators.' 'In the late 1950s and early 1960s Christopher Freeman played a key role in developing the analytical basis of science policy and it is significant that he also was one of the architects behind the Frascati manual that in 1963 gave the OECD and national authorities methods to measure R&D compare the effort across countries.' (Lundvall-Borrás 2005)

The OECD member states in 1960s were very active players in developing internationally comparable databanks and indicators. The Nordic countries were among the forerunners of international harmonisation. (Young-Westholm 2006) Parallel to the conceptualisation and construction of STI indicators, the collection and analysis of internationally comparable STI data and indicators were organised.

4 The forerunner of the OECD was the Organisation for European Economic Co-operation (OEEC), which was formed to administer American and Canadian aid under the Marshall Plan for the reconstruction of Europe after World War II. Since it took over from the OEEC in 1961, the OECD's vocation has been to build strong economies in its member countries, improve efficiency, home market systems, expand free trade and contribute to development in industrialised as well as developing countries.

OECD was established on 30 September 1961. The founding members are: Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States. Latter other countries became members Japan (1964), Finland (1969), Australia (1971), New Zealand (1973), Mexico (1994), the Czech Republic (1995), Hungary, Poland and Korea (1996), the Slovak Republic (2000).

Since the early 1960s, collected data coverage has broadened significantly. More and more issues were measured and various types of input-output data became available for the majority of countries and time series have been gradually developing. Nowadays several throughput (process) and impact data also occur.

In the field of STI indicators, the OECD manuals, called the *Frascati Manual Family*, became international standards. (Sirilli 2006, Gault 2009, OECD 2002)

Following the first milestone in the development of internationally comparable indicator methods, the publication of the Frascati Manual – focusing on measuring research and experimental development, financing issues and human resources devoted to R&D activities – other manuals have been prepared reflecting broadening needs for STI information. Table 1 summarises the Frascati Manual Family by the first appearance of new topics covered by new manuals.

Table 1. Frascati Manual Family: International standards for measuring STI

Year of publication		Title of the Manual	Type of Data	Availability in Hungarian
First	Revision			
1963	1988 1993 2002	***Frascati Manual:*** Proposed Standard Practice for Surveys of R&D	Research and Experimental Development	✓
1989	Since 1993 in the FM	*R&D Statistics and Output Measurement in the HE Sector.*	Higher education R&D	
1990	-	***TBP Manual*** : for the Measurement and Interpretation of Technology Balance of Payments Data	Technology balance of payments	✓
1992	1997 2005	***Oslo Manual:*** Proposed guidelines for Collecting and Interpreting Technological Innovation Data	Innovation	✓
1994	2009	***Patent Statistics Manual***	Patent data	(1994)✓
1995		***Canberra Manual***: The Measurement of Human Resources Devoted to S&T	S&T personnel	✓

Source: own creation on the basis of the Frascati Manual 2002, p. 16.

Notes: * since 1997, OECD and Eurostat joint publication

** TRIAD: United States, EU and Japan

The manuals provide internationally harmonised definitions and such tools that are vital in order to speak in the same language when comparing indicators internationally.

These manuals are basically technical, methodological documents that were written by experts for experts. The preparation of each manual took a few years with the involvement of many experts working on the conceptualisation, feasibility and pilot surveys at national and international levels.

Regular revision dates in Table 1 show how methodological development is an ongoing interactive process. Manuals support development in surveying and analysing processes, while accumulated data collection and analyses likewise encourage the revision of manuals from time to time, as illustrated in the second column of Table 1.

At the OECD, there are some experimental methodological works that have yet not resulted in internationally accepted, harmonised manuals but which are contributing to the development of STI measures in several fields. Table 2 summarises these manuals.

Table 2. OECD STI Manuals besides the Frascati Family

Type of data	Title	**Availability in Hungarian**
High technology	Revision of High-technology Sector and Product Classification (OECD, STI Working Paper 1997/2)	-
Bibliometrics	Bibliometric Indicators and Analysis of Research Systems, Methods and Examples, by Yoshiko Okubo (OECD, STI Working Paper 1997/1)	✓/-
Globalisation	Manual of Economic Globalisation Indicators	-

Source: own creation on the basis of the Frascati Manual 2002, p. 16.

Beside so-called STI manuals, there are some other relevant internationally harmonised statistical frameworks prepared primarily for other measuring purposes that are regularly employed in the preparation of STI statistics. (Table 3) These borrowed methodologies are important in combining various branches of statistics for analysing complex systems such as innovation system or higher education system.

Table 3. Other relevant OECD statistical frameworks

Type of data	Title	Availability in Hungarian
Education statistics	OECD Manual for Comparative Education Statistics	✓
Education classification	Classifying Educational Programmes, Manual for ISCED-97 Implementation in OECD countries (OECD 1999)	✓
Training statistics	Manual for Better Training Statistics – Conceptual, Measurement an Survey Issues (OECD 1997b)	
International standard of Industrial classification	ISIC Rev 3. (NACE)	✓
Classification of Occupations	ISCO (International Labour Organization, 1990)	✓
Field of Science Classification	FOS (OECD)	✓
Classification by field of research	ISI (classification of journals covered by Web of Science ISI) CWTS	✓
Classification of R&D activities by functions	COFOG SNA/OECD	✓

Source: own creation on the basis of the Frascati Manual 2002, p. 16.

The manuals and availability of data and indicators contribute considerably to the better understanding of the role and importance of science, technology and innovation, the importance of codified and tacit knowledge. We can understand better how the science system works, how the system of innovation is changing, what are the links between innovation activities, sectors and size of companies and so on.

The OECD at a global level and the EU as a regional organisation are playing important roles either as initiator and/or coordinator in developing novel RDI indicators to respond to new challenges. To mention only a few new activities: measuring R&D outsourced abroad inside or outside corporations; handling immaterial R&D assets in SNA (System of National Accounts); measuring new emerging fields such as ICT, biotechnology and nanotechnology; measuring various types of RDI collaborations; measuring the diffusion of knowledge; measuring the impact of globalisation (or Europeanisation) of RDI activities.

Appropriate indicators and time-series can be used not only in analyses but also to support other tools of intelligent policymaking such as evaluation, assessment and foresight exercises. Today national R&D and innovation statistics are quite detailed and quite a significant part thereof is internationally comparable.

6. Adaptation of OECD standards in a transition economy

Before the transition period Hungary, similarly to other former socialist countries, employed different standards (if any) to measure STI activities. As part of their accession to the OECD (1996) and to the European Union (2004), it was crucial for Hungary and for other transition economies to adopt the international standards that were employed by democratic market economies.

As Hungary is a full member of the OECD and EU, it had to accept their standards and organise its data collection in an internationally comparable way. EU laws are compulsory for Hungary as a member state. In addition to compulsory EU tasks, national demand for RDI time-series is certainly important as well.

The adoptation of these standards was not a simple exercise, as the OECD countries which had developed the Frascati Family manuals all shared the characteristic of being advanced economies. It worth emphasising this feature, as it has an important influence on the demand for information. Countries such as transition economies that joined as latecomers to the club could not use everything they got as readymade.

Since the beginning of the transition period, Hungary has done a lot to revise, modernise and adjust its STI system to market economy demand and international standards. (Hüttl et al. 1997, Inzelt 1994, 2002, 2003, Szunyogh-Varga 2004,)

The adaptation procedure and dissemination of STI indicator knowledge in Hungary are summarised in Table 4.

Table 4. Adaptation of Frascati Family and other STI manuals in Hungary

Hungarian publication of manuals (translations or summaries in Hungarian)		**Pilot surveys**		
OECD Manuals	Year	Type	Year	Prepared by
Oslo Manual	1993 & up-dated	Feasibility and pilot surveys on innovation - manufacturing sector (large and medium firms) - selected service sectors - manufacturing sector (large and medium firms) - small and micro firms - manufacturing sector (large sample)	 1994 1999 2000 2001 2000	 IKU IKU HCSO- IKU IKU-PTE HCSO
R&D at small businesses (OECD working document)	1994	Testing the journal publication based method	1994	IKU
Technology Balance of Payments (Summary) (TBP)	1995	Hungarian National Bank takes into account technology payments of its information system Introduction of R&D export/import survey	1996- 2004	MNB KSH
Frascati Manual	1996 up- dated	-inserting some elements into the regular economic survey - pilot survey for revising regular R&D survey by FM - revised R&D survey	1993 '96/7 1998	HCSO IKU- HCSO HCSO
Patent Statistic Manual (Summary)	1999	- research work has started	2003	
Canberra Manual	2000	- feasibility studies - Blue Sky projects (EU funded ENMOB, ERAWATCH)	'98/9 2000-	IKU IKU- HCSO IKU

Source: own creation

Notes: The first translations or summaries of the manuals were prepared by IKU except for the Oslo manual. The manuals were published by the OMFB (predecessor of the National Office of Research and Technology). In the pre-OECD membership period, the translations were supported by OECD. Pilot and feasibility studies were used as samples for other transition economies and developing countries.

IKU: Innovation Research Centre, Hungary (now belongs to Financial Research Ltd.)

HCSO: Hungarian Central Statistical Office

MNB: Hungarian National Bank

An important step of knowledge dissemination was the publication of a Hungarian translation or summary of the manuals. (See 1st and 2nd columns of Table 4) The publication of the Hungarian versions of manuals was accompanied by feasibility or pilot surveys and their analyses (listed in column 3). The regular R&D statistic survey was revised by the Frascati Manual, and previous time-series were made comparable with methodological bridges. Novel indicators and their survey methods on innovation were introduced based on the Oslo Manual and through an adoptation of EU-Eurostat CIS (Community Innovation Survey).

Hungary has at its disposal more than 10 years of time-series of many RDI data and indicators, but some important indicators (GBOARD, financial data on R&D programs) are still missing. Further revision is needed on higher education expenditures (HERD) data, while sectoral mobility and the international mobility of highly skilled workers are hardly measured.

A detailed overview on the availability of Hungarian RDI data and indicators by international standards can be found in Inzelt et al., 2008. Demands of national users are summarised in Inzelt et al., 2009. These studies identified the strengths and weaknesses of Hungarian RDI indicators, surveying methods and also discussed how the shortcomings of the STI information system can be overcome.

Besides developing its own system, Hungary can participate with its capacities in the revision of survey methods, existing international standards and in the international development of novel indicators that attempt to respond to new STI policy challenges. Hungary has to make its own decisions regarding which topics are important for its stakeholders in forthcoming years.

7. Concluding notes

Accumulated quantitative information on the availability of RDI data supports fact-based policymaking, business strategy formulation and further research. The fact-finding approach has improved our understanding of the innovation system and initiated a new track for STI indicator developments in the second half of the 20th century. All of the relevant indicators and their analysis helped to understand the mechanisms that influence scientific and innovative performance, as well as how policy can strengthen or diminish their roles. At the same time, STI statistical measuring gained a more important role in intelligent policymaking.

At the beginning of the 21st century, evidence-based policymaking requires indicators to monitor, assess and evaluate research programs and STI policies. The quality of information depends on improving the availability of statistical data and the development of indicators that reflect the complexity of the STI process.

Today, as this relatively young branch of statistics is becoming an adult member among the various branches of statistics, the country specific development of STI statistics strongly depends on the national culture of policymaking that influences national demand.

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