Chapter 15
Indicators for Science, Technology and Innovation on the Crossroad to Foresight

Leonid Gokhberg

15.1 Introduction

Science, technology and innovation (STI) related decision making has developed over the last decade to a more profound level which is in many cases and aspects based on solid data and information which is transformed into indicators. This development was first observed in company STI related decision making, and subsequently governments applied the indicator based approaches in the recent years towards evidence based policy making. However although the demand for robust STI indicators supporting more reliable and profound decision making which has significant impact on future development of companies and economies has risen, e.g. STI related indicators at the micro level of companies and the macro level of economies hence nations, major challenges to identify relevant indicators, provide feasible measurement tools for newly emerging phenomena, ensure indicators' comparability and compatibility as well as assure the quality of the underlying data still take its toll. Moreover the overarching challenge of more or less unclear path dependencies' of indicators puts serious pressures on the validity of indicators.

STI policy and related indicators aim at enabling and supporting the technological progress and development for enhancing and maintaining a nation's international competitiveness and wealth creation. For that purpose research (science) and innovation activities (technology) are regularly supported by public funds. STI policy aims at broad intellectual, social, cultural, environmental and economic impacts hence STI indicators are challenged to display the broad range of missions and expectations towards STI (Donovan 2007).

L. Gokhberg (✉)
Institute for Statistical Studies and Economics of Knowledge, National Research University - Higher School of Economics (HSE), Myasnitskaya st., 20, 101000 Moscow, Russia
e-mail: lgokhberg@hse.ru

D. Meissner et al. (eds.), *Science, Technology and Innovation Policy for the Future*,
DOI 10.1007/978-3-642-31827-6_15,

STI is one driver of constant change, and it still comes in different shapes. First of all, STI is expressed in the generation of codified but also of tacit knowledge which stems from either institution internal or external sources. Eventually the outcomes of STI related activities can either be embodied in capital goods and products or disembodied, i.e. included in patents, licenses, utility models or design, R&D activities, or embodied in skilled personnel (Archibugi and Pianta 1996).

Foresight is an established instrument of STI policy but also a tool for corporate strategic management which aims at developing scenarios of potential future development not only of STI at different levels but also in a broader context including societal developments among others. Therefore Foresight is by definition and nature strongly dependent on indicators which comprise information about current and potential future STI related developments. Thus STI indicators and Foresight indicators share numerous common features. Such commonalities are the adequacy of methodological concepts, the reliability of underlying data, the potential to aggregate indicators, and their robustness.

15.2 STI Indicators: A General Overview

STI indicators in many cases fulfill the commonly accepted purpose of monitoring institutions' regions' or countries' performance in science, technology and innovation. This implies an ongoing benchmarking or at least comparison of these actors in the STI dimension. Thus defining and interpreting indicators needs a clear and methodologically sound understanding of the processes underlying science, technology and innovation. STI indicators describe special characteristics of the overarching innovation processes (Kleinknecht et al. 2002; Godin 2004). STI indicators can in principle be classified as input, output, process or impact indicators and as lagging, leading and real time indicators considering the time dimension the indicators display. While input indicators like expenditure on research and development and the number of employees in R&D sectors and output indicators like the number of publications, citations or patents are broadly accepted and documented, process indicators referring to the evolution of scientific results, technologies and innovations are barely available (Scharnhorst and Wouters 2006). Impact indicators are even more seldom: given well-known difficulties to measure economic, social, cultural or environmental benefits of STI mostly indirect data have been provided such as percentages of enterprises experiencing certain effects of innovation activities, public attitudes toward STI, scientific literacy or CO2 emissions.

There is consensus that indicators employing economic data are not always adequate for foreseeing future trends in STI. Instead such indicators need to be considered against best practices combining relevant qualitative and quantitative indicators which are eventually of a broader social, environmental, cultural and economic public value (Donovan 2011). Hence the established indicators need to be revised respectively especially since these indicators are often used as

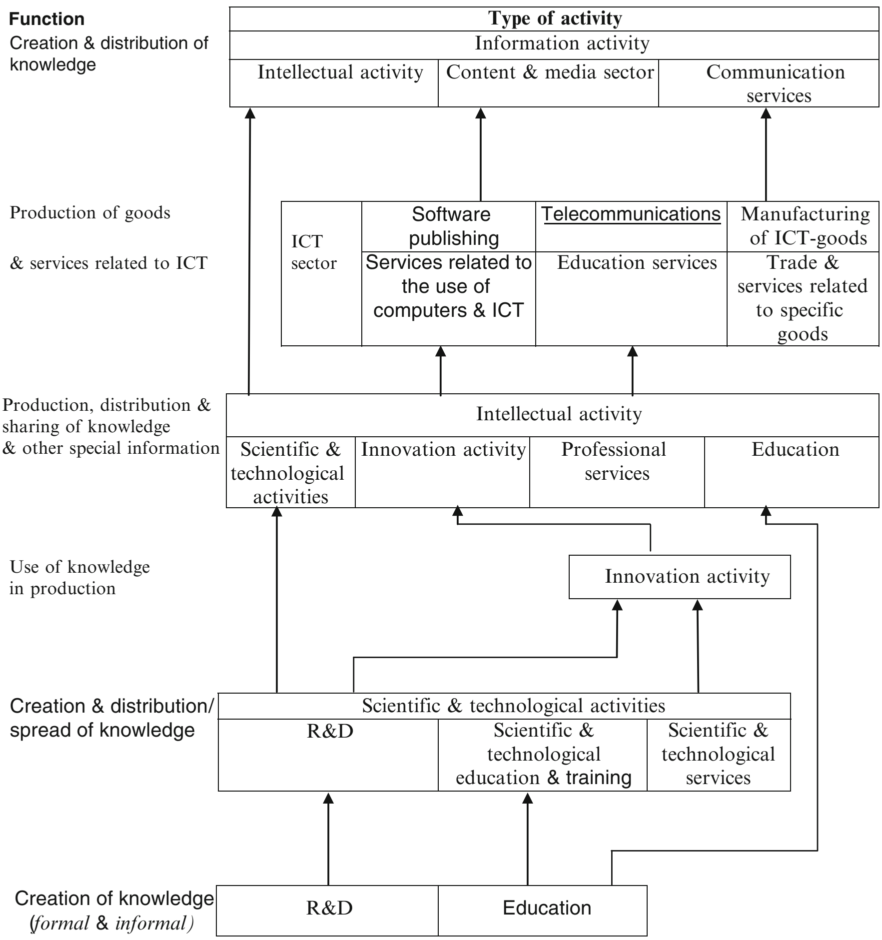

Fig. 15.1 Classification of economic activities related to knowledge creation, distribution and use (Note. ICT – information and communication technologies) (Source: Gokhberg 2000, 2003, 2012; Gokhberg and Boegh-Nielsen 2007)

'strategic weapons' for evidence-based governments and research funders policy making and implementation, e.g. for the enhancement of financial support. Still indicators are confronted with the challenge to consider the diverging characteristics of all research fields (including the humanities, social sciences, and creative arts) and technology areas (for example, ICT, bio- and nanotechnology) in their own terms.

In general STI indicators are challenged to reflect a broad range of activities related to the creation, distribution and use of knowledge (Fig. 15.1).

Since indicators are used for decision making the quality of indicators eventually strongly determines the validity of the subsequent decisions, namely decisions of long term and strategic nature with a significant and lasting impact. However indicators are confronted with numerous challenges:

- Firstly, there is a serious threat to STI indicators which stems from the unclear definition of the term 'technology'. In common practice 'technology' is understood as a result of creative work which can be based on codified knowledge or implicit tacit knowledge. This creative work spans the combination and reconfiguration of existing knowledge and technical solutions as well as the development of fully new knowledge by different means. Hence the term technology itself has different meanings in different science fields but also in different application fields, e.g. industrial sectors. Thus indicators measuring the technology intensity of industries but also science fields need to account for these differences (Freeman and Soete 2009). In this regard the challenge for designing indicators and collecting data for measuring technology is to distinguish between the different essentials of technology which are not limited to the configuration and composition of technical and knowledge bits and pieces into a new full solution but involves also the process of searching for existing knowledge, building and maintaining absorptive capacity and conversion of the technology into broad application. Here the problem is not only the indicator definition but rather the data collection since data required to describe these tasks and stages of technology components are usually not available.
- Secondly, indicators addressing innovation are sometimes incomplete and even misleading. Related currently available indicators focus primarily on input and output measurements, namely expenditures on R&D and other innovation activities (input), share of new products, process improvements, patents etc (output). However innovation processes also include a broad range of managerial, marketing and commercial activities before the start of innovation projects, complementary to innovation projects, at the stage of market introduction and after sales activities. Such activities however are not properly covered by innovation statistics although they account for a significant share of costs allied to innovation.
- Thirdly, standardised STI indicators barely take account of national and regional circumstances and characteristics. There is longstanding academic and political but also societal discussion about the appropriateness of STI investment. With the exemption of the European Union which articulated the 3 % target (GERD/GDP) under its Lisbon agenda very few countries have made such explicit statement. The reasons are that there is so far no direct evidence of the societal and economic impact of STI investment overall and investment indicators hardly reflect the industrial structure of the economies, e.g. there is a tendency towards misinterpretations if cross national comparisons are made using STI indicators only but not considering the underlying industrial structure and special characteristics of the different economies.

With the emergence of the "evidence-based" policy concept policy evaluation in many different shapes gained ground (Pawson 2002). Accordingly policy making is increasingly based on ex-post and ex-ante (often referred to as 'backwards looking' and 'forward looking') evaluation. While ex-post evaluation aims at finding evidence for the impact generated by a respective policy measure, ex-ante evaluation is

Table 15.1 Types of statistical units in science and innovation analysis

Kind of activity	Statistical unit	Accounting unit
Research and development:		
Performance	Organisations carrying out R&D	Organisations
Financing/funding	Departments (and agencies) providing funding	Departments (agencies)
	Government programmes	Departments (agencies)
Condition of scientific equipment	Organisations carrying out R&D	Organisations
Socio-economic status of researchers	Researchers/ Academic community	Organisations
Creation and diffusion of technologies:		
Patent activity	Inventions, utility models, industrial designs	National offices for intellectual property
Development of advanced technologies	Organisations developing advanced technologies	Organisations
Production of ICT-related goods and services	ICT sector enterprises	Organisations
Use of advanced technologies (industrial, energy, ICT, bio, nano etc.)	Enterprises that use advanced technologies	Organisations
Technology exports and imports	Enterprises engaged into agreements for technology exchange with foreign countries	Organisations
Innovation activity	Enterprises manufacturing goods and services	Organisations

Source: Gokhberg 2003

more targeted towards potential impact assessment of measures. The latter one is not so commonly widespread in policy making yet since it is an assessment of potential impacts which are still highly uncertain but evidence-based policy more or less considers learning from experience. Collection of data and their systemic and structured composition and aggregation into relevant, feasible, valid and robust indicators remain unmet challenges for many aspects of science, technology and innovation policy. This challenge is reasoned by the complexity STI indicators are expected to describe. The indicators have to take account of the STI activities which are performed by different bodies and institutions. These activities vary in nature including research and development, creation and diffusion of technologies and innovation activities. In course of measuring these activities the statistical units and the accounting units are not necessarily equal as shown in Table 15.1. Consequently a special challenge arises for data collection methods and eventually for indicator composition. Different methodologies are in many cases applied for collecting data, e.g. standardized questionnaires, semi structured interview guidelines and open interviews in some cases each depending on the characteristics, e.g. the nature, of the activity described. R&D related data are mostly financial data expressed in monetary values with the exception of the socio-economic status of researchers. The latter is measured in terms of hierarchical status and position of researchers. Although this seems a solid information base one has to take into account that such status is assigned depending on country and also institution specific criteria, e.g. status expressions are comparable in semantic terms but not necessarily in terms of duties and obligations related to the socio-economic status of researchers. Hence these data are of indicative nature rather than quantitative. Data describing the creation and diffusion of technologies are also mixed data, hence including quantitative and qualitative data. Patent activities and the technology exports and imports are quantitative data whereas the development of advanced technologies production of ICT-related goods and services and the use of advanced technologies (industrial, energy, ICT, bio, nano etc.) are semi quantitative data. Innovation activities are typically measured with quantitative and qualitative data. Usually questionnaires are used containing questions which aim at an assessment of the share of new products and services among many others. Such data are not systematically collected in organizations or due to the often vague nature of innovation rather difficult to provide.

STI indicators can be used for a broad range of applications. These applications include indicators to measure the STI related input, e.g. for comparative STI investment analysis and supply side analysis of research and engineering staff; or STI related output, e.g. technology specialization, the intellectual property position, the global science competitive position and the country innovation performance. Other indicators are used and suitable to describe the status of the knowledge economy development or used for classification of the economy development stage (Table 15.2). Each indicator shows numerous potentials for application but also limitations. In example patent statistics are easy to analyse and are in principle comparable across different patent databases but the underlying motivation and strategies of patent holders are not documented and known. This becomes ever more crucial when analyzing patent statistics. The major weakness of these statistics is the unknown range of application fields protected by a patent, e.g. the broadness of protection expressed in the respective claims. Also it's common knowledge the a significant share of patents are filed for strategic reasons hence the purpose of blocking competitors etc. but not necessarily used actively. Although each indicator shows certain limitations they are suitable to compare different regional and/or national innovation systems.

The majority of STI indicators are of ex post nature, e.g. describing systems and institutions at a given point in time which does not necessarily reflect the current status.

Table 15.2 STI indicators – application, advantages and limitations

Type	Indicator	Application	Advantages	Limitations	Level of analysis	Availability	Longitudinal studies
Input	R&D expenditure	Comparative STI investment analysis	Standardized measuring	Difficulties in counting R&D expenditure at company level and at level of PPP	Country	Broad	possible
			Terminology established and commonly accepted		Region[a]		
	Research staff	Supply side analysis of research and engineering staff	Indicative assessment of human resources supply possible	Terminology lacking, e.g. some statistics show Full Time Equivalents(FTE) others show headcounts (HC)	Country	Broad (for FTE level)	possible
			Complements R&D expenditure statistics	Expressed in persons but not in financial terms, raises difficulties for path dependency analysis	Region[a]		
				Quality of staff is not measured			
Input/ output	Tertiary graduates	Input indicator for knowledge economy / economy development stage classification	Comparative analysis of national education sector performance	Overall demand and need for tertiary graduates remains vague and unclear	Country	Broad (subject field specific)	possible
				In some cases leads to policy measures to increase number of graduates without solid evidence for related skills and competences demand	Region[a]		

(continued)

Table 15.2 (continued)

Type	Indicator	Application	Advantages	Limitations	Level of analysis	Availability	Longitudinal studies
Output	Patents	Technology specialization	Broad coverage	Patent statistics do not necessarily show the inventive power of nations	Country	Broad (IPC class specific)	possible
		Intellectual property positions	Standardized databases	Patent behavior of companies is not reflected			
			Comparability of national statistics possible	No correlation between innovation and patent, e.g. patent does not necessarily equal innovation			
	trademarks	Intellectual property positions	Comparability between countries possible	Assignees /Trademark/ holders protection strategy is unknown	Country	Broad (goods and services class specific)	possible
				Trademarks are a relatively new mechanisms in many countries, used for one or 2 decades only – statistics			
	Publications	Global science competitive position	Broad coverage of peer reviewed publications	Publication behavior varies between institutions and individuals	Country	Broad (subject and field specific)	possible
			Comparative analysis of countries is possible	Scientists outside established networks face serious challenges entering publication networks (emerging countries)			
				Publications are one output of science and research only			

Citations	Competitive Science position	Gives indication of the relative position of a country's science base in the world science community	Journal editors often require authors to include references from other papers in the journal they edit on even the reference are not necessarily needed Peer review process in many cases implies to reference leading scholars without need to market own research	Country	Broad(subject and field specific)	possible
High tech exports	Country innovation performance	Gives an indication of country's position in global value chain	Neglects industrial structure of countries, export orientation and size of internal market High tech is often assumed future industries but underlying industries (agriculture, raw materials) are not considered	Country	Broad (NACE specific)	possible

[a]Regional analysis is possible in most countries if data are used from national statistics offices, international organizations in most cases publish only aggregate country level data

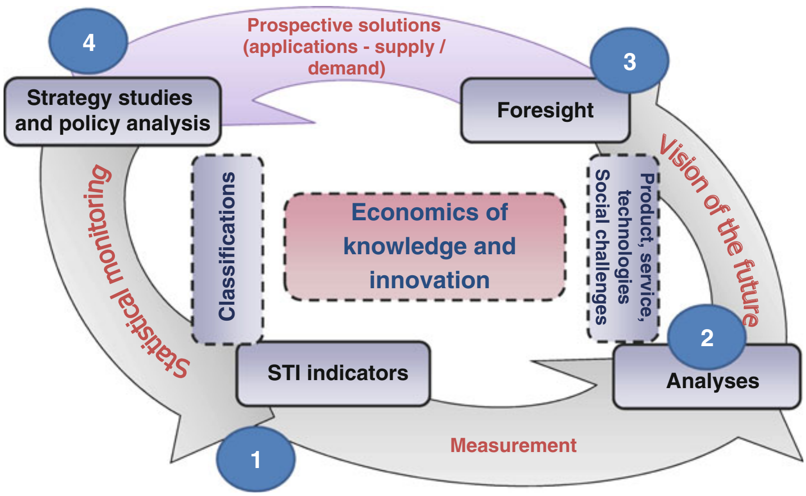

Fig. 15.2 Indicators – Analysis – Foresight – Strategy – Model (IAFS)

15.3 Application of Major STI Indicators in Foresight

Foresight studies are by purpose and nature ex ante oriented studies. As shown STI indicators are mainly of descriptive ex post nature thus at first sight STI indicators do not have much in common with Foresight. However a deeper look into the nature of Foresight reveals that these studies do not consider potential future developments only but take into account the potential and capabilities of the current national and also international STI system to cope with the challenges which inherent in the potential future developments.

A closer look at Foresight and STI indicators reveals that indeed STI indicators appear to be a significant input for Foresight. STI indicators are frequently used in Foresight for SWOT analysis and competitive position analysis. Moreover analysis's of countries, regions or companies are based on STI indicators and often the initiating momentum for Foresight. Foresight in turn results in prospective scenarios which require roadmaps and related strategic responses from decision makers hence strategy studies and policy analysis build on Foresight. These analysis' requires more sophisticated and up to date indicators, namely STI indicators. Eventually a model (**IAFS**) can be constructed which includes four major elements (Fig. 15.2).

1. STI **I**ndicators;
2. **A**nalysis based on STI indicators;
3. **F**oresight based on analysis;
4. **S**trategy studies and policy analysis based on Foresight.

15.3.1 STI Indicators

There is a broad range of STI indicators available. With regard to Foresight these indicators can be grouped into the following:

- Analysis of linkages between actors in the National Innovation Systems (NIS)
- Technology specialization – Intellectual Property and Publication analysis
  - Trademarks
  - Patents
  - Publications
- Network analysis
- Sustainability assessment
- Globalization of NIS

(a) Linkages in the NIS

The analysis of linkages between actors in the NIS provides a first impression and overview of the boundaries of science and innovation raising the challenge of the positioning of public research in the innovation value chain, its contribution to short term STI objectives and indications for the resulting capabilities of the national STI system to meet upcoming challenges from a systemic point of view.

Linkages between the actors in NIS are either horizontal or vertical. Horizontal linkages are linkages between actors at the same or similar, e.g. comparable, stage of the innovation value chain while vertical linkages express linkages between different stages of the value chain. In STI terms such linkages are mainly analyzed in research related context hence the linkages between the research communities and the industrial community. Such linkages are especially expected to be of high relevance in countries with a high share of public expenditure on research and especially an industrial structure which is mainly characterized by low- to medium tech industry. An example for such a country is Italy where the government's expenditure on research exceeds the industrial expenditure and the industrial structure is dominated by low to medium tech and a high number of micro- and small enterprises (Abramo et al. 2009). These characteristics need to be taken into account while designing and more important interpreting indicators describing the linkages between the research and the industrial community (Dlouhá et al. 2012).

To define STI indicators for measuring industry-science linkages one has to consider the major outcomes and impacts from science. These are mainly the generation of new scientific information, education and training of skilled graduates, support and enrichment of scientific networks and stimulating interaction; expansion of the capacity for problem-solving (absorptive capacity mainly); design and production of new instrumentation and application of new methodologies and techniques; creation of new firms; and provision of social knowledge (Butcher and Jeffrey 2005). Given this background typical indicators measuring these linkages are:

- Number of university articles in co-authorship with private researchers
- Number and volume of contract research
- Number and size of cooperative research projects
- Joint patents (joint inventorship)
- Industry related training and education courses
- Public service sector related training and education courses
- Spin offs from institutions
- Number and size of joint publicly funded research projects
- External graduate thesis (post graduate level)
- Consulting and advisory services by scientists to public sector and industry

However these indicators can only be interpreted in the light of the overall missions and tasks of the public institutes.

(b) Technology specialization

Technology specialization of countries is measured by an indicator set which is based mainly on intellectual property related information providing a solid base for trend analysis with potentially mid-term impact, e.g. displaying major activities in science and technology fields which are likely to be turned into innovation and remain in markets and application for a certain time. In addition trademark statistics analysis have the potential to display very recent structural changes in industrial activities, namely in the structure of gods and services in demand but also in preferences of society expressed in the choice of words and pictures for trademarks.

Intellectual Property Rights (IPR) are established in the industrial context mainly and the scientific/research community context for long time. Analysis of Intellectual Property (IP) statistics, namely patent and trademark statistics, is considered a suitable means towards the gathering of knowledge and capabilities (Freeman 1982; Hidalgo and Gabaly 2012; Pavitt 1988; Dosi 1988). Using a time series of patent and trademark data Hidalgo and Gabaly find that these data provide a tool for predicting the potential development of patent and trademark application in the future, e.g. predicting trends of application developments (Hidalgo and Gabaly 2012).

The two major forms of IPR are patents and trademarks being the most frequently and effectively used legal tools to protect the results of intellectual work. Patents and trademarks provide the owner a monopoly to use an invention for clearly specified and defined purposes, offer goods and services under a chosen name or logo or a combination of that in case of trademarks, while publications mainly serve the aim of diffusion knowledge at marginal or zero cost. However still publications are protected by means that the generator/producer of knowledge has to be named and mentioned. All three intellectual property types share the common feature that it is in the sole responsibility of the originator/owner to monitor potential infringements of his rights and take countermeasures to protect the intellectual property. While publications, namely scientific publications, describe inventions without clearly specifying applications, patents are clearly focused at applications of technologies, e.g. inventions. Trademarks on the other hand do not necessarily refer to inventions or technologies but have a strong application focus of goods and services regardless the technological and inventive content of the good or services labeled under a trademark.

15.3.1.1 Trademarks

Trademarks in principle play one major role which is to protect the delivery of a product from a provider to a customer. The protection is for the provider of the product which gives him a unique position to be recognized by the customer. The product in questions protected by a trademark can take many forms including services which are not tangible products as well. In this respect trademark based indicators do have a potential to deliver more indicative impressions about ongoing changes in economies. However the pure analysis of the number of trademarks does not allow a reasonable solid interpretation of the innovativeness and creativity of a country's trademark holder/owner. Moreover it's reasonable to analyze the fields selected by trademark corresponding to the goods and services classification. Trademark statistics give an indication of the development of especially service based innovation as measured by the number of trademarks. In general trademarks can be considered an indicator providing indication of the use of marketing related instruments not only for innovation but for general purposes.

At more detailed level, namely the analysis of goods and services in clearly described goods and service classes relating more clearly to STI, conclusion of more indicative nature can be drawn for the importance of STI related activities of a country. These more STI related goods and services classes are especially Class 38 Telecommunications, Class 40 Treatment of materials, Class 41 Education; providing of training; entertainment; sporting and cultural activities and Class 42 Scientific and technological services and research and design relating thereto; industrial analysis and research services; design and development of computer hardware and software (WIPO 2011). Recent statistics of Community Trademarks show a significant share of STI related trademarks (CTM) in the respective service classes (Table 15.3). In the overall statistics of CTM these services achieve surprisingly high ranks which can be interpreted as an indication of the importance of STI related service businesses. However since the service classes are still rather broadly defined it remains an indicator of indicative nature only lacking solid and profound calculation basis. As for comparative analysis of countries such analysis needs to be expanded by country specific analysis.

Mendonça et al. (2004) conclude that trademarks are a suitable indicator for measuring product innovation and sectoral change given the basic nature of trademarks as one instrument to differentiate products in the market. In addition trademarks reflect cultural and societal changes in a sense that trademarks as 'word marks' but also as 'picture marks' mirror at least to some extend the changing preferences and attitudes of society. Hence trademarks combine quantitative and qualitative information in one indicator. Eventually indicators based on trademarks give indications of the rates and directions of product innovations in different

Table 15.3 STI related service trademarks (Community trademarks)

1996–2011					2012				
rank	class	number	% of total trademarks		rank	class	number	% of total trademarks	
8	38	69,046	3.22	16,48	8	38	5,537	3.01	
17	39	48,743	2.28		18	39	3,790	2.06	
34	40	23,073	1.08		32	40	2,302	1.25	
5	41	113,438	5.3		4	41	10,977	5.96	
3	42	147,216	6.88		3	42	11,486	6.24	16.46

Source: OHIM 2012
Note: Data for 2012 are preliminary

industrial sectors, international patterns of specialisation, links between technological and marketing activities and the evolution of economic organizations and structures (Mendonça et al. 2004).

However trademark based indicators can be used complementary to other STI indicators, especially patent based indicators for testing the evidence found.

The index of trademark revealed comparative advantage (TRCA) provides an indication of the country's capacity introducing and marketing innovative goods and services which are protected by trademark hence statistics analysis. It is a ratio of goods and service class i's share in country j's total trademarks to goods and service class i's share in the world: $TRCA$. $TRCA = \frac{trademarksij / \sum_i trademarksij}{\sum_j trademarksij / \sum \sum_j trademarksij}$ where i denotes the sector, j is the country, $i = 1, 2, \ldots, I$, and $j = 1, 2, \ldots, J$. Alternatively, it can also be expressed as a ratio of country j's share of trademarks in goods and service class i, to country j's share of total trademarks (across I sectors) in the world (across I sectors and J countries):

For a given class i, a value of this index greater than one indicates that the country j has a comparative advantage in that class (Yusuf and Nabeshima 2009). The analysis shows that countries show clearly different specialization profiles with the exemption of scientific, nautical, surveying, electric, photographic, cinematographic, optical weighing etc. which is a strength of Korea, Japan and the US while vehicles; apparatus for locomotion by land air or water are specialization features of China, Korea and Japan. The trademark statistics analysis nit surprisingly mirrors the underlying industrial structure of these countries (Table 15.4).

15.3.1.2 Patents

Patent statistics together with innovation surveys are considered reasonable information sources to measure innovative activities of commercial entities, namely companies (Archibugi and Pianta 1996). However more recently research entities, namely Higher Education Institutes and Public Research Institutes, are becoming more active in patenting inventions for the purpose of commercialization of such.

Table 15.4 Top five sectors of trademark specialization, OHIM filings 2000–2007

	China	India	Korea	Japan	US	Euro6
Agricultural, horticultural and forestry products						1.2
Apparatus for lighting, heating, etc.			3.3			
Beers; mineral and aerated waters	2.5					
Building materials(non-metallic)						1.2
Chemicals used in industry, science and photography					1.4	
Firearms; ammunition and projectiles; explosives; fireworks					1.3	
Furniture, mirrors picture frames goods(not included in other classes) of wood	2.3					
Lace and embroidery, ribbons and braid	2.3			3.0		
Leather and imitations of leather	2.4	2.5				
Machines and machine tools; motors and engines (except for land vehicles)			2.8			
Musical instruments	3.1			4.9		
Pharmaceutical, veterinary and sanitary preparations					1.4	
Precious metals and their alloys and goods in precious metals or coated therewith	3.0					
Preserved, dried cooked and fruits and vegetables;						1.2
Scientific, nautical, surveying, electric, photographic, cinematographic, optical weighing etc.			3.4	2.4	1.5	
Surgical, medical, dental and veterinary apparatus and instruments					2.1	
Textiles and textile goods	3.2					
Tobacco; smokers' articles matches		5.2				
Transport; packaging and storage of goods			2.2			1.2
Vehicles; apparatus for locomotion by land air or water	3.2		3.6	3.6		
Yarns and threads, for textile use				2.2		1.2

Source: data taken from Godinho and Ferreira (2012), p. 508; values in table indicate TRCA

Hence patent statistics provide additional information with regard to the inventiveness and application orientation of these institutions.

One frequently used indicator to measure knowledge and technology specialization of countries is the Revealed Technological Advantage' index (RTA). RTA expresses the technological advantages of countries and firms in technology fields expressed and captured by patent classes (IPC). The RTA allows for the measurement of the level of country (or firm) patenting activity in particular technology fields and especially for international comparison. However the analysis is only possible for countries with a large number of patents (primarily developed countries) since analyzing a small number of patents in a country leads to a distorted picture of country's advantages. Especially taking into account the time dimension such analysis gives valuable insights in the changing importance of technology fields.

Godinho and Ferreira show remarkable results in their analysis of PCT applications, applications to EPO, JPO and USPTO the dynamics of Chinese and Indian patenting activities (Godinho and Ferreira 2012). In their analysis it becomes evident that China and India can be expected to catch up with leading patenting nations, namely the US as the recognized most patent active economy. China is likely to catch up in terms of PCT patents as early as in 6 years time, India in 13 years time. For achieving similar patent numbers at EPO it will take China another 20 years (India 30), USPTO 30 years for China (26 India) and JPO 27 (China) and 33 (India). Such analysis however rests on the assumption that patent applications and grants develop along the trend identified over the last 15–20 years. Moreover it presumes that there are no major changes and adaptions in national and international patent rules and laws.

It can be concluded that China and India do not exclusively follow national patenting strategies but are increasingly engaged in international patent operations. The first indicator for this finding is the rather short period for these countries to catch up with PCT applications, which in themselves are no patents but the entry gate to international patent applications and filings.

15.3.1.3 Scientific Publications

Wagner and Leydesdorff find that research funds, namely public research funds, are increasingly allocated using publication indicators of institutions as one (although not the only one but still an important one). Moreover at the individual level researchers and scientist employed in public institutions are promoted and tenure decisions made using indicators and impact factors based on citations to published work. These indicators are often object of controversial discussions between scientists and institutes but also at the funding allocation level. The Integrated Impact Indicator (*I3*) is an indicator recently developed weighting highly cited papers more than less-cited ones, allowing the unbundling of venues (i.e. journals or databases) at the article level and the re-aggregation in terms of units of evaluation Wagner and Leydesdorff (2012). The I3 indicator shows that the importance of journals might vary. It can be demonstrated that for example the Proceedings of the National Academy of Science, USA rank top according to I3 whereas they rank 3 according to the 2009 impact factor. Hence the ranks of Nature and Science are changing too against the Proceedings of the National Academy of Science (Table 15.5). The practical implications of such changes in rankings are obvious. Institutions and individuals will be tempted to publish their work in the highest ranking journals to benefit from budget allocations which in turn are decided upon depending on the publications journals' rankings.

Regardless the journal publication statistics allow an aggregate view on the specialization of countries. However such statistics might provide an initial view and understanding of the potential specialization of countries measured by comparison of the countries' major areas of activity and the world total publications in all fields and in individual science fields. However although this analysis might give an indication it's noteworthy to bear in mind that the publication behavior varies between the science fields and regions. The comparison of the world publications published by ISI Thomson Reuters shows the overall dominance of the natural

Table 15.5 Differences in the ranking of science fields in world publications and Russian publications

	Difference in ranks between world publications and Russian publications		
Field (ESI)	Rank papers total	Rank papers share of total publications	Rank citations
Agricultural sciences	1	17	1
Biology & biochemistry	2	4	−1
Chemistry	0	2	13
Clinical medicine	6	5	9
Computer science	0	18	1
Economics & business	3	21	−5
Engineering	−1	7	9
Environment/ecology	2	13	1
Geosciences	−6	3	1
Immunology	−1	15	−13
Materials science	−3	8	8
Mathematics	−7	12	−1
Microbiology	−7	11	−6
Molecular biology & genetics	−1	9	−1
Multidisciplinary	0	22	−19
Neuroscience & behavior	7	14	0
Pharmacology & toxicology	2	16	−6
Physics	−2	1	4
Plant & animal science	5	10	5
Psychiatry/psychology	3	20	6
Social sciences, general	8	19	6
Space science	−11	6	−12

Source: own calculations based on Source: ESI Thomson Reuters, http://esi.webofknowledge.com/fieldrankingspage.cgi; http://esi.webofknowledge.com/allmenus.cgi?option=C, Data January 1, 2002-June 30, 2012 (accessed 12.09.2012)

Note: Differences read as rank of science field in the Russian production of publications minus rank of science field in the total world production of publications by the respective science field. Positive values indicate that in the world comparison the science field is more important in Russia than in global terms, negative values indicate that the science fields is more important in the world than in Russia.

('hard') sciences, physics, chemistry and biology . The comparison of the meaning of the science fields in the global context as measured by the number and share of publications globally and in Russia especially reveals that selected science fields are in comparison significantly less important in Russia in terms of output than in the world but more important in terms of the citations of these papers (Table 15.5).

This observation can be made for chemistry, engineering, geosciences, material sciences and physics. It leads to the conclusion that although there are not as many publications in the science field in Russia (measured by the share of total publications) the number of citations of these paper is relatively higher in Russia than in the world average. This gives a first indication towards formulating hypothesis's regarding activities and composition of respective scientific communities and networks globally and in the countries, here Russia, especially. Hence one could conclude that there is either a relatively small or a relatively weak scientific community in the country which in turn is closely connected and uses citations more frequently than other national communities in the world. Simultaneously one could argue that the quality of the fewer publications of this national scientific community is higher than elsewhere thus members of this scientific community cite publications more frequently. A similar analysis can be done the other way around, e.g. in pharmacology and toxicology and economics and business Russia has slightly more publications in relative terms than the global community but citations are clearly less frequent. Immunology and multidisciplinary are two science fields which are almost similar in ranking of global and Russian total number of publications but which are characterized by a significantly lower number of citations of Russia publications than on the global level.

Braun and Dióspatonyi (2005) find evidence that the number of publications of a country or region is influenced by the membership of regional scientist in scientific journals editorial boards (Braun and Dióspatonyi 2005). Given that the sole number of publications might give an indication of scientists activities especially when analyzing time series of publications of 10 or more years. However comparison between countries is likely to be biased when comparisons' of countries' scientific performance is based on publications statistics.

(c) Network analysis

Networks appear in many different forms in the NIS. With the explosion of knowledge and especially growing number of highly specialized analysis science and technology fields in line with the increasing importance of platform technologies and presumably platform science fields in the future networks become evidently more important for the exchange of (mainly tacit) knowledge but also for leveraging the inherent knowledge potentials. Networks clearly are at the crossroad of Foresight and STI policy providing especially competences and capacities for information collection and processing which is essential for Foresight studies. Moreover networks, namely in the shape of technology platforms, have the potential to function as a hub for STI information and data collection but also for implementation of STI measures based on these information given their outreach and the assumed commitment of participants towards joint visions and goals in selected fields which in turn indicates the willingness to accept forward looking change.

Networks come in many different shapes. In some cases networks are informal loose connections of different actors with in some cases diverging agendas used and more occasional joint activities. The other extreme are networks initiated by third parties equipped with professional organization, joint visions and missions and professional management which supports in many different ways. Networks, especially technology platforms as one type of networks can be characterized as shown in Table 15.6.

Consequently networks play several roles in STI. Among the most prominent and important roles of networks is their significant potential to serve as a reliable information base for the development of targeted next generation of STI policy

Table 15.6 Characteristics of technology platforms as one type of networks

	Feature	Characteristic		
Policy priority characteristics	Meet the national (supranational) STI priorities	Short term	Mid term	Long term
	Meet national (supranational) industrial competitiveness goals			
Knowledge related characteristics	Complexity of the network	Low	Medium	High
	Ratio of existing knowledge versus the need of new knowledge generation	Knowledge combination dominant	Balanced	Knowledge generation dominant
	Competitive situation of national STI and application landscapes	Outstandingly strong internationally	Competitive	Weak
Application characteristics	Degree to which application fields can be defined and described in a clear and appropriate way	Precise	Illustrative	Vague
	Closeness of the network to application	Short term	Mid term	Long term
	Underlying degree of technical feasibility and uncertainty of reaching the intended goals	Predictable	Risky	Highly uncertain

measures and for Foresight studies. Thus its reasonable to analyze networks in the light of STI and of Foresight simultaneously.

One measure for network analysis is the "distance among pairs of inventors" measure which displays linkages in the network through calculating geodesic distance which is defined as the minimum number of steps that separate two distinct inventors in a network (Balconi et al. 2004). Such measure can give a proxy for the degree of directness of relationships between the actors but does not describe the intensity and the formality of the relationship. In addition some actors might show a large number of links in the network which is a pure indicative proxy for their activities in a STI network, e.g. the given the nature of STI the power of networks is largely determined by the intensity and frequency of interactions between the network members rather than the pure number of formal linkages between the actors.

Insights into the quality of relationships can be drawn from the number of patents which are either joint patents or have at least inventors from different institutions which belong to a network named, joint publications of scientific or academic papers between different actors but also to some extend by citation analysis of patents citing scientific publications of network members and vice versa.

Patent statistics and related indicators are means to measure the impact of university patents and scientific publications for innovations in industry. In addition to quantitative patent data innovation surveys deliver useful additional evidence on the impact of research activities either internal in companies or external to companies and other research related academic activities, such as meetings and informal contacts with university researchers (Balconi et al. 2004).

(d) Sustainability assessment

Sustainability is often understood as policies and related measures aiming and targeting at ecological aspects and demographic developments an related artefacts. However in the context of STI policy and Foresight which by definition have long term horizon sustainability is understood in the context of reliability of framework conditions which due to the nature of the underlying science especially do not call for continuous radical changes rather for modest adjustments. Still the environmental aspects need to be integrated in STI in a seamless manner which reflects both the science, technology and innovation dimensions as well as the explicit focus on environmental aspects (Rennkamp and Stamm 2009; Wieczorek et al. 2010). The challenge here is to integrate the global challenges inherent in environmental issues into current STI levels at different levels. Thus far environmental aspects are essential components of most Foresight studies either with an explicit focus on future environmental solutions, long term environmental impacts on STI or the impact of STI results on the environment. In that sense the environmental dimension is included in Foresight studies consequently in STI policies. However this dimension is not explicitly considered and covered by respective indicators yet.

In this light sustainability and STI policy inherit an explicit conflict of aims and goals since STI policy increasingly becomes a policy field which is subject of renewal and continuous adjustment by policy with numerous experiments to increase performance and value from this policy field. However the policy side regularly neglects the time horizon which is the major driver for value from science but also from sustainability and environmental conflict. In this sense sustainability oriented NIS, respectively STI, can be defined as driven by networks of private and public actors who generate STI outputs which are applicable and conducive environment. While Foresight studies deliver indications for potential STI policy measures such measures consequently can be targeted at the demand side, e.g. the application side of STI results mainly by enhancing markets providing absorptive capacities through regulations which make the application of technologies obligatory in certain fields but also at the supply side, namely by measures either creating or smoothly adjusting the infrastructures for public science, research and development and human resources (Rennkamp and Stamm 2009).

In a broader sense the interaction of STI with society increasingly requires enhanced knowledge acquisition and processing by society. Such also requires the alignment of research agendas and infrastructures with knowledge needs and action plans within and among societal spheres, i.e. science, politics, business, law, mass media, and education (Jappe 2006). These requirements are commonly known to stakeholders, especially to decision makers in the STI systems. However there are other gatekeepers in these systems whose intention does not necessarily follow the decision makers original ambitions (Lyall 2005).

(e) Globalization of NIS

Innovation and technology diffusion are a major driver of economic performance of countries especially in the age of globalization where national innovation systems are developing towards more integration crossing national, regional and cultural boundaries (Chan and Daim 2012). For the individual country the challenge arises to develop sharp profiles in the global STI competition and to set priorities in the allocation of especially public funds for STI in order to succeed in the medium to long term.

The integration of STI related policy measures is recognized to require integration in the governance scheme and especially in the adjustment of governance to new challenges such as globalization of the STI land sphere (Lyall and Tait 2005). Here globalization is putting additional pressure on national STI Foresight studies to determine STI fields which offer short time but at the same time sustainable competitive STI induced advantage over other countries which are expected to result in societal and economic benefit.

Thus far international cooperation in STI is not developed to the fullest extent. This holds especially true for the role and potential of national STI in the race with global challenges for which the global potential is not fully leveraged so far neither in respective globally oriented Foresight nor in respective STI measures. Global STI cooperation in most cases focuses on the knowledge generation as this is the usual and commonly accepted shape of cooperative STI while the absorption of generated knowledge is not considered and exploitation streams especially in case of public funded STI are commonly at national, regional or local level. Hence STI policy needs to pay increased attention to the demand side of STI and respective measures by education and (absorptive) capacity building.

Such measures at the crossroads of STI policy and Foresight include feasibility and Foresight studies, regulatory mechanisms, initial funding for the introduction of resulting solutions at global scale with respective coordinated approaches between countries. Most often Foresight studies take into account indicators which mirror the global networking of national STI systems. Among these indicators are the technology balance of payments, PCT patent applications, joint international co-authored publications, royalty payment flows between countries, STI induced FDI, complementarities of technological specialization profiles.

15.3.2 Analysis Based on STI Indicators

Foresight studies presume that STI policy needs to be either readjusted or continued in the current shape. Hence the issue arises if and how STI indicators can reflect the sustainability of policy measures which are in most cases a precondition of Foresight studies. Here measurement of the sustainability of Foresight studies as well as of STI measures is essential.

For long time STI indicators are measuring and reflecting the strength and power of NIS. Meanwhile it has become common wisdom that science, technology and innovation are no longer a phenomenon occurring in national boundaries but are in many shapes determined and influenced, if not generated, by global communities, e.g. by globalization of STI (Cantwell and Janne 1999). This holds especially true for global markets determining the respective application potentials. Consequently it follows that NIS are more globalized which is expressed in cross border technology flows, international co-authored publications, PCT applications for patents, community trademarks among others. Similarly Foresight exercises though with national focus always need to take into account global scenarios and developments instead of pure national developments. Done strategically Foresight inspires the organization to learn about possible future scenarios and enables them to prepare accordingly to meet the resulting challenges for their institutions / organizations by integrating Foresight into their strategic planning (Bezold 2010). Strategic planning at the same time is a central matter of STI policy which in turn is based in evidence thus indicators. It follows that the success of Foresight as a strategic planning tool is determined by the underlying STI related indicators among other determinants.

Analyzing STI policy based on indicators causes a number of reasonable methodological problems. Reasonable shares of indicators are non-quantifiable since they contain strong social-political dimensions. This implies that using traditional quantitative methods causal modeling, although possible in principle, shows limited analysis potential due to the unknown and hidden relationship between actors providing data and the multiple interrelations between different policy fields. Also the indicators are carrying a certain degree of uncertainty which due to the overarching complexity of the policy fields described is almost non-reducible neither can this uncertainty be fully described or even delineated. Moreover there is limited possibility to prove causality between the different indicators, e.g. the impact and influence of each policy measure which has an impact on the validity and reliability of the respective analysis. Thus conclusions drawn from such analysis need to involve not only quantitative indicators but be complemented with qualitative indicators which are considered to provide explanations or at least indications of the causality of indicators. This is to assure the traceability of causal relations indicated by quantitative indicators. Eventually the analysis of STI indicators describes complex social-political and socio-economic problem fields.

A possible solution to overcome these challenges lies in the morphological analysis which can assumed a useful, non-quantified method for investigating problem complexes, which cannot be captured by formal statistical and mathematical methods hence causal modeling and simulation. The morphological box developed eventually is complemented by a cross-consistency matrix. Although both methods are slightly subjective in development and calculation represent they allow a fairly traceable and plausible causality analysis. Prove for this has been delivered already by Ritchey who run compared identical morphological fields running consistency checks and finally by discussing the different assessments included in the morphological box gaining a deeper understanding of the nature and interrelationship of the policy fields involved and their respective impacts (Ritchey 1998).

15.3.3 Foresight Based on STI Indicator Analysis

In many cases Foresight studies follow STI indicator analysis. This does not imply that such analysis is done with the intention to launch Foresight are commonly initiated with the aim of launching Foresight. This is especially reasoned in the available information base which still consists of a mixture of (partial) knowledge, assumptions, and ignorance. The decision to launch Foresight on this basis can be assumed a policy related decision since especially in the initial phase of Foresight the expectations of stakeholders and potential participants are high with regard to their own personal and institutional interest. Such policy decisions need to be made before conclusive scientific evidence on these problems illustrated by the indicator analysis is available, while at the same time the potential error costs of wrong decisions can be huge. Hence the uncertainty inherent to a Foresight of complex problems needs to be taken into account. At this stage quite often controversies arise which aim at three interrelated factors: uncertainty in the knowledge and information base, differences in framing of the problem, and the inadequacy of the institutional arrangement at the science-policy interface (Van der Sluijs et al. 2005). However the underlying STI indicator analysis provides reasonable solid arguments for Foresight with the explicit target and aim of developing potential scenarios and future developments which are eventually being used to derive respective measures and responses to meet the upcoming challenges and prepare the NIS to compete globally, regionally and locally. Moreover the societal context needs to careful consideration given the fact that in a broader sense, e.g. in terms of technology and innovation since finally society is accepting or rejecting responses derived from Foresight and thus from STI indicators analysis. The inclusion of this societal context beyond the often quoted and used technology and application dimensions of Foresight requires a more sophisticated, e.g. deliberative, reflexive, and multidimensional approach to uncertainty assessment. Here uncertainty should be a central element in the development of scenarios and equally important in the initial design of Foresight. Uncertainty in this context refers to technical, methodological and societal uncertainty (Van der Sluijs et al. 2005). Hence Foresight methodologies need to been chosen and bundled to reduce the overall uncertainty to a reasonable level especially by combining quantitative and qualitative approaches. Thomson and Holland (2003) find that complementary cross-section and temporal analytic approaches, e.g. the combination of quantitative and qualitative methods meets this requirement.

15.3.4 Strategy Studies and Policy Analysis Based on Foresight

In result of Foresight studies roadmaps and strategy studies are employed to leverage the value of the findings from Foresight. Such studies and analysis are based on scenario-based investigations of possible futures which result from Foresight. Scenarios in turn are a tool to support decision making under uncertainty. Still scenarios are commonly build on assumptions which are subject of continuous change (Shearer 2005). These assumptions express the beliefs and perceptions but also the expectations of stakeholders, e.g. individuals and institutions involved in developing and building such scenarios. To assure the scenario building is reasonably objective and not determined by individual's perceptions and expectations.

Through the development of different kinds of scenarios for different applications and purposes it becomes evident that either other or more sophisticated STI indicators are needed. Wenstøp and Seip (2001) argue that multi-criteria decision analysis (MCDA) is a suitable tool for policy analysis including a variety of indicators, here STI indicators. Policy maker always need to make multi-criteria backed decision taking into account their legitimacy and quality of the respective decisions in terms of consequences (Wenstøp and Seip 2001).

15.4 Measuring the Impact of STI Policy: Implications for Foresight Studies

STI policy is measured by numerous indicators which have been described in the chapter. However the majority of these indicators are ex post indicators mirroring the recent status of the STI ecosystem, e.g. a national innovation system. Foresight studies on the other hand too are built on indicators which are used for the development of scenarios describing potential future developments. In course of that STI policy is in most cases developing policy responses to the potential developments which are evidently identified by Foresight studies. Hence it's reasonable to look at indicators which are used already or which have the potential to be used in both application, STI policy assessment and in Foresight. Although especially the Community Innovation Survey and the European Innovation Scoreboard intend to deliver indicators suitable to measure the economic impact of STI (Bloch 2007) there is still a gap in indicators mirroring the social and environmental impact of research activities (Luukkonen 1998; Lepori and Reale 2012). Lepori and

Reale use descriptors to capture more qualitiative data and information integrated in indicators, markers to capture assumed measureable outcomes and indicators which create the link between qualitative and quantitative dimensions. Ex-ante impact assessment of STI policy measures is commonly based on the analysis of participants of a respective STI policy measures, namely of funding support programs (Lepori and Reale 2012). In such cases applicants to funding from STI policy are usually required to describe the intended goal and output of the funded project work. From the large stock of funding applications trend analysis is in pricnciple feasible. However it needs to be kept in mind that such information is in many cases characterized by a bias of the funded party towards the funding party. The funding applicant will with some reasonable likelihood formulate promising potential outcomes and applications of the funded work which turns out to be unrealistic after a certain time of project work. The reason for this is the evaluation procedure and criteria applied by funders which commonly include assessment of the outcomes expected. Still such databases of funding project proposals also contain information though in verbal form which are useful information for the creation of indicators which stress a shift from input and output indicators spillovers, flows and process indicators by means of collaboration patterns, co-publications, co-patenting, etc. Another dimension of increasing importance is 'learning from experiences', e.g. past measures. Such learning is often achieved by the exchange of experiences with STI policy measures between the different NIS actors involved with the clear aim to refine and improve future initiatives (Kuhlmann 2003). Here ex post evaluation and impact measurement of STI policy measures is enriched by a future thinking dimension.

It's common practice for assessing the STI policy measures ex post. Quantitative indicators such as patent numbers, publications number, citation counts are publicly available from specialized databases. Other indicators are the number product and process innovation and the cooperation frequency and type of NIS actors are mainly collected by surveys and aimed at being converted into indicators. Patent indicators are frequently used in Foresight studies. The value of patent indicators lies in the availability of long time data series which analyzed over the years show tendencies of technology field development if differentiated following the international patent classification or industrial developments if industrial classifications are used (Blind 2008). Lagging, e.g. ex post type indicators used in the evaluation and impact assessment of STI policy measures are the R&D dynamics, e.g. the development of the absolute R&D related investments but also the relative investments, e.g. R&D as share of GDP. These indicators are then broken down at the performing level and the financing level, e.g. governments, industry, foreign funding for financing sources and government, HEI, industry for performance of R&D to name the major actors. A more precise indicator is the investive expenditure within the R&D budgets of companies. This is complemented by the inventory, e.g. the number of new companies which is considered an indicator for the volatility and the rate of change of industries. In case of technology based companies this indicator can also be considered an indicator of the either ongoing or expected technological change. Still although these indicators are typically used for STI policy measures these indicators need to be complemented by more in depth analysis of the underlying technology fields which then gives valuable input for future STI policy design. Such is often done in Foresight with the aim of scenario development. The education and qualification of human resources in an NIS is often measured and assessed in innovation studies or innovation reports which aim at SWO analysis of single NIS'. Standards, e.g. technical standards are issued by certified bodies/ agencies with different outreach and legal implications. Surveys in different shapes among researchers and innovators and reviews of national STI policies by expert panels are the most commonly used evaluation and impact assessment approaches (Georghiou and Larédo 2006). The composition and application of transparent indicators are a meaningful way to enable expterts often asked for doing such impact assessments to explore the overall meaning and position of the STI policy measures in question hence providing an even more objective and solid assessment of such measures (Trochim et al. 2008).

Very recently a classification approach for technologies was developed considering three basic criteria for differentiating technologies. Firstly the underlying field (s) of science, e.g. the science base or origin is considered, secondly the actual application field measured as the industrial class (goods and services) and thirdly the socio-economic dimensions is taken into consideration which expresses the expected diffusion and adoption of the technology hence its (impact) (Gokhberg et al. 2013). The discussed STI indicators are per se reasonable and useful for use in Foresight studies but they need to be classified, structured and complemented by in depth additional analysis (Blind 2008).

The structuring and classification of indicators is essential to ensure a comprehensive understanding of the indicators and the spillovers between indicators. The pure extrapolation of STI indicators into the future will very likely lead to misleading results because most if not all indicators are not only determined by the STI policy measures and the surrounding framework conditions but also by the human factor, psychological influences and processual determinants. The human factor and psychological influences are important in case of budget allocation related decisions which are eventually expressed in any STI expenditure related indicator. Here issues like political stability and economic stability are important for decision makers to allocate resources or reschedule such decisions. Such effects are mirrored in statistics, e.g. indicators with a reasonable time lag only. Processual determinants are for example the time lag between patent applications and issue of patent rights by issuing agencies and respective measures which are taken or not taken by these agencies to change the current regime. Another example for critical assessment of the suitability of STI indicators for Foresight studies is the number of new (sometimes also called 'young') technology firms. The absolute number of these may give an indication of the attractiveness of a market or a technology but over longer time it's more reasonable to consider the survival rate of these companies and their attachment to the originally focused market or technology. The reason for that concern being that established companies especially are usually using their market power or even dominance to limit new companies expansions hence diffusion of their technologies. Moreover especially in technology driven industries a reasonable mergers and acquisitions tendency has been recognized in the last decade. Here established companies might take over new companies with the aim of incorporating their competences in their own processes and product portfolios. Thus the importance and success of corporate venturing of established market actors reaches a new dimension. Although there are solid indicators available for venture capital as external funding of new companies such are rarely available for established companies which might declare it in their balance sheets in varying form, be it as R&D investive expenditure treated like equipment investment or financial investment with unspecified purpose.

15.5 Conclusions

There is a broad range of STI indicators available currently with sufficient time coverage. However as it was shown STI indicators lack a future orientation so far but are more restricted to ex post status quo description and analysis. The internet development has direct implications for the development and use of STI indicators since numerous new data sources are available beyond the established statistics which provide new data for both existing indicators and for the development of new indicators which may supplement traditional STI indicators (Scharnhorst and Wouters 2006).

Traditionally the focus of STI indicators was and still is mainly on R&D related indicators. The reason for this is probably of statistical nature. It took decades to establish the nowadays common R&D statistics in most countries in the world. Although the nature of innovation is changing and so is the nature of science and technology there is so far no STI indicator response on more than regional level which seriously mirrors these changes. Moreover existing indicators do not account for the fact, some might argue for the assumption, that research (science) thus technology and innovation are mainly driven by creativity. Therefore Foresight studies and in line with them future oriented STI indicators should consider the human factor more prominently and pay attention to the science and innovation climate at micro, meso and macro level. The usual headcounts of R&D personnel (alternatively FTEs) are indicators for quantity but not for quality and climate conducive science and innovation.

The process of generating science, technology and innovation results and outcomes itself involves more functions of different actors which are not mirrored in indicators but which are often more implicitly included in Foresight studies. New forms of STI, namely innovation, reflect increasing the complexity of economic system, especially through eco-innovation which internalises negative externalities of resource productivity and open innovation which internalises positive externalities of knowledge productivity. This paradigm shift in growth model implies new innovation ‘ecosystem’, new economic ‘laws’ govern innovation activities (increasing returns) and governance for ‘system innovation’ of innovation system (sustainability). The implications for governance for STI systems are manyfold and need to be matched by respective indicators.

- With the still progressing globalisation of STI a governance of international interdependence, fourth wave of globalization, is needed.
- Countries are already on the path to develop and implement differentiation strategies and complementarities instead of mere catching-up on leaders in the fields.
- The broader innovation concept reflects the increasing complexity of system but is not covered by indicators yet.
- This concept calls for governance of STI for sustainable growth, economic prosperity and societal development. The challenge for STI indicators and Foresight lies in including 'innovation policies' instead of 'innovation policy' which goes beyond the 'horizontal innovation policy'.
- Due to ongoing changes in the growth regime the governance of system change/ transition with policy as co-actor for defining appropriate institutional arrangements to achieve societal challenges needs to be mirrored. This implies monitoring the governance of knowledge dynamics to enhance system innovation for sustainable growth and (international) cooperation. The new features in this paradigm to be included in future indicators and dealt with by Foresight studies are cumulative knowledge where positive feed-back mechanisms are dominant, the public good character of knowledge where spillovers are pervasive and an increasing instability of the system where innovation bubbles are inevitable.

A new generation of STI indicators needs to go beyond the common NIS concept which is currently too static and too closed raising the need for a wider systemic framework which includes new patterns of innovation which are emerging from interactions ('coopitition' in open innovation; reorganisation of international value chains; blurring boundaries: multi-'everything'), growth model changes (how positive feed-back loops are managed), sustainability (digitalization & dematerialization which imply more weight of economics of increasing returns), small 'fluctuations' at the start which eventually make big differences (path dependency) and the fact that knowledge dynamics are of different nature (common pool). Moreover the Foresight studies should be expanded by the dimension of changes in STI governance in self-reinforcing systems, the co-creation of supply and demand conditions, the co-evolution of policy, theory and other 'belief systems' and the capacity to make choices under uncertainty. Governance thus is expected to take care of stable frameworks of shared STI objectives with strategic positioning, prioritization and differentiation strategies and eventually increasing share of experimentation with STI policy measures. It seems reasonable to detect such features in course of Foresight studies but nethertheless indicators must provide a reliable solidly founded base for monitoring developments in ever shorter time frames.

Summing up it can be concluded that existing STI indicators are suitable for a broader use of impact assessment activities hence in Foresight studies. This is justifiable by the arguments:

- STI indicators have reached a development stage which allows targeted indicator composition in the recent years. These indicators are increasingly ex ante indicators combining quantitative and qualitative dimensions.
- The interpretation of STI indicators is progressing. There is an increasing in depth understanding for the rational of NIS actors to behave in certain ways und different circumstances which allows to assign more meaning to the indicators.
- STI indicators increasingly take time dimensions into account instead of focusing on static analysis.
- Analysis techniques are progressing, such as semantic analysis which contributes to STI indicators reaching new dimensions. In such more information sources, namely a broad range of by different different information sources can be used for analysis. In doing so these indicators are becoming increasingly relevant for Foresight studies by contributing to build solid base for Foresight studies through more realistic ex ante impact assessments.

Despite the promising potential of STI indicators for Foresight an ex ante impact assessment some major requirements need to be fulfilled:

- STI indicators need to be robust and most current. Extrapolation of STI indicators time series needs complementary qualitative analysis to test the validity of trends which can be detected.
- The quality and comparability of STI indicators needs to be checked using again qualitative analysis. There are different understanding especially in the collection of raw data for STI indicators composition in most countries. Still Foresight will not rest on STI indicators which are purely national indicators.
- STI indicators like patenting and publications can be used for trend and tendency detection but should not necessarily be used for SWOT analysis of countries, regions or industries. Here additional research is required to determine the quality of these indicators.
- In addition to the traditional STI indicators standards and international regulations need to be considered. Standards refer to nationally and to some extend internationally binding technology driven standards which are in place and enforced already but equally important is the analysis of ongoing standardization procedures at national and international levels.
- Despite standards set by indended bodies industrial agreements on standards are important indicators. Such standards are agreements between different industry actors about technologies or interfaces between technologies which are not subject to government regulations. Once set such standards are likely to set the basic framework for a whole industry for a long period.

The IAFS model introduced in this chapter is a systemic model which combines the different aspects of indicators for STI policy and Foresight eventually building the bridge between the existing information and knowledge base and the potentials for extension which are offered by Foresight studies. IAFS is not thought to be a model which can be applied one to one in the overarching STI context netherless it aims at highlighting the major challenges towards STI indicators and Foresight indicators and the potential indicators from both spheres have to generate inspirations for development of the next generation of STI indicators and also Foresight studies and indicators. The major conclusion to be drawn from the IAFS model is that STI in itself is a dynamic phenomena which is creating continuously changing conditions and requirements of the NIS as a whole. Foresight plays an important role here since Foresight mirrors and displays ongoing changes at different levels. Hence the systemic thinking of Foresight and STI, here expressed in terms of STI indicators, is a contribution to a new thinking of NSI with the aim of systems thinking, e.g. systems innovation.

References

Abramo G, D'Angelo CA, DiCosta F, Solazzi M (2009) University–industry collaboration in Italy: a bibliometric examination. Technovation 29:498–507

Archibugi D, Pianta M (1996) Measuring technological change through patents and innovation surveys. Technovation 16(9):451–468

Balconi M, Breschi S, Lissoni F (2004) Networks of inventors and the role of academia: an exploration of Italian patent data. Res Policy 33(2004):127–145

Bezold C (2010) Lessons from using scenarios for strategic foresight. Technol Forecast Soc Change 77:1513–1518

Blind K (2008) Regulatory foresight: methodologies and selected applications. Technol Forecast Soc Change 75:496–516

Bloch C (2007) Assessing recent developments in innovation measurement: the third edition of the Oslo Manual. Sci Public Pol 34(1):23–34

Braun T, Diόspatonyi I (2005) Counting the gatekeepers of international science journals a worthwhile science indicator. Curr Sci 89(9):1548–1551

Butcher J, Jeffrey P (2005) The use of bibliometric indicators to explore industry–academia collaboration trends over time in the field of membrane use for water treatment. Technovation 25:1273–1280

Cantwell J, Janne O (1999) Technological globalisation and innovative centres: the role of corporate technological leadership and locational hierarchy. Res Policy 28:119–144

Chan L, Daim T (2012) Exploring the impact of technology foresight studies on innovation: case of BRIC countries. Futures 44:618–630

Dlouhá J, Barton A, Janousková S, Dlouhý J (2012) Social learning indicators in sustainability-oriented regional learning networks. J Clean Prod 1–10, http://dx.doi.org/10.1016/j.jclepro.2012.07.023

Donovan C (2007) The qualitative future of research evaluation. Sci Public Policy 34(8):585–597

Donovan C (2011) State of the art in assessing research impact: introduction to a special issue. an integrated impact indicator: a new definition of 'Impact' with policy relevance. Res Eval 21 (3):183–188

Dosi G (1988) Sources, procedures and microeconomic effects of innovation. J Econ Lit XXVI:1120–1171

Freeman C (1982) The economics of industrial innovation. MIT Press, Cambridge

Freeman C, Soete L (2009) Developing science, technology and innovation indicators: what we can learn from the past. Res Policy 38:583–589

Georghiou L, Larédo P (2006) Evaluation of publicly funded research: recent trends and perspectives. In: Futures, Volume 44, Issue 10, December 2012, Pages 905–913 OECD science, technology and industry outlook. OECD, Paris. pp 177–199
Godin B (2004) The who, what, why and how of S&T measurement, project on the history and sociology of S&T statistics, working paper no. 26, http://www.csiic.ca/PDF/Godin_26_a.pdf. Last accessed 30 Oct 2012
Godinho MM, Ferreira V (2012) Analyzing the evidence of an IPR take-off in China and India. Res Policy 41:499–511
Gokhberg L (2000) Intellektual'naya deatel'nost' v structure ekonomiki informacionnogo obschestva (voprosy metodologii). Voprosy statistiki N 6 pp 41–51 (in Russian) [Intellectual activity in the structure of the information society economy (methodological issues)]
Gokhberg L (2003) Statistika nauki. TEIS, Moscow (in Russian) [Statistics of Science]
Gokhberg L (ed) (2012) Ekonomika znaniy v terminakh statistiki: nauka, tekhnologii, innovacii, obrazovanie, informacionnoe obschestvo. Moscow: Ekonomika (in Russian) [Economics of knowledge in terms of statistics: science, technology, innovation, education, information society. Glossary]
Gokhberg L, Boegh-Nielsen P (eds) (2007) Information society statistics in the Russian Federation: harmonization with international standards. Higher School of Economics, Moscow
Gokhberg L, Fursov K, Miles I, Perani G (2013) Developing and using indicators of emerging and enabling technologies. In: Gault F (ed) Handbook of innovation indicators and measurement. Elgar, Cheltenham/Northampton, Ch. 15
Hidalgo A, Gabaly S (2012) Use of prediction methods for patent and trademark applications in Spain. World Patent Inform 34:19–29
Jappe A (2006) Four major task domains of science for sustainability. Fraunhofer ISI discussion papers innovation system and policy analysis, no 10/2006
Kleinknecht A, Montford Kv, Brouwer E (2002) The non-trivial choice between innovation indicators. Econ Innov New Technol 11(2):109–121
Kuhlmann S (2003) Evaluation of research and innovation policies: a discussion of trends with examples from Germany. J Technol Manage 26(2–4):131–149
Lepori B, Reale E (2012) S&T indicators as a tool for formative evaluation of research programs. Evaluation 18:451
Luukkonen T (1998) The difficulties in assessing the impact of EU framework programs. Res Policy 27(6):599–610
Lyall C (2005) Concurrent power. The role of policy networks in the multi-level governance of science and innovation in Scotland. INNOGEN working paper no. 33, May 2005
Lyall C, Tait J (2005) Shifting policy debates and the implications for governance. In: Lyall C, Tait J (eds) New Modes of governance: developing an integrated policy approach to science, technology, risk and environment. Ashgate Publishing, Aldershot/Burlington, pp 1–18
Mendonça S, Pereira TS, Godinho MM (2004) Trademarks as an indicator of innovation and industrial change. Res Policy 33(9):1385–1404
OHIM (2012) Statistics on community trade marks, community designs and appeals. Office for the harmonization in the internal market 2012. http://oami.europa.eu/ows/rw/resource/documents/OHIM/statistics/ssc009-statistics_of_community_trade_marks_2012.pdf. Accessed 30 Sept 2012
Pavitt K (1988) Uses and abuses of patent statistic. In: van Raan AFJ (ed) Handbook of quantitative studies of science and technology. Elsevier, Amsterdam
Pawson R (2002) Evidence-based policy: the promise of 'Realist Synthesis'. Evaluation 8 (3):340–358
Rennkamp B, Stamm A (2009) Towards innovation systems for sustainability – the role of international cooperation. In: Federal Ministry for Education and Research: innovation for sustainability in a changing world. Proceedings of the 2nd South-African-German dialogue on science for sustainability, Bonn, pp 72–77

Ritchey T (1998) General morphological analysis – a general method for non-quantified modeling. In: Presented at the 16th EURO conference on operational analysis, Brussels, 1998, available http://www.swemorph.com/pdf/gma.pdf. Accessed 20 Dec 2012

Scharnhorst A, Wouters P (2006) Webindicators: a new generation of S&T indicators. Cybermetrics 10(1). ISSN 11375019. http://www.cindoc.csic.es/cybermetrics/articles/v10i1p6.html. Accessed 30 July 2012

Shearer AW (2005) Approaching scenario-based studies: three perceptions about the future and considerations for landscape planning. Environ Plann B Plann Des 32(1):67–87

Thomson R, Holland J (2003) Hindsight, foresight and insight: the challenges of longitudinal qualitative research. Int J Soc Res Methodol 6(3):233–244

Trochim WM, Marcus SE, Masse LC, Moser RP, Weld PC (2008) The evaluation of large research initiatives: a participatory integrative mixed methods approach. Am J Eval 29:8–28

Van Der Sluijs JP, Craye M, Funtowicz S, Kloprogge P, Ravetz J, Risbey J (2005) Combining quantitative and qualitative measures of uncertainty in model-based environmental assessment: the NUSAP system. Risk Anal 25:481–492

Wagner CS, Leydesdorff L (2012) An integrated impact indicator: a new definition of 'Impact' with policy relevance. Res Eval 21(3):183–188

Wenstøp F, Seip K (2001) Legitimacy and quality of multi-criteria environmental policy analysis: a meta analysis of five MCE studies in Norway. J Multi-Criteria Decis Anal, Special Issue: Multicriteria Anal Environ Manage 10(2):53–64

Wieczorek AJ, Hekkert M, Smits R (2010) Systemic policy instruments and their role in addressing sustainability challenges. http://umconference.um.edu.my/upload/43-1/papers/014%20AnnaJWieczorek_MarkoHekkert_RuudSmits.pdf. Accessed 30 July 2012

WIPO (2011) International classification of goods and services for the purpose of the registration of marks (nice classification), 10th edn, Part II with list of goods and services in class order. WIPO Publication No. 500.2E/10

Yusuf S, Nabeshima K (2009) Tiger economies under threat – a comparative analysis of Malaysia's industrial prospects and policy options. The World Bank, Washington, DC