
Volume 76, Number 7
September 2009
ISSN 0040-1625
ELSEVIER
Technological Forecasting & Social Change
An International Journal
Available online at www.sciencedirect.com
ScienceDirect

Technological Forecasting & Social Change 76 (2009) 917–931

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

The technological capabilities of nations: The state of the art of synthetic indicators

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ARTICLE INFO

Article history:
Received 31 July 2008
Received in revised form 22 December 2008
Accepted 11 January 2009

Keywords:
Composite indicators
Innovation measurement
National systems of innovation
Cross-country comparisons

ABSTRACT

Composite synthetic indicators of the technological capabilities of nations have been used more frequently over the last years becoming a sort of Olympic medal table of the innovation race. The European Commission, specialised United Nations Agencies, the World Bank, the World Economic Forum, and individual scholars have developed several of these measurement tools at macroeconomic level. All these indicators are based on a variety of statistical sources in order to capture the multidimensional nature of technological change. This paper reviews these various exercises and: i) it brings into light the explicit and implicit assumptions on the nature of technological change; ii) it discusses their pros and cons; and iii) it explores the consistency among the results achieved. Most of the final rankings at the country level are fairly consistent, but significant discrepancies for some nations emerge. The value of synthetic indicators of technological capabilities for public policy, company strategies and economic studies is finally discussed.

1. Introduction

There are at least three good reasons which justify the efforts to collect systematic statistical data on national technological capabilities [1]:

1. *Theoretical analysis:* innovation indicators can be used to increase and broaden our knowledge of technological change and to test innovation theories. There is a large consensus within economic and social theories about the fact that technological change represents the engine of development and even of progress. More specifically, innovation is considered the determinant of economic growth, productivity, competitiveness, and employment. Appropriate measurement tools are needed to test and quantify these hypotheses.
2. *Source of information for public policies:* policy makers need to locate their country position in the global landscape to identify national strengths and weaknesses, to secure technological opportunities, and to assess the effectiveness of the policies adopted [2,3]. Reading and interpreting statistics of technological change provides a fundamental source of information to design and carry out an effective innovation policy.
3. *Input for firms' strategies:* managers use innovation studies to have a deeper understanding about technological advance, especially in a period of fierce internal and international competition. Data on the technological capability of different countries allow a better understanding of the geographical contexts in which firms can develop and establish their innovative activities.

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[1] The opinions expressed in the article reflect the position of the author and do not absolutely reflect the view of the Institution.

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doi:10.1016/j.techfore.2009.01.002

We will focus on a specific instrument for measuring innovation: synthetic indicators at the country level. The production of innovation indicators has recently been spreading both at micro and macroeconomic levels: data collection and surveys are systematically developed at firm, industry, technological field and country level (for reviews, see [4,5]). Within this renovated effort of measuring innovation, a larger attention has been paid to compare the technological activities of different nations. Various United Nations specialised agencies, including the World Bank, UNDP, UNIDO and UNCTAD, business associations, like the World Economic Forum, and individual scholars have collected data about technological capabilities at national level. Also the European Commission has provided appropriate tools such as the European Innovation Scoreboard and the Global Innovation Scoreboard, in particular for evaluating the progresses of the Lisbon Strategy, focusing on a smaller and less diverse group of countries (see European Commission [6–8]).

What are the features of these synthetic indicators? They take into account the various aspects which constitute the technological capability of a country and aggregate them into a single figure. They are typical macroeconomic indicators aiming at comparing the positions of different countries and their changes. Their merit is to provide a clear and immediate image of a country's ranking, while the drawback is to sacrifice the inherent complexity of the process of knowledge production and distribution.

Mass media, economists, politicians and managers are the main users of these indicators. The media use them since the public opinion is captured by the direct ranking of countries: these rankings are often seen as a sort of technological Olympic medal table which ignites the spirits of supporters. Economists use them to scrutinize the relationship between innovation and other economic phenomena such as competitiveness, trade, growth and productivity. Policy makers and managers are also keen to read and comment on these data, but they are less eager to guide their actions on the ground of these indicators, perhaps because they realize that they are far too aggregate to be connected to specific policies and strategies.

The objectives of this paper are:

a. to provide a comprehensive exposition of the main exercises of innovation measurement based on composite indicators;
b. to gather evidence about the results of these exercises; and
c. to test the consistency of the results achieved by these exercises and to assess their usefulness and limits.

The next section discusses the theoretical assumptions on which the synthetic indicators of technological capabilities are grounded. Section 3 describes the data sources, methodologies, and statistics used by each approach. We then analyse in Section 4 the results obtained, comparing the positions of different countries according to each synthetic indicator, seeking and discussing the causes of any significant difference. Section 5 contains a comparison between the ranking provided by the various composite indicators and the most widely used simple indicator, namely the ratio R&D to GDP Section 6 concludes.

2. In search of the theory underlying the measurement of technological capabilities

2.1. Uncovering the implicit assumptions

The theoretical assumptions underlying these macroeconomic measures of technological capabilities are not always explicit. What are the implicit assumptions encountered in the majority of the exercises here reviewed?

The first methodological assumption is related to entrusting the use of "countries" as unit of analysis: countries are made of differentiated areas and regions and they are far from being homogeneous. Using one single figure to capture the overall technological capabilities of such different entities hides several simplifications. Macroeconomic analysis is used to this type of simplifications: the GDP is used daily even if its real economic meaning is often questioned because it aggregates very heterogeneous phenomena. When we consider the aggregate rate of unemployment, we disregard the fact that in some regions there can be full employment, while in others unemployment rate can be far higher than the national average. Similar problems are encountered when technological capabilities are measured: there are important differences across regions, industries and companies within the same country. The possibility of inter-country comparisons is based on the implicit assumption that a national system of innovation is somehow capable to distribute knowledge across the whole country [9,10].

The second assumption regards the usefulness of international comparisons. Differences in technological capabilities are very broad [2,11]. Thus one can doubt about the usefulness to comparing such different countries like Sweden and India, United States and Ghana because each of these countries is characterized by technological capabilities that are so different to be often disparate. James [12] stresses that the selection of data to calculate composite indicators is often biased and it does not reflect adequately national differences in development stages. Comparisons became more significant if they are carried out between more similar national systems of innovation, like Sweden and Denmark, Ghana and Togo.[2] These international comparisons also allow us to identify convergences or divergences across countries. The analysis of convergence is of particular interest for the European Union: in a moment in which the member states intend to strengthen their cohesion and to adopt a common strategy for innovation, it gains relevance to identify the contribution provided by each member state.

The two assumptions above are related to both simple and composite technological capability indicators. Composite indicators raise a third additional problem: they present a typical problem of aggregation between apples and oranges. When a composite indicator is obtained as the arithmetic mean of single statistics, we are assuming that a unit of an indicator can be substituted by a

[2] For an exercise regarding Africa, and using a more appropriate set of indicators, see [13].

unit of another indicator and vice versa. This leads to a third implicit assumption, namely the substitutability among ingredients. Considering the fundamental differences between the aspects gauged by different indicators, this assumption is questionable [14]. Thus it is not surprising that some scholars [15,16] have criticized this measurement instrument given its questionable foundations.

The various components included in the making of a composite indicator also need to be weighted. But when we impose *ex ante* a weight to each indicator, we provide a subjective value judgment [17]. Moreover, the aggregation methodology and the choice of the indicators can largely affect the results of comparative analysis between different units of analysis [15,16].[3]

Finally, the different factors which contribute to the development of composite indicators often show high correlation among them: countries with a high share of graduates have at the same time a high rate of scientific publications, patents and so on. In order to capture the differences it is sometimes needed to look at more homogeneous groups of countries [19].

The exercises considered here are not seeking to highlight similarities and differences among countries, but rather to put forward a sort of ranking. The significance of developing such a classification lies implicitly on the idea that a country which shows a good position in two areas is two times better off than one having twice a bad position. Likewise, a person who eats an apple and an orange receives double doses of vitamins compared to a person who eats neither an apple nor an orange. These empirical exercises do not aim at classifying countries within homogeneous groups; different statistical tools would be needed to do that. They rather aim at ordering countries depending on their capabilities related to technologies and innovation activities.

With respect to previous studies [20], this study aims at broadening the spectrum of the analysis using up-to-date data. Moreover, it takes into account a greater number of exercises including, among others, the *European Innovation Scoreboard*. Finally, it compares the results provided by the various composite indicators with the most used simple indicator, namely the ratio R&D to GDP.

2.2. Which theory of technological change?

We have already noted that the number of innovation surveys has considerably grown over the last decade. A first glance at these surveys might give the impression that several of them undertake some of the famous walks of “measurement without theory”, to cite a well-known expression by Koopmans [21]. It might be useful to make explicit what in many of these analyses is only implicit, namely what these indexes intend to measure and on the ground of which theory.

First of all, it is worth reminding that technological capability reflects an heterogeneous phenomenon, composed by several elements. Were that not the case, composite indicators would be useless. The need of using different sources derives from the awareness that a single statistical source – as for example the resources devoted to R&D, the number of patent applications, data on high-technology trade etc. – can shed light on specific aspects about technological competences but are incomplete. These statistics usually underestimate others aspects of knowledge, such as those “minor” or incremental forms of innovation as stressed by Rosenberg in particular [22]. Technological capabilities must indeed be considered in a broader sense, including both the creation of new knowledge and their applications to real economic and social problems [23].

In most cases, the exercises taken into account in this paper do not include statistics about production. This needs to be justified since there is an established consensus in considering technological and productive capabilities strictly interwoven. On the one hand, technological capability is preparatory to production; on the other hand, production process generates new competences via *learning by doing* and *learning by using*. One could consequently argue that it is impossible to measure technological developments separately from the production processes. In fact, the UNIDO exercise here reviewed also includes some indicators of productive capacity. Nevertheless, there are good reasons to measure technology and production separately, as it is done in the majority of the exercises reviewed here, since this allows identifying how the two sets are dynamically linked. Inserting indicators of production into measures of innovation will not allow any longer exploring the effects of innovation on production and vice versa.

The nexus between technology and production calls for a fundamental feature of the innovation process: it has both an *embodied* and *disembodied* nature. We can for example refer to an embodied technology considering capital goods, equipment or infrastructures. But it is equally important what is embodied in human competences which makes workers able to effectively use capital goods. In fact, any innovation system requires both disembodied knowledge and capital equipment to work effectively: on a desert island, a group of Nobel prize winners would have a hard life as much as a group of illiterates endowed with the most updated infrastructures. An innovation system needs an appropriate balance of the two components to prosper.

From a cognitive perspective, knowledge is composed of *codified elements* (like those available in scientific and technical literature, in patents, manuals, or blueprints), and *tacit elements* embodied in an expert and qualified labour force [24]. Tacit knowledge is today recognized as a fundamental element of the innovative process, but this does not make things easier for measurement. Given its “tacit nature”, it is difficult to quantify it: if it becomes quantifiable it also becomes explicit and not any longer tacit. As we will see, some analyses tend to address the problem by using indicators related to the educational qualifications of employees, under the assumption that education and work experience contain and contribute to develop the tacit knowledge of the labour force.

We devote some attention to the different phases of the innovative activity. Innovation can be understood as a long path including generation of new ideas, design, development, industrialization, commercialization, transmission and diffusion. Contrary to what is assumed in the linear model of innovation, these phases are not sequential but interrelated. Expertise and

[3] A complete and detailed analysis of the most used techniques to develop synthetic indicators and of related problems can be found in [18].

competences on the various phases are not at all uniformly distributed within the economic space. Thus, some countries show a greater capability to generating new ideas, for example because they have reliable public research centres, good universities and efficient industrial labs; others are more capable at exploiting them commercially; others are more inclined to absorb knowledge acquired externally and diffuse it internally, although most diffusion processes entail the generation of incremental adaptive innovations.

Finally, the indicators here considered deal with "technological capabilities" more than with "innovative capabilities". Innovations are the direct and indirect outcomes of different activities: basic research carried out in universities, research in firms R&D labs, production. Additionally, innovations can have different nature, i.e. technological and non-technological, tangible and intangible. It is still difficult to gather quantitative information on all these aspects, and even more to get them in a comparable standard for a large number of countries. One of the justifications to using technological capabilities indicators only is that the latter represent the *condition sine qua non* to create, absorb and diffuse technological innovations across an economic system. The limit of this approach is that it may not be able to gauge other forms of innovation such as non-technological innovations, organizational innovations, marketing innovations and others. Since these forms of innovation are gaining importance in countries' competitiveness, composite indicators should also address this challenge in the near future.

An attempt to build an indicator based on innovative performance, and also taking into account new forms of innovation, comes from the Summary Innovation Index developed within the European Innovation Scoreboard, and here discussed in Section 3.1. But the other composite indicators cannot be taken as a direct measure of innovative performance. They rather represent the current endowment of a country to base its current and future competitiveness and growth on the creation, use and diffusion of technological innovations.

The exercises considered here are mostly devoted to assess the past and current state of national technological capabilities, but there are a few exceptions. Some of them have also the ambitious task of forecasting the economic performance likely to be achieved on the ground of the current technological capabilities. This is the case of the *HTI Index* employed by the National Science Foundation and, to a lesser extent, also of the World Economic Forums' Global Competitiveness Index.

This brief overview already suggests that we are asking a lot of information to technological indicators. To sum up, we desire indicators that will be able to capture at least:

- disembodied and embodied knowledge;
- codified and tacit knowledge; and
- the generation and the imitation of innovation.

Is it possible to compare such a different group of national systems of innovation? The ways to technological capabilities, even if not infinite, are certainly more than one. We can seek comfort in reflecting on the fact that today there are more similarities than two decades ago. Until 1980s, the so-called "First", "Second" and "Third" world (corresponding, respectively, to the advanced capitalist nations, the planned economies and the less developed nations) also had distinctive differences in technological capabilities. Planned economies, for example, did not have a business sector which developed innovations on a competitive base and the lack of a proper intellectual property rights system did not allow to use patents as a technological indicator. At the same time, planned economies combined high investments in R&D, a well educated population and a high level of workforce qualification. The planned economies were similar to underdeveloped countries in terms of patents, but closer to the most advanced capitalist nations in terms of years of education and number of engineers. It was therefore difficult to rank countries on the ground of a single line.[4] The disappearance of planned economies has made it easier to rank countries since all of them can today be ordered according to similar criteria.

We will consider nine different exercises to measure the technological capabilities of a country: the *Summary Innovation Index* and the *Global Innovation Index*, both of the European Commission; the *Technology Index*, the *Technological Readiness Index* and the *Technological Innovation Index* of the World Economic Forum; the *Knowledge Index* of the World Bank; the *Technological Activity Index* of the UNIDO; the *Technological Advance Index* of the UNCTAD; and finally, the *ArCo* [26].

2.3. Exercises not considered here

Apart from the indicators considered here, there are others attempts to measure technological capabilities at country level. Among others, the *Technology Achievement Index*, developed by UNDP and reported in the *Human Development Report 2001* [27] and the *S&T Capacity Index* (*STCI*) proposed by the *RAND Corporation* [28,29]. These two attempts, already reviewed in [17], have been carried out for one period only and have been discontinued. The *Technology Infrastructure and Scientific Infrastructure* included in the *World Competitiveness Yearbook* (*WCY*) of IMD [30] is also excluded as more business oriented.

A special attention should be devoted to the *High-Tech Indicators* (*HTI*) developed at the Georgia Tech Technology Policy and Assessment Center and reported by the National Science Foundation's *Science & Engineering Indicators* [31,32]. This attempt is designed not just to measure the current technological capabilities, but to forecast how the present capabilities can lead to secure quotas of high-tech exports. The *HTI* is composed of four *input* indicators which reflect national propensity for *future* technology-based competitiveness, and three *output* indicators. These indicators are built through a combination of an expert opinion survey and hard data.

[4] For an attempt to map statistically the various clubs in the world economy, see for example [25].

The *HTI*'s four inputs indicators are: a. *technological infrastructure* referring to the social and economic institutions that help a nation develop, produce, and market new technology; b. *socioeconomic infrastructure* referring to the social and economic institutions necessary to sustain and advance technology-based development; c. *productive capacity* referring to the physical and human resources devoted to manufacturing products and the efficiency with which these resources are used; d. *national orientation* referring to national policies, institutions, and public opinion that help a nation become technologically competitive. These indicators are designed to forecast long-term changes in national high-technology competitiveness in terms of future high-tech exports potential. Output indicators are: a. *technological standing* in manufacturing and exports capabilities for high-tech products; b. *technological emphasis* in export mix; c. *rate of technical change*. These indicators gauge current competitiveness. The *HTI*'s inputs indicators are used by the NSF [33] for comparing perspective nations' competitiveness in high tech trade.

The *HTI* is not strictly comparable with the other surveys since: a) it covers a lower number of countries (about 30); b) it has a distinctive focus on foresight; c) it employs a combination of hard and soft data, a characteristic shared by the World Economic Forums' Global Competitiveness Report only. For this reason, it will not be further discussed herewith.[5]

3. An analysis of the most used indicators

3.1. The Summary Innovation Index (European Commission)

Since 2000 the European Commission (Directorate-General Enterprise and Industry) has published every year the *European Innovation Scoreboard* (*EIS*) [6–8] aiming at assessing the progress of the objectives concerning innovation set by the Lisbon Strategy as of March 2000. The *EIS* sixth edition, released in 2006, includes 25 indicators and develops an articulated structure to measure the strengths and weaknesses of the various national systems of innovation (Table 1).

The 25 indicators have been divided, according to a rationale well-established in the literature [35], within two groups: *Innovation inputs* and *Innovation outputs*. These, in turn, include five subgroups: *Innovation driver*, *Knowledge creation*, *Innovation & entrepreneurship* are classified as innovation inputs; *Application* and *Intellectual property* are instead regarded as innovation outputs.

The 25 indicators are aggregated in a synthetic index named *Summary Innovation Index* (*SII*). For each country, *SII* is estimated as the arithmetic mean of the 25 indicators' normalized values. Then the same weight is attributed to all the indicators composing the *SII*. Normalization has been carried out with respect to the EU-25 value (or alternately to the EU-15 value when the former is not available) of the same year. Finally, the resulting time series has been re-estimated on a scale ranging from 0 (which corresponds to the country showing the minimum value), to 1 (which identifies the country with the maximum value). Thus, the obtained *SII* summarizes an aggregate and comparative value for the innovative performance of each country. In the 2006 *EIS*, *SII* is calculated for 34 countries: two new EU member states (Bulgaria and Romania), and seven extra-UE countries (Croatia, Turkey, Island, Norway, Switzerland, United States, and Japan) have been added to the 25 EU members states.

Since *SII* is more oriented towards the assessment of the innovative performances of countries, it also includes some measures related to the innovative activities of firms derived from the *Community Innovation Survey* (*CIS*), a periodical survey carried out on European firms to scrutinize their innovative performance and strategy. In spite of the improvements obtained over the four *CIS* ventures, the comparability across countries of the indicators is still imperfect, and *EIS* inherits from *CIS* some bias. Moreover, *EIS* seeks to take into account the new forms of innovation by including trademarks and design registrations in addition to patents.[6]

3.2. The Global Summary Innovation Index (European Commission)

The *Global Summary Innovation Index* (*GSII*) is a composite indicator included in the *Global Innovation Scoreboard* (*GIS*) [8] which compares the EU-25 member states innovative performance with respect to their major international partners. *GSII* was constructed for the first time in 2006 [8], and calculated for 48 countries. Besides the 34 countries included in *SII* and *EIS* (see previous section), *GIIS* also considers the other 14 major R&D performing countries in the world.[7]

Many of the 25 indicators used in *EIS* for building *SII*, in particular those based on the Community Innovation Survey, are not available for non-European countries. Thus, *GSII* includes 12 indicators, chosen on the basis of their availability for most of the examined countries: adding more countries implies a reduction of the set of indicators and vice versa. As *SII*, *GSII* is also divided into five composite sub-indicators, each of them measuring a key dimension of innovative capabilities: *Innovation drivers*, *Knowledge creation*, *Diffusion*, *Application*, and *Intellectual property*.

[5] The most relevant finding of the HTI exercise is that China displaces the United States as the top-ranking economy as of 2007. As we will see later, this is in contrast with the results of most of the other measuring attempts. The majority of indicators shows that China has experienced a dramatic increase in technology-based economic competitiveness, but it is still lagging behind compared to the more advanced countries. The main difference between HTI and the other exercises considered here is that the former uses absolute values whereas the latter use data normalized by the size of the economy. In absolute terms China scores highly on most indicators, while on the base of a size-dependent metrics it is far from the top. For a comparison between the methodologies employed by the Technology Policy and Assessment Center and the World Economic Forum, see [34].

[6] The 2008–2010 *SII* will also include two indicators derived from the CIS: firms' non-R&D innovation expenditures (as a percentage of turnover), and the share of small and medium enterprises which carried out organizational and marketing innovations.

[7] Countries have been included according to the share of global R&D expenditures in 2002 (at least equal to 0.1% of the world total). The countries included are: China, Republic of Korea, Canada, Brazil, Australia, Israel, India, Russian Federation, Mexico, Singapore, Honk Kong, Argentina, South Africa, and New Zealand.

3.3. The Technology Index (World Economic Forum)

The most successful attempt to rank countries' position on the ground of economic and technological indicators comes from the World Economic Forum (*WEF*). Thanks to the availability of research resources and promotional capacities, the indexes developed by the *WEF* have become regular guests of international mass media. While the *WEF* generates a wealth of indexes for a variety of economic aspects, we will concentrate here on those related to technological change only.

The main indicator developed by the *WEF* is the *Growth Competitiveness Index* (*GroCI*). The index was developed to analyse the growth potentialities of an economic system in the medium run through the evaluation of its competitiveness macroeconomic factors.[8] *GroCI* is composed by three pillars, each reflecting a critical element of the growth's process of a national economic system. They are: 1) quality of the macroeconomic setting, 2) robustness of the public institutions and 3) technological innovation capabilities. To each of them is associated a different sub-indicator, calculated considering a combination of data coming both from data banks belonging to institutional bodies (*hard data*), and from the results of the WEF's *Executive Opinion Survey* (*EOS*, *soft data*).[9] We will focus here on the *Technology Index* (*Tech*) only since it is the *GroCI* sub-indicator dealing with technological capabilities. *Tech* includes three principal categories of technology: *Innovative capability*, *Technology transfer* and *Diffusion of new information and communications technologies*.

Tech has been calculated for the first time in 2001/2002 for 75 countries. In the 2006/2007 *GCR* edition, *Tech* considered 125 countries, divided in two groups: *core* economies and *non-core* economies, according to the number of granted patents.[10] Concerning *core economies*, the first two *Tech* sub-indicators, innovative capability and ICT diffusion, are considered as adequate to assess the development and competitive capabilities of their competitive systems. That is because these countries, according to the WEF view, are in a development stage in which they can take few advantages from the imitation of technologies already developed abroad. In order to grow and compete, *core economies* need to innovate. Therefore, for the most advanced economies, *Tech* is calculated as the arithmetic mean of the two sub-indicators, *Innovative capability* and *ICT diffusion*. For *non-core economies*, *Tech* is calculated also taking in consideration a third sub-indicator relative to technology transfer, and assigning a lower weight to the innovative capability index.

3.4. The Technological Readiness Index and the Technological Innovation Index (World Economic Forum)

The *Global Competitiveness Index* (*GloCI*) was published for the first time in the 2004/2005 edition of the *Global Competitiveness Report* (*GCR*) [37–39]. *GloCI* is a composite indicator developed by the *WEF* which evaluates the competitive capacity of economic systems, both for advanced and developing countries. The main *GloCI* objective is to synthesise in a single indicator both the economic drivers of productivity and the microeconomic components of growth capabilities. Up until 2004, these were analysed through two different synthetic indexes included in the *GCR*: *GloCI* (described in the previous section) and the *Business Competitiveness Index* (*BCI*, calculated since 1998 to analyse the microeconomic aspects of countries' competitive capability). In the 2006/2007 *GCR* edition, *GloCI* has been calculated for 125 countries, divided in 5 groups according to the stage of development measured by per capita GDP.

GloCI groups the considered variables by pillars which reflect different aspects of economic systems. Each sub-group includes both *hard* and *soft* data. *GloCI* is composed by nine categories. These are further sub-divided into three groups, *Basic requirements*, *Efficiency enhancers*, *Innovation and sophistication factors* which have different importance according to each country's stage of development.[11] This reflects the idea that their contribution varies depending on the development and growth processes of an economic system, and has a relative importance being a function of a country's endowments and level of development. Among the nine categories, those considering the various dimensions characterizing innovative capabilities are the seventh and the ninth.

The seventh pillar, the *Technological Readiness Index*, measures the capacity of firms to adopt new technology, the reliability of the judicial system concerning the ICTs, the amount of foreign direct investments, and the ICTs diffusion. The ninth group, the *Technological Innovation Index*, includes variables related to R&D investments made both from public and business institutions, human capital, legal protection of intellectual property rights and patents.

3.5. The Knowledge Index (World Bank)

The World Bank has created the more comprehensive dataset of internationally comparable economic and social indicators. Data can be consulted and downloaded from the web site, giving to anyone the possibility to make his own elaboration *on-line*. Thanks to the ICT, it is even possible to build *tailor-made* composite indicators. Besides providing a very *user-friendly* data base, the World Bank has also developed its own synthetic indicators. In particular, the *Knowledge Index* (*KI*) is an indicator developed

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8 For a critical analysis of the WEF methodology, see [36].

9 The *Executive Opinion Survey* is a panel composed by manager and experts who give an evaluation (on a scale ranging from 0 – the lowest level – to 7 – the highest level) on general aspects affecting the competitive environment of an economic system for which official data (hard data) are not available.

10 Economies having more than 15 patents per million population granted at the USPTO have been classified as *core economies*, while those with less than 15 US patents per million population as *non-core economies*.

11 In particular, there are three different aggregation schemes. According to countries development stage – initial, intermediate or advanced, as measured by a level of per capita GDP – the normalized weight attributed to *Basic requirements*, *Efficiency enhancers* and *Innovation factors* will be respectively equal to 0.5, 0.4 and 0.1; 0.4, 0.5 and 0.1; and 0.3, 0.4 and 0.3.

Table 1
Attempts to measure technological capabilities: a synopsis.

Institution	European Commission (EUComm)	European Commission (EUComm)	World Economic Forum (WEF)	World Economic Forum (WEF)	World Economic Forum (WEF)
Synthetic indicator	Summary Innovation Index (SII)	Global Summary Innovation Index (GSII)	Technology Index (Tech)	Technological Readiness Index (TechRead)	Technological Innovation Index (TechInnov)
Creation of new scientific and technological knowledge	Public R&D expenditures (% GDP)				
	Business R&D expenditures (% GDP)				
	Share of high-tech R&D (% manuf. R&D exp.)				
	Share of enterprises receiving public funding for innovation (%)	Public R&D expenditures (% GDP)			
	Innovation expenditures (% of total turnover)	Business R&D expenditures (% GDP)	Patents per million population		Business R&D expenditures (% GDP-survey)
	Share of innovative SMEs (%)	Patents per million population	R&D expenditure (% GDP-survey)	Foreign direct investments (survey)	Patents (hard data)
	Share of innovative SMEs co-operating with others (%)	Scientific articles per million population			
	Share of SMEs using organizational innovation (%)				
	Patents, trademarks and design registrations per million pop.				
Infrastructures and diffusion of the new ICT	Broadband penetration rate (lines per 100 pop.)		Cooperation activities between university and firms in research (survey)	Firms' capabilities in adopting new technologies (survey)	Quality of research institutions (survey)
	Early-stage venture capital (% GDP)		Land lines per 100 pop. (hard data)	ICT laws (survey)	Co-operation between universities and firms in research related activities (survey)
	ICT expenditures (% GDP)		Mobile phones per 100 pop. (hard data)	Mobile phones per 100 pop. (hard d.)	Public demand for high-tech products (survey)
		ICT expenditures (% GDP)	PC users per 100 population (hard data) Internet users per 10,000 pop. (hard data)	PC users per 100 pop. (hard data)	Intellectual property right (survey)
			Internet host per 10000 pop. (hard data)	Internet users per 10,000 pop. (hard d.)	
			Capacity of the institutions of creating a propitious environment the diffusion and efficient use of ICT (survey)		
Human capital	Science & engineering graduates per 1000 pop. aged 20–29				
	Population with tertiary education per 100 pop. aged 25–64	Scientific & engineering graduates (% labour force)			
	Participation in life-long learning per 100 pop. aged 25–64	Researcher per million population	Tertiary enrolment rate (hard data)		Scientists and engineers availability (survey)
	Youth education attainment level (% of pop. aged 20–24 having completed upper secondary education)				

(continued on next page)

Table 1 (*continued*)

Institution	European Commission (EUComm)	European Commission (EUComm)	World Economic Forum (WEF)	World Economic Forum (WEF)	World Economic Forum (WEF)
Competitiveness	Share of employment in high-tech services (% tot. workforce) Share of exports in high-tech services (% tot workf.) Share of sales of new-to-the-market products (% tot workf.) Share of sales of new-to-the-firm products (% tot workf.) Share of employment in high-tech industry (% tot workf.)	Share of exports in high-tech industries (% total exports) Share of added value in high-tech industries (% total value added)	Country's competitive capability (survey)		Taken into account in other GloCI sub-indicators: macroeconomic and institutional conditions in the "Institutions Index"; firms strategies in the "Business Sophistication Index"
Considered years	2004–2006	2006	2004–2006	2004–2006	2004–2006
Number of countries	34	48	125	125	125
Associated economic indicator	None	None	Growth Competitiveness Index	Global Competitiveness Index	Global Competitiveness Index
Source	European Commission [6]	European Commission [8]	WEF [37–39]	WEF [37–39]	WEF [37–39]

Institution Synthetic Indicator	WORLD BANK (WB) Knowledged Index (KI)	UNIDO Technological Advance Index (TechAdv)	UNCTAD Technological Activity Index (TAI)	Archibugi Coco (2004) ArCo
Creation of new scientific and technological knowledge	Patents per million pop. Scientific articles per million pop.		Patents per million pop. Scientific and technical articles per million pop.	Patents per million pop. Scientific and technical articles per million pop.
Infrastructures and diffusion of the new ICT	Land lines per 1000 pop. PC per 1000 pop. Internet users per 1000 pop.			Land lines per 1000 pop. Mobile phones per 1000 pop. Internet users per 1000 pop.
Human capital	Literacy rate Secondary school enrolment University enrolment Researchers per million pop.		Personnel involved in R&D activities per million pop. Literacy rate Secondary school enrolment	Literacy rate Tertiary science & engineering enrolment ratio Mean years of schooling over 14
Competitiveness		Export share in high-tech industries Added value share in high-tech industries		
Considered years	2006	1990 and 2002	1995 and 2001	1990 and 2000
Number of countries	132	161	117	162
Composite Indicator	Knowledged Economy Index (KEI)	Industrial-cum-Technology Advance (ITA) Index	The UNCTAD Innovation Capability Index (UNICI)	None
Source	World Bank website	UNIDO [40]	UNCTAD [41]	Archibugi D., Coco A. [26]

within the *Knowledge Assessment Methodology* (*KAM*). The latter was conceived in 2006 aiming at measuring countries capacity in competing within knowledge economy. *KAM* collects data about 132 countries on 81 qualitative and structural variables. These are chosen in order to represent four main categories related to national competitiveness: the accountability of the economic and institutional system, the educational level of the population, the innovative capability of the economic system, and the ICTs diffusion. *KI* takes in consideration only human capital, the innovation system and ICTs.

3.6. The Technological-Advance Index (UNIDO)

The *Technological-Advance Index* (*Tech-Adv*) is one of the two sub-indicators composing the *Industrial-cum-Technological-Advance Index* (*ITA*). *ITA* was included in the 2005 *Industrial Development Report* edited by the UNIDO (United Nations Industrial

Table 2
Ranking of the G_{45} countries included in all the considered indicators (last available year for each indicator).

Country	Tech WEF	TechRead WEF	TechInnov WEF	GSII EUComm	KI WB	ArCo	TAI UNCTAD	TechAdv UNIDO	Media rank	St. dev. rank	SII EUComm
Sweden	2	1	6	2	1	1	1	8	2,75	2,71	1
United States	1	8	3	7	6	5	4	3	4,63	2,33	7
Switzerland	8	5	2	3	12	3	3	9	5,63	3,62	2
Finland	3	12	4	1	3	2	2	18	5,63	6,07	3
Japan	4	17	1	4	13	8	5	2	6,75	5,60	5
Denmark	6	9	8	9	2	9	6	20	8,63	5,18	4
Netherlands	10	10	10	11	8	11	12	12	10,50	1,31	10
UK	16	6	11	12	9	13	15	4	10,75	4,20	8
Germany	17	18	5	8	14	12	9	5	11,00	5,07	6
Singapore	15	2	9	5	25	20	11	1	11,00	8,57	.
Canada	14	15	12	10	11	6	7	14	11,13	3,31	.
Israel	9	3	7	6	22	4	17	22	11,25	7,89	.
Iceland	7	4	18	15	4	14	8	33	12,88	9,66	9
Korea, Rep.	5	16	14	13	20	18	19	6	13,88	5,69	.
Norway	11	13	17	17	7	7	10	29	13,88	7,24	15
Australia	12	7	21	18	5	10	13	30	14,50	8,19	.
France	27	22	13	14	17	19	16	11	17,38	5,21	11
Austria	18	19	16	19	16	17	18	17	17,50	1,20	12
Belgium	28	24	15	16	15	16	14	19	18,38	5,04	13
Ireland	29	21	19	20	19	22	21	7	19,75	6,07	14
New Zealand	23	20	22	21	10	15	20	41	21,50	8,96	.
Honk Kong	22	11	20	22	28	21	32	28	23,00	6,44	.
Slovenia	24	25	29	24	18	25	22	23	23,75	3,11	16
Spain	21	28	30	26	23	24	24	15	23,88	4,58	20
Estonia	13	14	26	28	21	30	25	34	23,88	7,43	18
Czech Republic	20	23	24	27	26	29	29	16	24,25	4,53	17
Hungary	25	30	27	29	29	31	27	10	26,00	6,74	23
Italy	34	27	33	25	24	23	26	25	27,13	4,12	19
Slovak Rep.	26	26	32	33	34	27	37	21	29,50	5,32	24
Portugal	19	29	28	34	32	33	30	38	30,38	5,58	25
Greece	30	36	36	31	33	26	28	42	32,75	5,15	28
Lithuania	31	32	37	30	27	38	31	40	33,25	4,53	22
Russian Fed.	44	44	41	23	35	28	23	31	33,63	8,75	.
South Africa	35	34	25	35	42	40	33	27	33,88	5,77	.
Poland	41	38	34	42	31	32	36	32	35,75	4,23	27
Brazil	32	33	42	39	30	36	38	44	36,75	4,92	26
Latvia	36	41	31	38	40	43	41	24	36,75	6,36	.
Mexico	39	40	40	40	41	41	42	13	37,00	9,74	.
Cyprus	33	31	39	44	36	35	39	45	37,75	4,98	21
Bulgaria	43	42	45	36	37	34	35	36	38,50	4,17	29
Argentina	42	43	44	41	38	37	34	35	39,25	3,77	.
China	45	45	35	32	44	44	44	26	39,38	7,37	.
India	38	39	23	43	45	45	45	37	39,38	7,41	.
Turkey	40	37	38	37	43	42	43	39	39,88	2,53	31
Romania	37	35	43	45	39	39	40	43	40,13	3,36	30

Source and acronyms: see Table 1.

Development Office) [40]. It has been calculated for 161 countries for 1990 and 2002. This indicator, inspired by Sanyaya Lall [13,38] and his colleagues, is the result of two sub-indicators: the *Industrial-advance indicator* (*Ind-Adv*) and the *Tech-Adv*. We will focus on the latter. The *Tech-Adv* sub-indicator is defined as the arithmetic mean of the share of the medium- and high-tech added

Table 3
Coefficients correlation matrix between the G_{45} positions present in all indicators (last available year for each indicator).

G_{45}	Tech WEF	TechRead WEF	TechInnov WEF	GSII EUComm	KI WB	ArCo	TAI UNCTAD	TechAdv UNIDO
Tech WEF	1							
TechRead WEF	0.9112	1						
TechInnov WEF	0.8515	0.8436	1					
GSII EUComm	0.8352	0.8474	0.9059	1				
KI WB	0.8519	0.8474	0.7769	0.8451	1			
ArCo	0.8567	0.8648	0.8435	0.9219	0.9174	1		
TAI UNCTAD	0.8519	0.8304	0.8538	0.9424	0.9245	0.9441	1	
TechAdv UNIDO	0.5415	0.5278	0.7221	0.7057	0.4788	0.5561	0.6075	1

Source and acronyms: see Table 1.

Table 4
Coefficients correlation matrix between the G_{45} positions present in each couple of indicators (last available year for each indicator).

G45	Tech WEF	TechRead WEF	TechInnov WEF	SII EUComm	GSII EUComm	KI WB	ArCo	TAI UNCTAD	TechAdv UNIDO
Tech WEF	1								
No countries	125								
TechRead WEF	0.9798	1							
No countries	125	125							
TechInnov WEF	0.8964	0.8925	1						
No countries	125	125	125						
SII EUComm	0.8188	0.9099	0.9108	1					
No countries	34	34	34	34					
GSII EUComm	0.8277	0.8432	0.8979	0.9474	1				
No countries	48	48	48	34	48				
KI WB	0.8868	0.8893	0.7857	0.9144	0.8256	1			
No countries	115	115	115	33	47	132			
ArCo	0.8593	0.8738	0.7576	0.8753	0.9101	0.9733	1		
No countries	121	121	121	34	48	129	150		
TAI UNCTAD	0.8429	0.8388	0.8232	0.9431	0.9427	0.9456	0.9246	1	
No countries	103	103	103	31	45	117	117	117	
TechAdv UNIDO	0.7291	0.7177	0.7554	0.6819	0.6847	0.7148	0.7076	0.7528	1
No countries	114	114	114	34	48	121	138	110	139

Source and acronyms: see Table 1.

value industry on the total added value, and on the total of manufacturing exports. The former represents a measure of the concentration degree of the countries' productive structure in the medium- and high-tech industries, whereas the latter the capability of a national economic system to compete on international markets in advanced sectors.

3.7. The Technological Activity Index (UNCTAD)

The *Technological Activity Index* (*TAI*) is one of the two sub-indicators of the *Innovation Capability Index* (*UNICI*), developed by the UNCTAD (United Nations Conference on Trade and Development) and included in the 2005 *World Investment Report* [41]. The *UNICI* has been calculated relatively to the years 1995 and 2001 using social–economic data for 117 countries. It is constructed as the arithmetic mean of *TAI* and the *Human Capital Index* (*HCI*). Each of the two sub-indexes is, in turn, calculated as an aggregation of three variables. While *HCI* synthesis the availability of skills related to the innovative activity, we will focus on *TAI*. This measures the technological activity using both input and output measures, respectively represented by labour force employed in R&D related activities, and the amount of patents and scientific publications.

3.8. ArCo

ArCo is a composite indicator which takes in consideration variables relative to three different dimensions of technological change for 162 countries and two years, 1990 and 2000 [26]. The first category is represented by the innovative activity of a country's economic system measured in terms of number of patents and scientific publications. The second dimension concerns the diffusion of old and new technologies (Internet, land lines and mobile phones), while the third concerns the quality of human capital. Lastly, the *ArCo* aggregation scheme is the arithmetic mean of the three described sub-indicators, constructed in turn as the arithmetic mean of the variables composing them.

4. Indicators in comparison: do they tell the same story?

We have seen that the statistical sources used in the various exercises are often similar and sometime identical, but we have also signalled the differences encountered.[12] Are the results consistent? The first observation deals with the years considered in the analysis. In fact, for the first six indicators (*Tech*, *TechRead* and *TechnInnov* by the WEF, *SII* and *GSII* by the European Commission, and the World Bank's *KI*) last available data refer to the same year, 2006. On the contrary, as to the other three indicators, *TAI* (UNCTAD), *Tech-Adv* (UNIDO) and *ArCo*, data refer respectively to 2001, 2002 and 2000, and there are no plans to update them. Thus we need to evaluate the existence of a potential problem of comparability between the results of the two groups of indicators. For this purpose we tested the stability over time of the indexes referred to 2006, when time series are available (thus excluding the *GSII* and the *KI*). Rank correlations show values higher than 90% for the same indicator across years, confirming that technological capability represents a *structural factor* and substantial modifications in the hierarchy between countries do not occur in the short term. This result makes us more confident on carrying out a comparative analysis between all the indicators, even when they refer to different years.

[12] More details concerning the composition of the composite indicators are included in the methodological annex of the paper which can be found at www.danielearchibugi.org.

Table 5
Coefficients correlation matrix between the G_{1-22} countries in the ranking (last available year for each indicator).

G_{1-22}	Tech WEF	TechRead WEF	TechInnov WEF	GSII EUComm	KI WB	ArCo	TAI UNCTAD	TechAdv UNIDO
Tech WEF	1							
TechRead WEF	0.6303	1						
TechInnov WEF	0.6056	0.3145	1					
GSII EUComm	0.6821	0.4851	0.9322	1				
KI WB	0.5201	0.2394	0.1917	0.2664	1			
ArCo	0.7323	0.4621	0.6307	0.6928	0.6382	1		
TAI UNCTAD	0.6802	0.3582	0.7113	0.7853	0.709	0.7698	1	
TechAdv UNIDO	0.1788	0.0466	0.6669	0.5669	−0.1783	0.0335	0.3145	1

Source and acronyms: see Table 1.

Table 6
Coefficients correlation matrix between the G_{23-45}countries in the ranking (last available year for each indicator).

G_{23-45}	Tech WEF	TechRead WEF	TechInnov WEF	GSII EUComm	KI WB	ArCo	TAI UNCTAD	TechAdv UNIDO
Tech WEF	1							
TechRead WEF	0.9113	1						
TechInnov WEF	0.6164	0.552	1					
GSII EUComm	0.4561	0.4355	0.3538	1				
KI WB	0.7232	0.7643	0.2795	0.6614	1			
ArCo	0.534	0.5694	0.1492	0.6828	0.8055	1		
TAI UNCTAD	0.5663	0.5344	0.2617	0.8156	0.8191	0.8425	1	
TechAdv UNIDO	0.2375	0.1791	0.4441	0.4625	0.2259	0.2625	0.2636	1

Source and acronyms: see Table 1.

Table 2 shows the position, the mean and the standard deviation for the 45 countries (G_{45}) for which all indicators are available. Although Table 2 reports data for the more developed countries, the group is heterogeneous: there are all the OECD countries, many emergent countries from East Europe and South America and the four BRIC.[13] For these countries, data regarding competitive capabilities and innovative activities are more reliable and complete, allowing assessing the robustness of the results.

On the whole, the position of countries is rather stable, with a few remarkable exceptions. At the top of the league, there are significant differences for Finland, Japan, and Denmark. In the case of Finland and Japan, the outlier is the WEF *TechRead* index, which places the two countries respectively at the 12° and 17° position. In both cases, this is due to the low score obtained by these countries for foreign direct investments and technology transfer. The low values scored in the *TechRead* depend on the scarce diffusion of personal computers in Finland (22° position), and of mobile phones in Japan (39° position). In Japan it also emerges a poor confidence for the legal protection provided for ICTs. As to Denmark, the high variability is mainly due to the UNIDO *Tech-Adv* index. While all the indicators put Denmark steadily between the 6° and 9° position (apart from the *KI* which puts it at the second place after Sweden), the UNIDO exercise ranks Denmark at the 20° position.

Interestingly, the BRIC countries show very low ranks with respect to most of the other countries. This comes as a consequence of the fact that composite indicators consider measure of *intensity* rather than of size to make cross-countries comparisons significant. Findings on BRIC in Table 2 are consistent with the fact that these countries, even if their importance has been enormously growing over the last decade, are still lagging behind in terms of relative technological capabilities, not only compared to the more advanced countries, but also with respect to small dynamic Eastern European economies such as Slovenia, Estonia, and Czeck Republic.[14] Table 3 shows the correlation matrix among the indicators of the G_{45} considered in Table 2. Within this top of the league club, correlation coefficients are very high.

ArCo is strongly correlated with *TAI* (0.94), *GSII* (0.92) and *KI* (0.92). The lower correlations are those between *Tech-Adv* and the others, in particular with *KI* (0.48). *Tech-Adv* measures different aspects than the other synthetic indicators; the UNIDO indicator takes into account national production and exports, while it does not address fundamental aspects of countries' technological capabilities. To increase the number of observations in each comparison, Table 4 shows the pairwise correlations between all the indicators taking into consideration the whole set of countries for which data related to every measurement exercise are available.

Overall, a consistent picture emerges, with the notable exception of UNIDO's *Tech-Adv*. The UNIDO indicator is calculated on the share of high-tech industry on the added value and the exports. Finally, it is worth stressing that *SII*, not reported in Table 3 because it has been calculated for 34 countries only, also shows strong correlations with the other technological measures. Such a correlation between groups of so variegated countries can provide misleading results just for their different development level, so

[13] The BRIC countries include Brazil, Russian Federation, India, and China.
[14] Although the analysis of the dynamics over time of countries' technological capabilities goes beyond the scope of this paper, it is worth noting that the results of a time-comparison exercise conducted by the World Bank. Using data for 1995 and 2007 the World Bank computes variations in countries' ranks relative to the two main indicators, *KEI* and *KI*, developed within the KAM project (see Section 3.5 for a description) and the four sub-indicators (economic system, human capital, innovation, and ICTs). The results show that the ranking of the BRIC countries was rather low in 1995, but they have catch-up considerably. China, in particular, experienced a substantial leap, rising on average by twenty positions.

Table 7
R&D intensity (as a percentage of GDP).

Country	R&D/GDP	Country	R&D/GDP
Israel	4.51	New Zealand	1.16
Sweden	3.80	Spain	1.12
Finland	3.48	Italy	1.09
Japan	3.32	Russian Federation	1.07
Korea, Rep.	2.98	Hungary	0.94
Switzerland	2.90	Estonia	0.94
Iceland	2.78	South Africa	0.92
United States*	2.62	Brazil	0.91
Germany	2.48	Portugal	0.81
Denmark	2.45	Honk Kong	0.80
Austria	2.41	Turkey	0.79
Singapore	2.30	Lithuania	0.76
France	2.13	India	0.69
Canada	2.01	Greece	0.58
Belgium	1.84	Poland	0.57
Australia	1.78	Latvia	0.57
United Kingdom	1.76	Slovak Republic	0.51
Netherlands*	1.74	Mexico	0.50
Norway	1.52	Bulgaria	0.50
Slovenia	1.46	Argentina	0.46
Czech Republic	1.41	Romania	0.41
China	1.33	Cyprus	0.40
Ireland*	1.26		

Year 2005.
*Provisional.
Source: OECD [43,44].

Table 8
Correlations rates between composite indicators' scores and R&D intensity.*

Indicator	G_{45}	G_{1-22}	G_{23-45}
Tech	0.81	0.64	0.21
TechRead	0.77	0.48	0.32
TechInnov	0.89	0.74	0.66
SII**	0.93	0.86	0.55
GSII	0.91	0.82	0.78
KI	0.61	0.27	0.22
ArCo	0.81	0.63	0.15
TAI	0.77	0.60	0.35
TechAdv	0.62	0.33	0.59
Mean	0.79	0.60	0.42

*R&D data refer to 2005 (or 2004 when not available).
**The SII correlations have been calculated only for the available 34 countries.
Source and acronyms: see Tables 1 and 7.

as hiding the real differences between similar countries. We have therefore divided the sample in two groups, taking the first 22 (G_{1-22})[15] and the last 23 (G_{23-45})[16] countries separately. Tables 5 and 6 show the correlations between the indicators in these two subgroups: figures are generally lower compared with those calculated on the entire set of countries. In particular, remarkable differences emerge concerning the *TechRead* in the first group of countries and for the *TechInnov* in the second. Moreover, in the G_{1-22} *Tech-Adv* shows very low correlation with *Tech* and with *TAI*, approximately zero with *TechRead* and *ArCo*, and even a negative one with *KI*.

5. Comparing national composite indicators with R&D intensity

The main advantage of composite indicators is to synthesise all the information about technological capabilities in a number. However, there are other measures able to establish countries rankings based on some innovative capability dimension, and one of the most frequently used is R&D intensity. R&D plays two complementary roles in enhancing countries' technological capabilities. The first is in generating innovation, and has received most attention in the existing empirical literature. The second is in facilitating the adoption of innovations developed elsewhere through the development of a certain *absorptive capacity* [42].

[15] G_{1-22} includes the first 22 countries according to the ranking for all the considered indicators (see Table 2).
[16] G_{23-45} includes the last 23 countries according to the ranking for all the considered indicators (see Table 2).

Do R&D intensity measures (such as expenditures as a percentage of GDP) provide similar ranking to composite indicators? In other words, is R&D intensity a proxy of innovative capabilities able to "capture" the same reality than composite indicators? Were the *one-dimensional* R&D measure able to synthesise a country's innovative capability as well as *multidimensional* composite indicators, then the Occam razor principle would suggest using the simple and not the complex indicator [15,16]. Intra-countries scores are based on a single number which comes out from synthetic indicators, independently from the fact that these indicators are based on a battery of statistics. Hence, if R&D based rankings ended up to be identical to synthetic indicators rankings, all this fuss about synthetic indicators would be useless.

Table 7 reports the R&D intensity of the most advanced countries. The ranking is rather consistent with that reported in Table 2. The comparison between R&D intensity and synthetic indicators is carried out in Table 8 firstly considering all G_{45}, and then the two sub-groups G_{1-22} and G_{23-45}, separately. Table 8 shows the correlation rates between each composite indicator and R&D intensity. Not surprisingly, the indicators which incorporate R&D data (*SII*, *GSII* and *TechInnov*) show the highest correlations with R&D intensity. *TechInd* and *TAI* also include R&D-based statistics and, in fact, correlations indexes are around 0.89. As to the other indicators, correlation rates are also fairly high. The UNIDO's *Tech-Adv* as well as the World Bank's *KI* have lower correlation indexes.

When we consider the two subgroups of countries, G_{1-22} and G_{23-45}, correlation rates decrease significantly. R&D intensity is fairly able to capture differences in the G_{45} but when we look within more homogenous groups of countries, R&D intensity is less capable of grasping differences. G_{1-22} countries are characterized by similar levels of R&D intensity, apart from the heavy R&D spenders like Israel, Sweden, Finland and Japan (all above 3% of GDP). Thus, focusing on the G_{1-22}, R&D intensity is less capable of explaining differences in innovative performance because *non-R&D factors* play an important role in differentiating national paths of innovation and performances. In particular, *Tech-Adv* and *KI* show very low correlations with R&D intensity. The former is a peculiar indicator shaped by exports and value added in high-tech industries. As to the *KI*, it measures mainly those structural factors which represent the competitiveness and innovative capacities of an economic system, also based on non-R&D components. When we take in consideration the G_{23-45} countries, correlations significantly drop: the average correlation rate is equal to 0.44. The fact that R&D intensity is not suitable to highlight differences in technological capabilities of this sub-group of countries was somehow expected since it is problematic to distinguish countries' characteristics through activities that they do not perform or perform at a very limited extent.

What can we conclude? R&D is able to explain differences in innovative capabilities in the case of a large and heterogeneous number of countries. The coefficient of variation in the G_{45} is equal to 0.66, while it ranges from a maximum of 0.45 to a minimum of 0.18 for the composite indicators. This reflects the fact that when we deal with the G_{45}, differences between countries in R&D intensity are extremely large, ranging from 4.5% of Israel to 0.4% of Cyprus. Nevertheless, R&D intensity measure is not able to grasping differences in technological capabilities across more homogeneous countries. Composite indicators are therefore useful, especially to single out the differences within homogeneous groups of countries.

6. Instead of a conclusion: uses and abuses of macro-indicators of technological capabilities

Synthetic indicators give quite a faithful and uniform picture on national relative positions in innovative activities. The most relevant divergences can be attributed to different interpretations of technological change (as in the case of the UNIDO approach), or to an overlapping of qualitative and quantitative methodologies (as is the case of the WEF indexes). In spite of a few significant outliers, a certain convergence about the methodologies to measure technological change at country level has been achieved which is faithfully reflected also in the results achieved by the empirical analyses.

What is the real meaning of a macroeconomic indicator of technological change? Technological capabilities are a stock and not a flow, and they are less suitable to be described by aggregate values as it is done with other macroeconomic variables such as GDP, unemployment, investments and consumption.[17] Annual variations are much less significant since technological capabilities are generated (and destroyed) slowly over time, even during periods of rapid expansion or social upheavals.

Measurement exercises need to take into consideration the evolution of countries over the medium-long run, having in mind that radical accelerations can turn out ephemeral events. It is not surprising that we have recorded few variations in the national rankings in the short run. But long-run variations become more relevant: some countries have managed to undertake virtuous circles, in which the process of creating competences enhances the creation of new competencies. At the same manner, a momentary decline can rapidly turn into a structural phenomenon and trigger a vicious circle hard to break off. To reverse a technological decline requires a lot of time and huge amount of resources.

Aggregate indicators also provide preliminary information for policy action. Taking into consideration the various factors, it is possible to identify what distinguishes each country, and how it compares with partners and competitors. It should be kept in mind that the implicit assumption of perfect substitution between the various components holds only for the statistical construction, while does not hold at all concerning the public policies. For example, if a country is lacking electricity, it is not possible to compensate it with an increase in academic production (measured by bibliometric indicators). But a battery of indicators can allow identifying the main obstacles to national development and leading appropriate public policies. Those who intend to ground their choices of public policies also on statistical information, have to take care of distinguishing properly the indicators from the related phenomena. The policy aim is not, of course, to increase the value of the indicators, but the far more difficult problem of improving

[17] See [45] for an exercise limited to ICTs.

the economic and social conditions that the indicators are expected to capture. Scientific publications and patents, for example, are means and not ends. But there is danger that some policy makers will concentrate on actions that have an effect on the indicator even when it is unclear if they have also an effect on the economic and social reality. For example, some governments distribute the resources devoted to academia on the ground of bibliometric indicators, giving an incentive to researchers to increase their publishable output rather than the knowledge generated. The outcome could be to transform scholars in scientific-articles maximizers rather than in generators of knowledge.

When used in the right perspective, aggregate indicators can help to take important decisions concerning international cooperation agreements, choosing partners according to their competences. Since groups of countries establish common objectives, the statistical tools can help verifying in which measure each nation is contributing to their achievement. We have already mentioned that the European Innovation Scoreboard was conceived also as a tool to monitor the Lisbon Strategy objectives. This recalls what happened with the European Monetary Union: once the Maastricht parameters had been established, EU member states had also to develop an informative system able to monitor if the financial parameters were respected by each country.

Aggregate indicators can be extremely useful for business strategies, especially in order to make decisions about localization of innovative activities and recruitment of qualified staff. It is not surprising that firms need both structural and conjuntural data. The WEF, which is very close to the business community, gathered a lot of data on firms' expectations about countries technological capabilities. Similarly, also the exercise of the Georgia Tech Technology Policy and Assessment Center looks at predicting high-tech trade shares. Expectations play an important part in decision making, and often today's expectations affect tomorrow's ones. Notwithstanding, we preferred to keep *hard data* separated from *soft data* (i.e. based on opinions).

Probably, the greatest users of aggregate indicators are members of academe. In their heroic attempt to explain and interpret the process of economic development, scholars must be able to measure the differences in technological capabilities across countries. The assumption, often implicit but nevertheless largely shared, is that current technology lays the foundations for tomorrow prosperity. Innovation and technological capabilities are considered the engine of productivity, international competitiveness, growth, employment, human capital and well-being. These assumptions need also to be grounded on an empirically base. Taking into account a battery of statistical sources helps at identifying the technological components which are more closely associated with the development process. We do not expect that the same causal links between technology from the one side, and growth from the other side will affect in the same way countries that are so different in terms of dimension, income, infrastructures and human resources. An analysis of the different elements composing the synthetic indicators can help to quantify the crucial elements which contribute to trigger a process of growth for homogenous groups of countries.

We would take the liberty to conclude with a suggestion, mostly for young scholars. Information technologies have drastically reduced time, efforts and costs necessary to develop tools for measuring technological capabilities. We have seen that the World Bank, the provider of the more complex data source, provides a large number of statistics on-line. Moreover, it is now possible to elaborate and manipulate these data also on-line. Indicators associated to technological capabilities can today become more complex and with lower efforts. Such easiness in computational elaboration has many advantages, but also the risk to induce scholars to manipulate numbers before having reflected about the nature of technological change and the appropriate methods to measure it. The danger of measurement without a theory is coming back. It is then useful to have first a good picture of which aspects of the technological change we want to deal with, and then start to develop and manipulate the increasingly sophisticated measurement tools.

Acknowledgements

This paper is part of a research project on Measuring Innovation promoted by the European Commission, Directorate-General Enterprises and Industry and coordinated by MERIT. We wish to thank Anna Giunta, Hugo Hollanders, Keith Sequeira, Giorgio Sirilli and Antonello Zanfei for their helpful comments on a previous version. We are also very grateful to the suggestions provided by two anonymous referees.

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